TCEQ Interoffice Memorandum

TO: Office of the Chief Clerk
Texas Commission on Environmental Quality

THRU: Chris Kozlowski, Team Leader
Water Rights Permitting Team

FROM: Sarah Henderson, Project Manager
Water Rights Permitting Team

DATE: March 29, 2019

SUBJECT: San Antonio River Authority
WRPERM 13515
CN600790620, RN110465085
Application No. 13515 for a Water Use Permit
Texas Water Code § 11.042, Requiring Limited Mailed Notice
Martinez Creek and Cibolo Creek, San Antonio River Basin
Bexar and Wilson Counties

The application and partial fees were received on July 30, 2018. Additional information and fees were received on December 20, 2018. The application was declared administratively complete and accepted for filing with the Office of the Chief Clerk on March 29, 2019. Mailed notice to the interjacent water right holders of record in the San Antonio River Basin is required pursuant to Title 30 Texas Administrative Code § 295.161(b).

All fees have been paid and the application is sufficient for filing.

Sarah Henderson, Project Manager
Water Rights Permitting Team
Water Rights Permitting and Availability Section

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY
2019 MAR 29 PM 2: 37
CHIEF CLERKS OFFICE

OCC Mailed Notice Required ☑ **YES** ☐ **NO**

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Protecting Texas by Reducing and Preventing Pollution

March 29, 2019

Mr. Edmond McCarthy, Jr.
McCarthy & McCarthy, LLP
1122 Colorado Street, Suite 2399
Austin, Texas 78701

Re: San Antonio River Authority
WRPERM 13515
CN600790620, RN110465085
Application No. 13515 for a Water Use Permit
Texas Water Code § 11.042, Requiring Limited Mailed Notice
Martinez Creek and Cibolo Creek, San Antonio River Basin
Bexar and Wilson Counties

Dear Mr. McCarthy:

This acknowledges receipt, on December 20, 2019 of additional information and fees in the amount of $67.62 (Receipt No. M909963, copy enclosed).

The application was declared administratively complete and filed with the Office of the Chief Clerk on March 29, 2019. Staff will continue processing the application for consideration by the Executive Director.

Please be advised that additional information may be requested during the technical review phase of the application process.

If you have any questions concerning this matter please contact me via email at sarah.henderson@tceq.texas.gov or by telephone at (512) 239-2535.

Sincerely,

Sarah Henderson, Project Manager
Water Rights Permitting Team
Water Rights Permitting and Availability Section

Enclosure

TCEQ - A/R RECEIPT REPORT BY ACCOUNT NUMBER

TCEQ 27-DEC-18 10:30 AM

Fee Description	Fee Code Account# Account Name	Ref#1 Ref#2 Paid In By	Check Number Card Auth. User Data	CC Type Tran Code Rec Code	Slip Key Document#	Tran Date	Tran Amount
NOTICE FEES-WUP-WATER USE PERM	PTGU PTGU NOTICE FEES WUP WATER USE PERMITS	M909963 13515 MCCARTHY & MCCARTHY LLP	1190 122118 CDELAROS	 N CK	BS00070565 D9802226	27-DEC-18	-$67.62
					Total (Fee Code):		-$67.62

LAW OFFICES OF

McCARTHY & McCARTHY, L.L.P.

1122 COLORADO STREET, SUITE 2399
AUSTIN, TEXAS 78701
(512) 904-2310
(512) 692-2826 (FAX)

RECEIVED
DEC 20 2018
SC
Water Availability Division

Sarah Henderson, Project Manager, MC-160
Water Rights Permitting Section
Water Availability Division
Texas Commission on Environmental Quality
P.O. Box 13087
Austin, Texas 78711-3087

via e-mail & regular mail

Re: San Antonio River Authority
WRPERM 13515
CN600790620, RN110465085
Application No. 13515 for a Water Use Permit
Texas Water Code § 11.042, Limited Mailed Notice Required
Martinez and Cibolo Creeks, San Antonio River Basin
Bexar and Wilson Counties

Dear Ms. Henderson:

This letter provides the responses of the San Antonio River Authority (SARA) to the November 16, 2018, request for additional information ("RFI") regarding Application No. 13355 for a water use permit authorizing the reuse of treated groundwater based effluent discharged by SARA into Martinez Creek and transported down the bed and banks of that water course to SARA's proposed point of diversion. Each item of requested additional information is set out below <u>in bold type</u>, followed by SARA's response.

1. Confirm the location of the requested diversion point. Commission records indicate that the authorized diversion point in Water Use Permit No. 5611 is located on the east bank of Cibolo Creek, and located at Latitude 29.094963'N, Longitude 97.970915'W. The map provided with the application shows the diversion point as being on the west bank of Cibolo Creek.

<u>SARA's Response</u>: Attached please find a corrected Worksheet 3.0 and revised Map depicting the location of SARA's requested point of Diversion on Cibolo Creek based upon the existing point of diversion authorized by Water Use Permit No. 5611. (Appendix "A").

2. Clarify the combined diversion rate. Staff notes the application indicates a combined rate of 2.76 cfs. However, Water Use Permit No. 5611 is authorized for 1.56 cfs and page 13 of 23 indicates a rate of 1.16 cfs, which staff calculates is a combined rate of 2.72 cfs.

SARA's Response: The Staff's calculation is correct. The 2.76 cfs is a typographical error. The correct diversion rate request is a combined 2.72 cfs.

3. Provide an assessment of the adequacy of the quantity and quality of the flows remaining after the proposed diversion to meet instream flow needs and bay and estuary freshwater inflow needs.

SARA's Response: There should be no discernable impact on the quantity or quality of flows in Cibolo Creek from SARA's diversions of its groundwater based effluent from the flows in Cibolo Creek. Prior to SARA's diversion, the flows between SARA's discharge and diversion points will be enhanced. When SARA makes its diversions all transport losses will be accounted for, and the remaining flow past SARA's diversion point should be similar to pre-diversion flow conditions. SARA has not yet commenced discharges from the Martinez IV WWTP, so no contribution to, nor opportunity for reliance upon the groundwater based effluent return flow discharges by either the environment or downstream water rights has occurred.

4. Confirm that any discharge of return flows under WQ0010749007 commenced after July 31, 2018.

SARA's Response: Confirmed. SARA has not begun to discharge return flows pursuant to WQ 001749007. SARA had targeted an October 1, 2018, date to initiate the discharges from the Martinez IV WWTP that are the subject of this Application. The unusually heavy and prolonged rains in late summer and early fall 2018 delayed the Martinez IV project, including the targeted date for commencement of discharges. No discharges occurred prior to July 31, 2019; and, in fact, to date none have occurred. SARA anticipates the commencement of discharge of its groundwater based effluent return flows in February 2019.

5. Provide an additional explanation of the 78% loss provided on WORKSHEET 4.0. Staff recognizes the application states that this value was calculated using TWDB methodology; however, additional detail would be needed for staff to perform a technical review of the application.

SARA's Response: Attached please find revised WORKSHEETS 4.0 and 4.1, including a revised Map (Appendix "B"). The 78% was erroneously identified on WORKSHEET 4.0 as the calculated transportation loss between SARA's requested points of discharge and diversion. In fact, SARA's calculated transportation loss is only 22% of planned effluent return flows. The 78% is the calculated volume to be available at the proposed diversion point for SARA's beneficial reuse.

Additional detail regarding SARA's calculation of the transportation losses between its proposed point of discharge and diversion point is provided in the Technical Memorandum entitled

"Channel Loss Rates in Martinez and Cibolo Creeks for the Martinez IV WWTP Bed & Banks Permit" attached hereto as Appendix "C." The SARA Technical Memorandum is supported by the HDR Channel Loss Memorandum appended thereto, together with the following additional references:

(i) Recharge Enhancement Study: Guadalupe-San Antonio River Basin Volume II – Technical Report (HDR 1993), attached as Appendix "D";

(ii) Intensive Survey of Martinez Creek – Report IS-23 (Texas Department of Water Resources, June 1981), attached as Appendix "E";

(iii) Intensive Survey of Cibolo Creek Segment 1902 – Report IS-39 (Texas Department of Water Resources, June 1982), attached as Appendix "F";

(iv) Simulation of Streamflow, Evapotranspiration, and Groundwater Recharge in Lower San Antonio River Watershed, South-Central Texas, 2000-2007 (USGS Scientific Investigations Report 2010-5027), attached as Appendix "G"; and

(v) Channel Gain and Loss Investigations Texas Streams – 1918-1958 (Texas Board of Water Engineers April 1960), attached as Appendix "H"

6. Remit fees in the amount of $67.62 as described below. Please make checks payable to the TCEQ or Texas Commission on Environmental Quality.

Filing Fee	$ 100.00
Recording Fee	$ 25.00
Notice Fee ($2.94 x 23 WR Holders	$ 67.62
Total Fees	**$ 192.62**
Fees Received	**($ 125.00)**
Fees Due	**$ 67.62**

SARA's Response: Enclosed please find my Firm's Check No. 1190 payable to the TCEQ in the amount of $67.62 to cover the full amount of requested additional fees. Please credit these funds to SARA's account for this Application. A copy of the check is attached hereto as Appendix "I".

Please let me know if you have any questions. As always, both I and SARA appreciate the support and hard work of you and your team on these projects.

Best wishes.

Sincerely,

Edmond R. McCarthy, Jr.

ERM/tn
Encl.

cc: San Antonio River Authority
Attn: Melissa Bryant, P.E., Project Manager

APPENDIX "A"

Revised WORKSHEET 3.0 & Map

WORKSHEET 3.0
DIVERSION POINT (OR DIVERSION REACH) INFORMATION

This worksheet **is required** for each diversion point or diversion reach. Submit one Worksheet 3.0 for **each** diversion point and two Worksheets for **each** diversion reach (one for the upstream limit and one for the downstream limit of each diversion reach).

The numbering of any points or reach limits should be consistent throughout the application and on supplemental documents (e.g. maps).

1. Diversion Information (Instructions, Page. 24)

a. This Worksheet is to add new (select 1 of 3 below):

1. Existing Permit 5611 Diversion Point No.
2. __________Upstream Limit of Diversion Reach No.
3. __________Downstream Limit of Diversion Reach No.

b. Maximum Rate of Diversion for **this new point** 1.16__________ cfs (cubic feet per second) or 521__________gpm (gallons per minute)

c. Does this point share a diversion rate with other points? **Y / N** Y
If yes, submit Maximum ***Combined*** *Rate of Diversion for all points/reaches* 2.76__________cfs or 1220 82__________gpm

d. For amendments, is Applicant seeking to increase combined diversion rate? **Y / N**

*** An increase in diversion rate is considered a new appropriation and would require completion of Section 1, New or Additional Appropriation of State Water.*

e. Check (√) the appropriate box to indicate diversion location and indicate whether the diversion location is existing or proposed):

Check one		**Write: Existing or Proposed**
X	Directly from stream	Existing
	From an on-channel reservoir	
	From a stream to an on-channel reservoir	
	Other method (explain fully, use additional sheets if necessary)	

f. Based on the Application information provided, Staff will calculate the drainage area above the diversion point (or reach limit). If Applicant wishes to also calculate the drainage area, you may do so at their option.

Applicant has calculated the drainage area. **Y / N** Y

If yes, the drainage area is 756 06__________ sq. miles.
(If assistance is needed, call the Surface Water Availability Team at (512) 239-4691, prior to submitting application)

2. Diversion Location (Instructions, Page 25)

a. On watercourse (USGS name): Cibolo Creek tributary of San Antonio River

b. Zip Code: [illegible]

c. Location of point: In the Caballerias Original Survey No. 1, Abstract No.________, Wilson County, Texas.

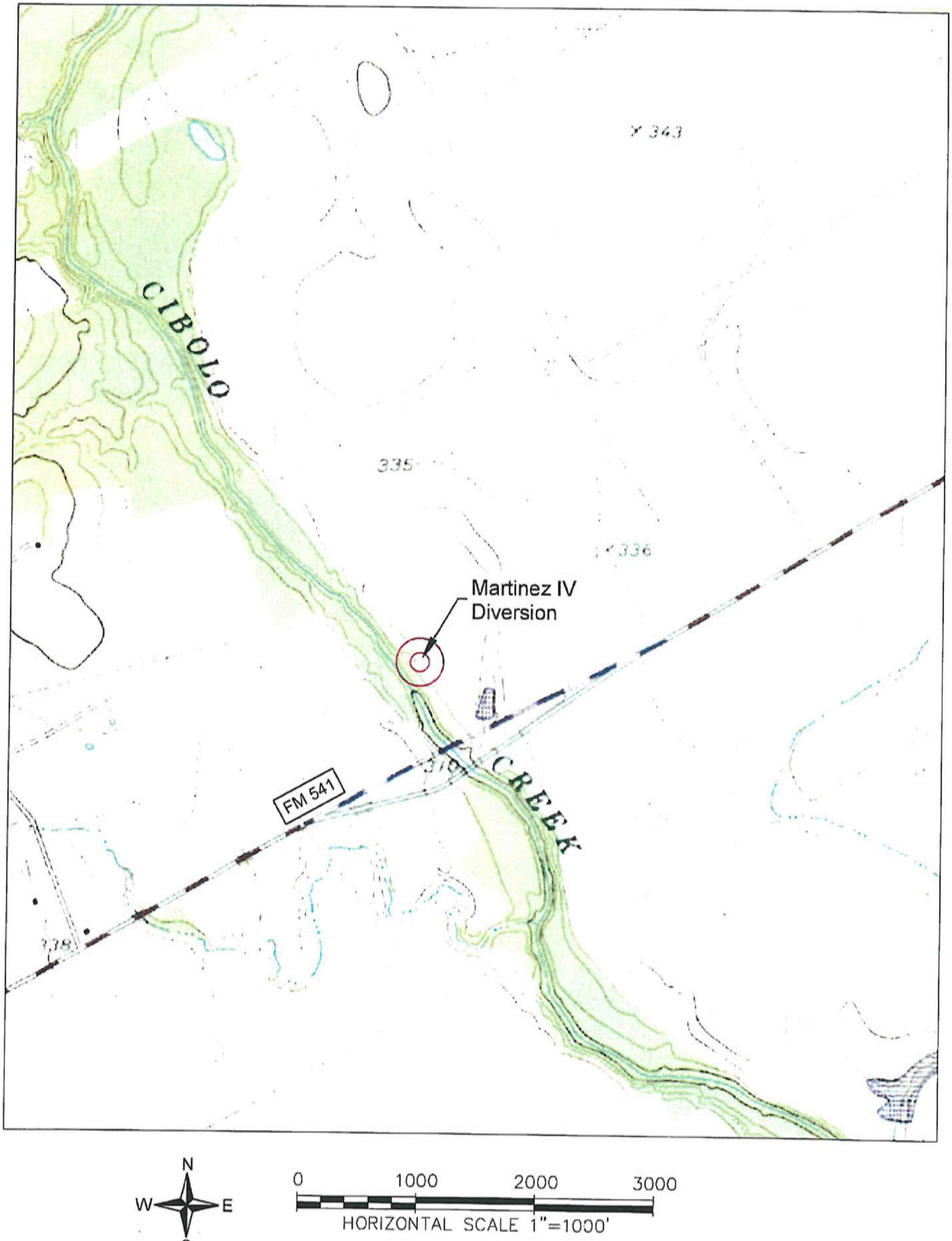
> ***A copy of the deed(s) with the recording information from the county records must be submitted describing tract(s) that include the diversion structure. For diversion reaches, the Commission cannot grant an Applicant access to property that the Applicant does not own or have consent or a legal right to access, the Applicant will be required to provide deeds, or consent, or other documents supporting a legal right to use the specific points when specific diversion points within the reach are utilized. Other documents may include, but are not limited to: a recorded easement, a land lease, a contract, or a citation to the Applicant's right to exercise eminent domain to acquire access.***

d. Point is at: Latitude *29.094963'* °N, Longitude *97.970915'* °W.
Provide Latitude and Longitude coordinates in decimal degrees to at least six decimal places

e. Indicate the method used to calculate the location (examples: Handheld GPS Device, GIS, Mapping Program): Previous Water Right Application/Google Maps GPS Coordinates

f. Map submitted must clearly identify each diversion point and/or reach. See instructions Page. 38. See attached Map.

g. If the Plan of Diversion is complicated and not readily discernable from looking at the map, attach additional sheets that fully explain the plan of diversion.



343
CIBOLO
335
336
Martinez IV
Diversion
CREEK
FM 541
338
N
W
E
S
0
1000
2000
3000
HORIZONTAL SCALE 1"=1000'

APPENDIX "B"

Revised WORKSHEETS 4.0 – 4.1 & Map

WORKSHEET 4.0
DISCHARGE INFORMATION

This worksheet required for any requested authorization to discharge water into a State Watercourse for conveyance and later withdrawal or in-place use. Worksheet 4.1 is also required for each Discharge point location requested. **Instructions Page. 26.** ***Applicant is responsible for obtaining any separate water quality authorizations which may be required and for insuring compliance with TWC, Chapter 26 or any other applicable law.***

a. The purpose of use for the water being discharged will be municipal, agricultural, industrial, recreation, & environmental.

b. Provide the amount of water that will be lost to transportation, evaporation, seepage, channel or other associated carriage losses 22 % and explain the method of calculation: TWDB Methodology

Is the source of the discharged water return flows? **Y / N** Y If yes, provide the following information:

1. The TPDES Permit Number(s). WQ0010749007 (attach a copy of the **current** TPDES permit(s))

2. Applicant is the owner/holder of each TPDES permit listed above? **Y / N** Y

PLEASE NOTE: If Applicant is not the discharger of the return flows, the application should be submitted under Section 1, New or Additional Appropriation of State Water, as a request for a new appropriation of state water. If Applicant is the discharger, then the application should be submitted under Section 3, Bed and Banks.

3. Monthly WWTP discharge data for the past 5 years in electronic format. (Attach and label as "Supplement to Worksheet 4.0").

4. The percentage of return flows from groundwater 100 _____, surface water______?

5. If any percentage is surface water, provide the base water right number(s) __________.

c. Is the source of the water being discharged groundwater? **Y / N** N If yes, provide the following information:

1. Source aquifer(s) from which water will be pumped:________________

2. Any 24 hour pump test for the well if one has been conducted. If the well has not been constructed, provide production information for wells in the same aquifer in the area of the application. See http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp. Additionally, provide well numbers or identifiers________________.

3. Indicate how the groundwater will be conveyed to the stream or reservoir.

4. A copy of the groundwater well permit if it is located in a Groundwater Conservation District (GCD) or evidence that a groundwater well permit is not required.

ci. Is the source of the water being discharged a surface water supply contract? **Y / N** N If yes, provide the signed contract(s).

cii. Identify any other source of the water____________________

WORKSHEET 4.1
DISCHARGE POINT INFORMATION

This worksheet is required for **each** discharge point. Submit one Worksheet 4.1 for each discharge point. If there is more than one discharge point, the numbering of the points should be consistent throughout the application and on any supplemental documents (e.g. maps). **Instructions, Page 27.**

For water discharged at this location provide:

a. The amount of water that will be discharged at this point is 560 acre-feet per year. The discharged amount should include the amount needed for use and to compensate for any losses.

b. Water will be discharged at this point at a maximum rate of 1.16 cfs or 521 gpm.

c. Name of Watercourse as shown on Official USGS maps: Martinez Creek tributary of Cibolo Creek tributary of San Antonio River

d. Zip Code: 78152

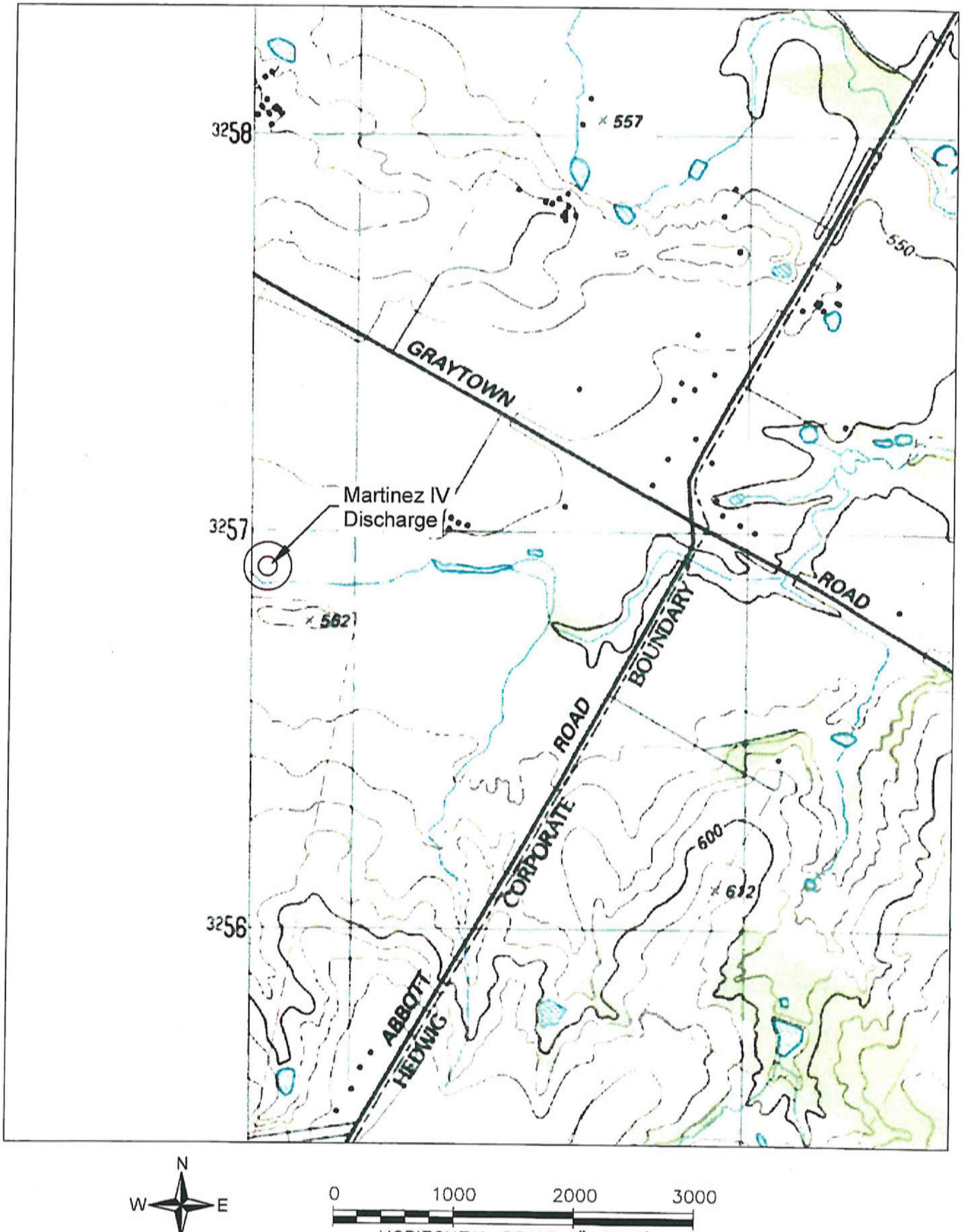
f. Location of point: In the John Isham Original Survey No. 27, Abstract No. 365, Bexar County, Texas.

g. Point is at:
Latitude 29.440918 °N, Longitude 98.250020 °W.

Provide Latitude and Longitude coordinates in decimal degrees to at least six decimal places

h. Indicate the method used to calculate the discharge point location (examples: Handheld GPS Device, GIS, Mapping Program): Handheld GPS Device

Map submitted must clearly identify each discharge point. See instructions Page. 15.



3258
3257
3256
557
550
Martinez IV
Discharge
582
GRAYTOWN
ROAD
BOUNDARY
ROAD
CORPORATE
600
612
ABBOTT
HEDWIG
N
S
W
E
0
1000
2000
3000
HORIZONTAL SCALE 1"=1000'

APPENDIX "C"

SARA Technical Memorandum on Stream Loss Calculations

Technical Memo

RE: Channel Loss Rates in Martinez and Cibolo Creeks for the Martinez IV WWTP Bed & Banks Permit

SAN ANTONIO RIVER AUTHORITY

Analysis:

Data from the Guadalupe-San Antonio Model (GSA WAM) along with data from several studies developed in the San Antonio Basin were used for the following calculations:

$$\%Loss/mile = \frac{Qupstream - Qdownstream + Qdischarge}{Qupstream + Qdownstream} * \frac{100}{Segment\ Length}$$

$$Delivery\ Factor = \left(1 - \%\frac{Loss}{mile}\right)^{segment\ length}$$

The calculations for Martinez Creek were based on the August 2005 streamflow survey data collected and submitted with the original San Antonio River Authority (SARA) Bed and Banks permit for Martinez I, II, & II WWTPs. The HDR Technical Memo is attached for reference. The Martinez IV WWTP would be in the segment of Martinez Creek below the confluence with Salatrillo Creek, so a 5.36% loss per mile was used for the 9.3 miles to the confluence of Martinez Creek and Cibolo Creek. Between the Martinez IV WWTP discharge to the confluence of Cibolo Creek would indicate a delivery of approximately 60% (Delivery Factor = (1-5.36%)^9.3miles).

Streamflow survey data was not available for the 36.7 mile stretch to the diversion location on Cibolo Creek, so the USGS gauge data for Cibolo Creek at Sutherland Springs (08185500) and Cibolo Creek at Falls City (08186000) were used for the calculations. This segment of the stream has been identified as a gaining stream segment based on the USGS study on Simulation of Streamflow, Evapotranspiration, and Groundwater Recharge in the Lower San Antonio River Watershed, South-Central Texas, 2000-2007. Based on the USGS gauge data, all months except for July and August showed the stream to be a gaining stream. August was the driest month of the 2018 so flows for the month of August were used from these stations (15 cfs and 12 cfs respectively). The percent loss per mile used was 0.7015% (%loss/mile = [(15 – 12 + 1.16)/(15+1.16)] X (100/36.7)). Based on this loss, the delivery factor was approximately 6.9% (Delivery Factor = (1-0.7015%)^36.7miles).

The total delivery factor is approximately 67% based on the calculations from the two reaches (60% + 6.9%). Based on the studies, the delivery factor would be greater during wetter periods as shown in this past year, so channel losses would be less.

HDR | ONE COMPANY *Many Solutions*℠

Memo

To: Steve Raabe, Ed McCarthy, & Melissa Bryant	
From: R Brian Perkins	Project: Indirect Reuse
CC: Sam Vaugh	
Date: October 20, 2005	Job No: 07755-15480

Channel Loss Memo 9-21-05.doc

RE: Channel Losses Between Martinez 1/Martinez 2 and Alamo Turf Farm

We have reviewed the streamflow survey data collected in August 2005 for Martinez and Salatrillo Creeks. There are a total of eight stream segments for which there is data at the upstream and downstream points measured on the same day. Figure 1 identifies the measurement locations and Table 1 summarizes the stream segments relevant to assessment of channel losses between two San Antonio River Authority (SARA) wastewater treatment plants (Martinez I and Martinez 2) and the Alamo Turf Farm.

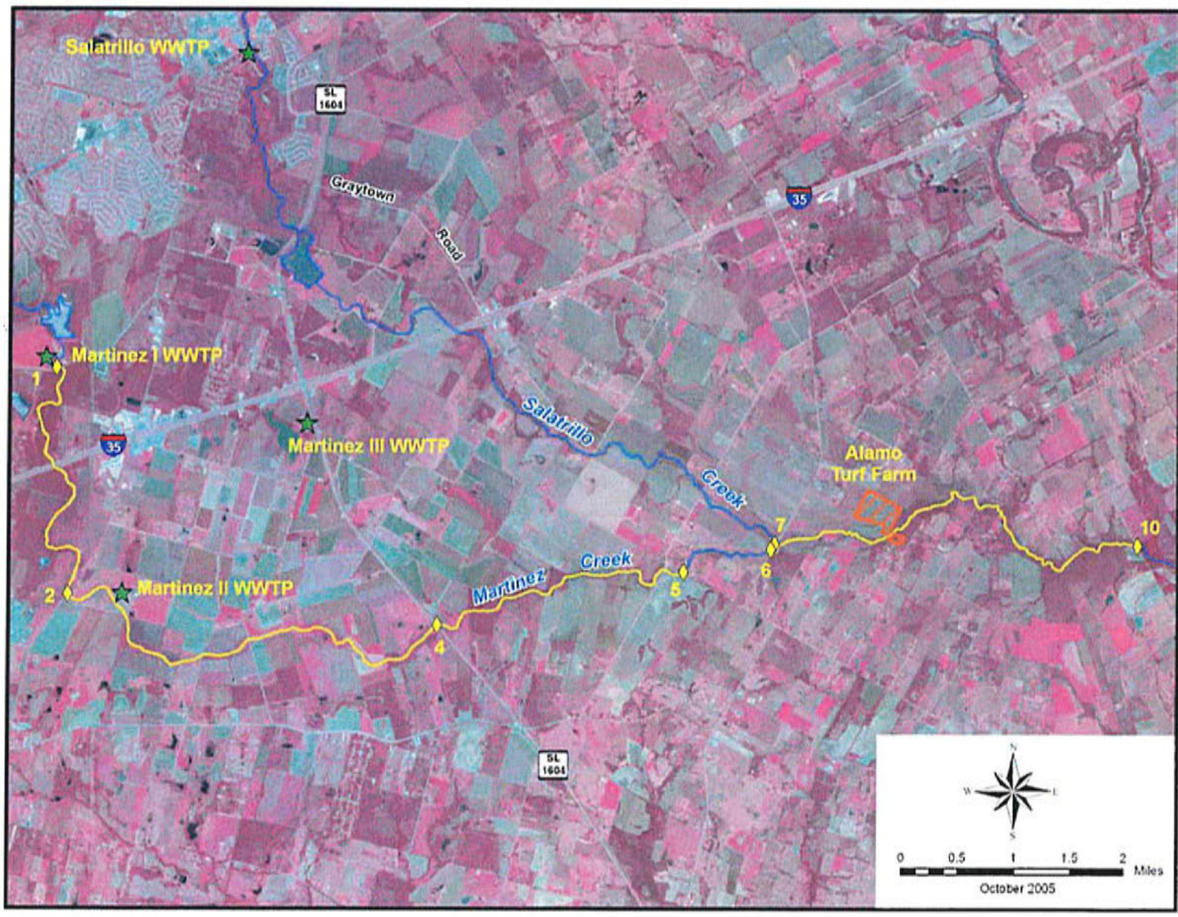


Figure 1 –Stream Segments and Flow Measurements Used in Estimation of Channel Losses

Table 1 – Streamflow Segments and Estimated Loss Rates

August 4, 2005

From	*To*	*Location*	*Segment Length (mi)*	*Upstream Measured Flow (cfs)*	*Downstream Measured Flow (cfs)*	*WWTP Discharge (cfs)**	*% Loss/Mile*
Site #1	Site #2	Martinez Crk	2.74	2.228	2.186		0.7%
Site #2	Site #4	Martinez Crk	4.18	2.186	3.750	1.788	1.3%
Site #4	Site #5	Martinez Crk	2.66	3.750	3.268		4.8%

August 5, 2005

From	*To*	*Location*	*Segment Length (mi)*	*Upstream Measured Flow (cfs)*	*Downstream Measured Flow (cfs)*	*WWTP Discharge (cfs)**	*% Loss/Mile*
Sites #6 & #7	Site #10	Martinez Crk	4.27 4.19	3.535 3.691	5.595		5.4%

**Discharge listed for Martinez II WWTP only, as it occurred within a measured segment. Discharge for Martinez I WWTP occurred above all flow measurements.*

For comparison purposes, losses for the four stream segments used in the calculation are plotted in Figure 2 showing the relation between transmission loss and outflow rates in small watersheds from United States Geological Survey (USGS)[1] studies. The results from this analysis are consistent with the 1 – 10% per mile loss rate for flows around 10 acft/day (~5 cfs) indicated in the USGS report.

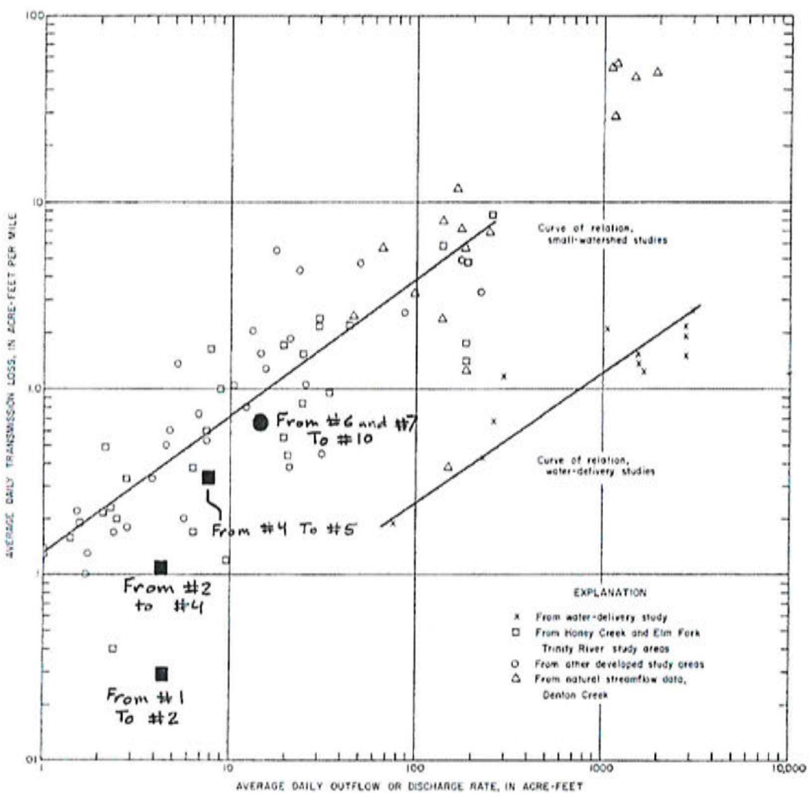


Figure 2 – Typical Streamflow Loss Rates in Small Watersheds

[1] USGS, "Hydrologic Effects of Floodwater Retarding Structures on Garza Little Elm Reservoir, Texas," City of Dallas and Texas Water Development Board, September 1989.

The General Equation used for calculation of the percentage of upstream flow lost per stream mile is shown below. Average loss rates for segments of Martinez Creek above and below the Salatrillo Creek confluence are shown in Table 2.

General Equation

$$\%Loss/mile = \frac{(Q_{Upstream} - Q_{Downstream} + Q_{Discharge})}{(Q_{Upstream} + Q_{Discharge})} x \frac{100}{SegmentLength}$$

Table 2 –Average Loss Rates

Location	*% Loss/Mile*
Martinez Creek above the confluence with Salatrillo Creek	2.29%
Martinez Creek below the confluence with Salatrillo Creek	5.36%

Based on these preliminary findings, it is reasonable to expect channel losses during dry periods of between 2.29% and 5.36% per mile in Martinez Creek. Between Martinez I and the Alamo Turf Farm, that would indicate a delivery of approximately 62% (Delivery Factor = [(1 – 2.29%)^10.6 miles x (1 – 5.36%)^4.2 miles]). Between Martinez II and the Alamo Turf Farm, that would indicate a delivery of approximately 67% (Delivery Factor = [(1 – 2.29%)^7.2 miles x (1 – 5.36%)^4.2 miles]). During wetter periods with greater streamflow, channel losses would likely be less and the delivery factor greater.

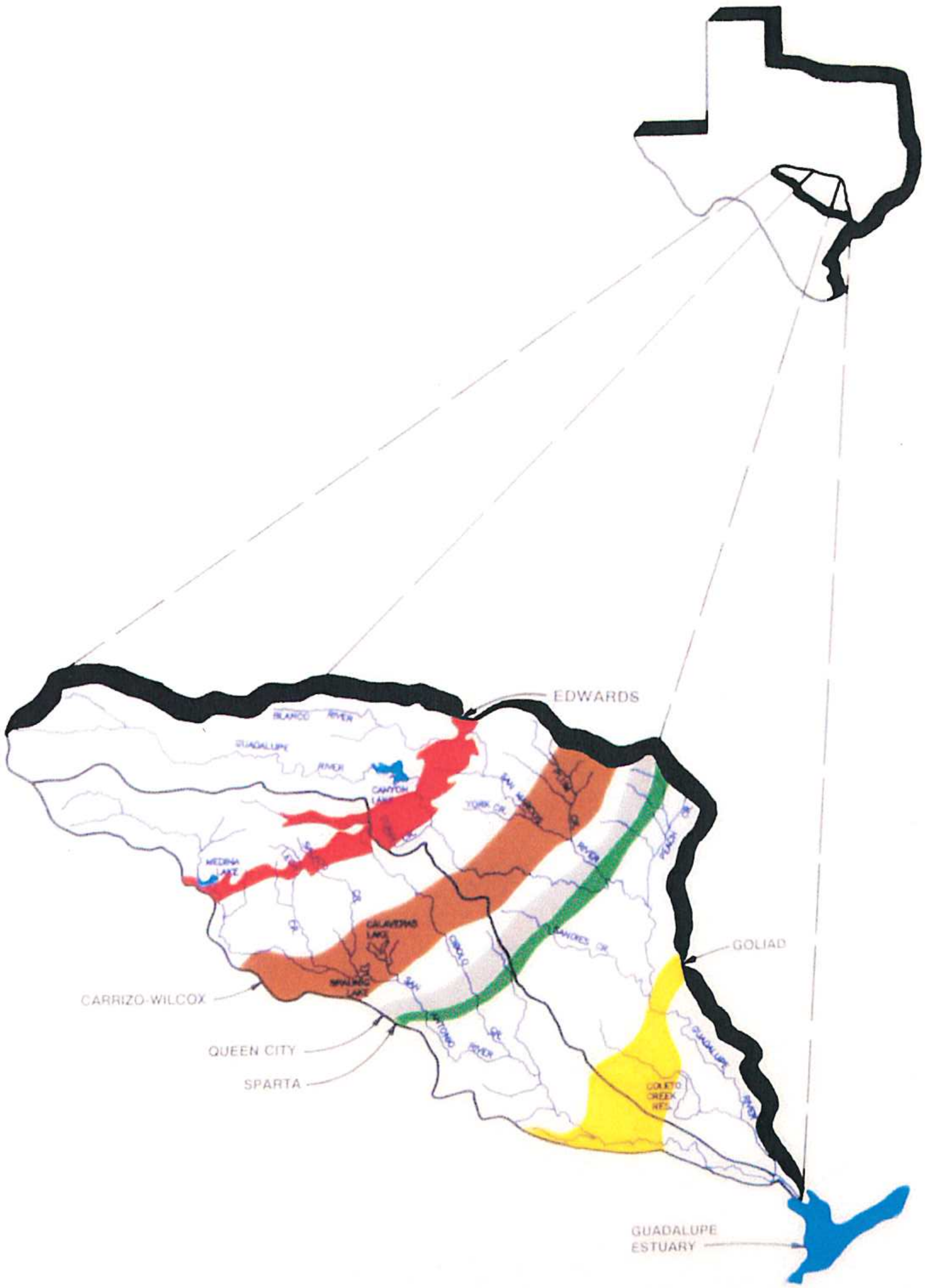
APPENDIX "D"

Recharge Enhancement Study: Guadalupe-San Antonio River
<u>Basin Volume II – Technical Report (HDR 1993)</u>

Recharge Enhancement Study

Guadalupe - San Antonio River Basin

Volume II - Technical Report



Edwards Underground Water District

HDR

HDR Engineering, Inc.
in association with
Espey, Huston & Assoc., Inc.

GUADALUPE - SAN ANTONIO RIVER BASIN

RECHARGE ENHANCEMENT STUDY

VOLUME II - TECHNICAL REPORT

Prepared for

Edwards Underground Water District

by

HDR Engineering, Inc.
and
Espey, Huston & Associates, Inc.

September, 1993

Advisory Committee Participants
for
Guadalupe - San Antonio River Basin
Recharge Enhancement Study

Edwards Underground Water District*
Russell Masters

San Antonio Water System
Joe Aceves

Guadalupe - Blanco River Authority
Thomas Hill

Bexar Metropolitan Water District
Tom Moreno

San Antonio River Authority
Fred Pfeiffer

City of San Marcos
Larry Gilley

Canyon Regional Water Authority
David Davenport

Springhills Water Management District
Ray Buck

Nueces River Authority
Con Mims

City of Corpus Christi
James Dodson

Industrial Water Users Association
Bob Wright

Texas Water Development Board
Gordon Thorn

* **Study Sponsor**

VOLUME II - TECHNICAL REPORT
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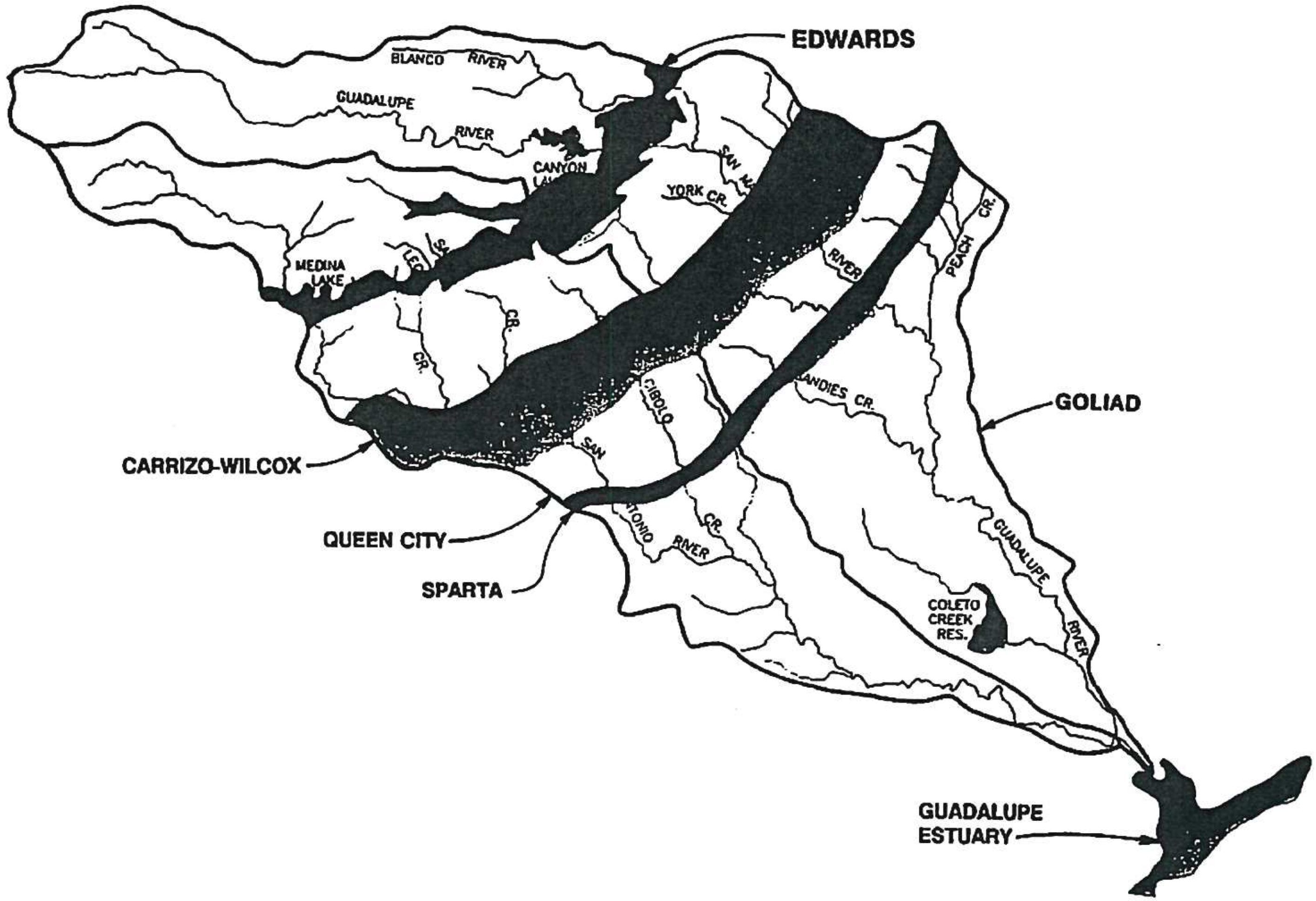
TECHNICAL REPORT

GUADALUPE - SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

1.0 INTRODUCTION

The Guadalupe - San Antonio River Basin encompasses over 10,100 square miles extending from the headwaters on the Edwards Plateau north and west of San Antonio through the Texas Blackland Prairie and Claypan Area, the Northern Rio Grande Plain, and the Gulf Coast Prairies to the Guadalupe Estuary south of Victoria. Land use in the basin is predominantly classified (Ref. 21) as range and pasture (79%) with the remainder classified as cropland (14%), urban (6%), or miscellaneous uses (1%). As is apparent in Figure 1-1, the Guadalupe - San Antonio River Basin is crossed by at least five aquifer outcrops or recharge zones, including the Edwards, Carrizo-Wilcox, Queen City, Sparta, and Gulf Coast (Goliad). The most transmissive of these recharge zones is associated with the Edwards limestone aquifer and is generally located along the Balcones Escarpment. The Edwards Aquifer is presently the water supply source for the City of San Antonio as well as numerous other cities and agricultural interests throughout Uvalde, Medina, Bexar, Comal, and Hays Counties. The aquifer also feeds Leona, San Pedro, San Antonio, Comal, and San Marcos Springs, creating unique environments and recreational opportunities while providing base flow to the Nueces, Leona, San Antonio, Comal, Guadalupe, and San Marcos Rivers.

The present and future economic dependence of entities currently served by the Edwards Aquifer and the flows emanating from its springs has prompted the Edwards Underground Water District (EUWD) to sponsor this Guadalupe - San Antonio River Basin



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

STUDY AREA MAP

HDR Engineering, Inc.

FIGURE 1-1

Recharge Enhancement Study. An Advisory Committee representative of the diverse interests potentially affected by enhancement of Edwards Aquifer recharge was assembled by the EUWD to provide guidance and technical review throughout the study effort.

The concept of recharge enhancement is not new. In 1964, the U. S. Army Corps of Engineers (USCE) published a report identifying a number of potential projects located near the Edwards Aquifer recharge zone intended to capture and recharge additional flood flows which would not have entered the aquifer naturally. Since that time, the EUWD and others have constructed projects on Seco, Parkers, Verde, San Geronimo, Salado, Dry Comal, Sink, and Purgatory Creeks which have served to enhance recharge. The EUWD has also sponsored detailed studies of 19 potential recharge enhancement projects in the Nueces River Basin. Significant results and products of studies of the Nueces River Basin include new estimates of historical Edwards Aquifer recharge and development of a new river basin model capable of calculating potential recharge enhancement while considering downstream water rights and estuarine inflows.

1.1 Study Objectives

The key objectives of the Guadalupe - San Antonio River Basin Recharge Enhancement Study are summarized as follows:

- Development of new monthly estimates of historical Edwards Aquifer recharge consistent with those for the Nueces River Basin, thereby completing recharge estimates for the entire aquifer for the 1934-89 historical period.

- Development of a river basin computer model capable of evaluating recharge enhancement projects and water availability subject to variable water rights constraints and springflows.

- Calculation of maximum enhanced recharge potential and estuarine inflow reductions associated with a program of recharge projects subject to a range of springflow and water rights utilization scenarios.

- Calculation of maximum water potentially available at selected locations subject to a range of springflow and water rights utilization scenarios.

The following sections of this Technical Report describe the basic data collected, previous studies referenced, methodologies applied, and results obtained in accomplishing these objectives.

2.0 WATER RIGHTS AND USE

2.1 Water Rights

The Texas Water Commission (TWC) maintains a master listing of all water rights and applications for water rights within the state. A current listing of all water rights and applications in the Guadalupe and San Antonio River Basins was extracted from the master listing, sorted by river order number (downstream to upstream), and included in Appendix A (Volume III). Water rights in terms of authorized diversion for consumptive use are summarized by river basin and type of use in Table 2-1. Table 2-1 shows that industrial water rights are the most dominant type of use in the Guadalupe River Basin and irrigation water rights are the most dominant type of use in the San Antonio River Basin. Municipal, industrial, and irrigation rights comprise virtually all of the rights for consumptive use in the Guadalupe - San Antonio River Basin. The Edwards Underground Water District (EUWD) currently holds the only authorized diversion right for recharge which accounts for 0.2 percent of total basin diversion rights.

Several non-consumptive hydroelectric power generation rights exist in the Guadalupe River Basin. Most of these hydroelectric rights are located in series along the Guadalupe River, with the largest authorized right being 796,363 ac-ft/yr held by the City of Gonzales. The City of Gonzales hydroelectric rights, however, are subordinated to other rights to use the water of the Guadalupe River for municipal, industrial, irrigation, and/or mining purposes. The Guadalupe-Blanco River Authority (GBRA) holds six hydroelectric rights upstream of the City of Gonzales site ranging from 574,832 ac-ft/yr to 663,892 ac-ft/yr.

Table 2-1 Summary of Consumptive Use Water Rights[1]						
	Guadalupe River Basin		San Antonio River Basin		Total	
Type of Use	Authorized Diversion (Ac-Ft/Yr)	Percent of Total Diversion	Authorized Diversion (Ac-Ft/Yr)	Percent of Total Diversion	Authorized Diversion (Ac-Ft/Yr)	Percent of Total Diversion
Municipal	105,800	18.3%	71,862[2]	12.4%	177,662	30.7%
Industrial	149,912[3]	25.9%	48,925[4]	8.5%	198,837	34.4%
Irrigation	98,648	17.0%	102,180	17.7%	200,828	34.7%
Mining	153	0.0%	5	0.0%	158	0.0%
Recharge	0	0.0%	961	0.2%	961	0.2%
TOTAL	354,513	61.2%	223,933	38.8%	578,446	100.0%

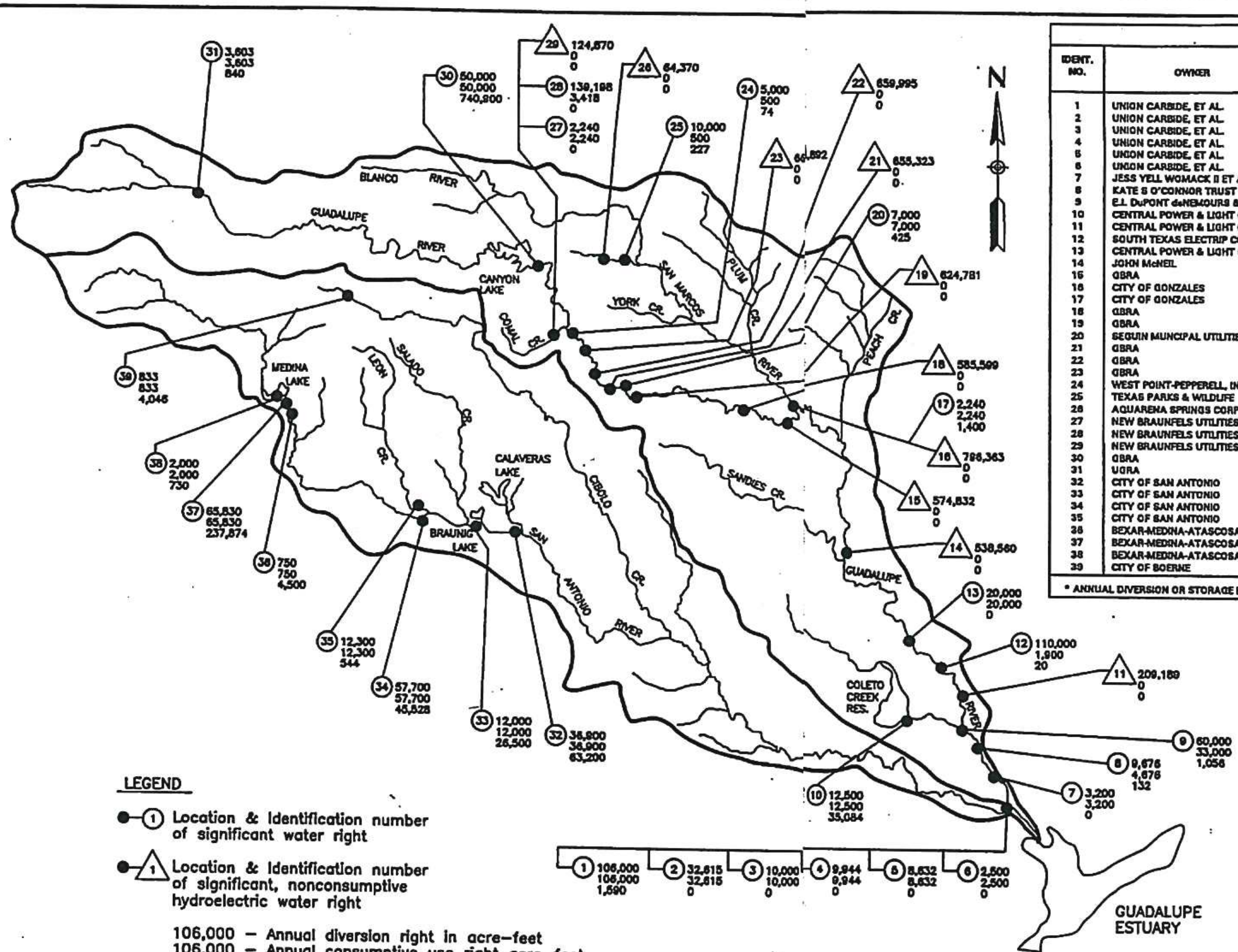
Notes:

1) Summary excludes all non-consumptive water rights including non-consumptive hydroelectric, industrial, and recreation water rights. The non-consumptive hydroelectric and non-consumptive industrial water rights were included in the GSA River Basin Model. See Section 5 for a description of water rights assumptions used in the GSA River Basin Model.
2) Includes the Applewhite Reservoir diversion rights totalling 70,000 ac-ft/yr which are presently undeveloped.
3) Includes the 20,000 ac-ft/yr diversion right from the Guadalupe River upstream of Victoria for use as make-up water and the 12,500 ac-ft/yr diversion right from Coleto Creek for Central Power and Light at Coleto Creek Reservoir.
4) Includes the 12,000 ac-ft/yr and 36,900 ac-ft/yr diversion rights associated with Braunig Lake and Calaveras Lake, respectively.

A total of about 580 individual water rights currently exist in the Guadalupe - San Antonio River Basin, with the vast majority of these being individual irrigation water rights with authorized annual diversions of less than 100 ac-ft. There are 39 owners of storage or annual diversion rights which are in excess of 2,000 ac-ft. The geographic location of each of these significant water rights is shown in Figure 2-1 along with a listing of the authorized diversion, consumptive use, and storage amounts. These significant water rights represent

SIGNIFICANT WATER RIGHTS*					
IDENT. NO.	OWNER	DIVERSION RIGHT (AC-FT/YR)	CONSUMPTIVE RIGHT (AC-FT/YR)	STORAGE RIGHTS (AC-FT/YR)	NOTES
1	UNION CARBIDE, ET AL.	106,000	106,000	1,590	
2	UNION CARBIDE, ET AL.	32,615	32,615	0	
3	UNION CARBIDE, ET AL.	10,000	10,000	0	
4	UNION CARBIDE, ET AL.	9,944	9,944	0	
5	UNION CARBIDE, ET AL.	8,632	8,632	0	
6	UNION CARBIDE, ET AL.	2,500	2,500	0	
7	JESS YELL WOMACK II ET AL.	3,200	3,200	0	
8	KATE S O'CONNOR TRUST	9,676	4,676	132	
9	E.I. DuPONT deNEMOURS & CO.	60,000	33,000	1,056	
10	CENTRAL POWER & LIGHT CO.	12,500	12,500	35,084	COLETO CREEK RES.
11	CENTRAL POWER & LIGHT CO.	209,189	0	0	
12	SOUTH TEXAS ELECTRIP COOP	110,000	1,900	20	
13	CENTRAL POWER & LIGHT CO.	20,000	20,000	0	
14	JOHN McNEIL	538,560	0	0	HYDROELECTRIC
15	GBRA	574,832	0	0	HYDROELECTRIC, H-5
16	CITY OF GONZALES	786,383	0	0	HYDROELECTRIC
17	CITY OF GONZALES	2,240	2,240	1,400	
18	GBRA	585,599	0	0	HYDROELECTRIC, H-4
19	GBRA	624,781	0	0	HYDROELECTRIC, TP-5
20	SEGUIN MUNCIPAL UTILITIES	7,000	7,000	425	
21	GBRA	655,323	0	0	HYDROELECTRIC, TP-4
22	GBRA	659,995	0	0	HYDROELECTRIC, TP-3
23	GBRA	663,892	0	0	HYDROELECTRIC, TP-2
24	WEST POINT-PEPPERELL, INC.	5,000	500	74	
25	TEXAS PARKS & WILDLIFE	10,000	500	232	
26	AQUARENA SPRINGS CORP.	64,370	0	0	HYDROELECTRIC
27	NEW BRAUNFELS UTILITIES	2,240	2,240	0	
28	NEW BRAUNFELS UTILITIES	139,198	3,418	0	
29	NEW BRAUNFELS UTILITIES	124,870	0	0	HYDROELECTRIC
30	GBRA	50,000	50,000	740,900	CANYON LAKE
31	UGRA	3,603	3,603	840	
32	CITY OF SAN ANTONIO	36,900	36,900	63,200	CALAVERAS LAKE
33	CITY OF SAN ANTONIO	12,000	12,000	26,500	BRAUNIG LAKE
34	CITY OF SAN ANTONIO	57,700	57,700	45,528	APPLEWHITE RES.
35	CITY OF SAN ANTONIO	12,300	12,300	544	
36	BEXAR-MEDINA-ATASCOSA WCID	750	750	4,500	DIVERSION LAKE
37	BEXAR-MEDINA-ATASCOSA WCID	65,830	65,830	237,874	MEDINA LAKE
38	BEXAR-MEDINA-ATASCOSA WCID	2,000	2,000	730	
39	CITY OF BOERNE	833	833	4,046	

* ANNUAL DIVERSION OR STORAGE RIGHTS IN EXCESS OF 2,000 ACRE-FEET.



LEGEND

- (1) Location & Identification number of significant water right
- △1 Location & Identification number of significant, nonconsumptive hydroelectric water right

106,000 – Annual diversion right in acre-feet
106,000 – Annual consumptive use right acre-feet
2,643 – Storage right in acre-feet

GUADALUPE-SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

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SIGNIFICANT WATER RIGHTS LOCATION MAP

FIGURE 2-1

87 percent of the total authorized consumptive use in the Guadalupe - San Antonio River Basin, including 96 percent of the municipal rights, 99 percent of the industrial rights, and 68 percent of the irrigation rights. Some of the major water rights in the basin have specific conditions associated with their authorized diversion amount. A more detailed description of how specific water rights were addressed in the GSA River Basin Model is presented in Section 5 of this report.

2.2 Historical Surface Water Use

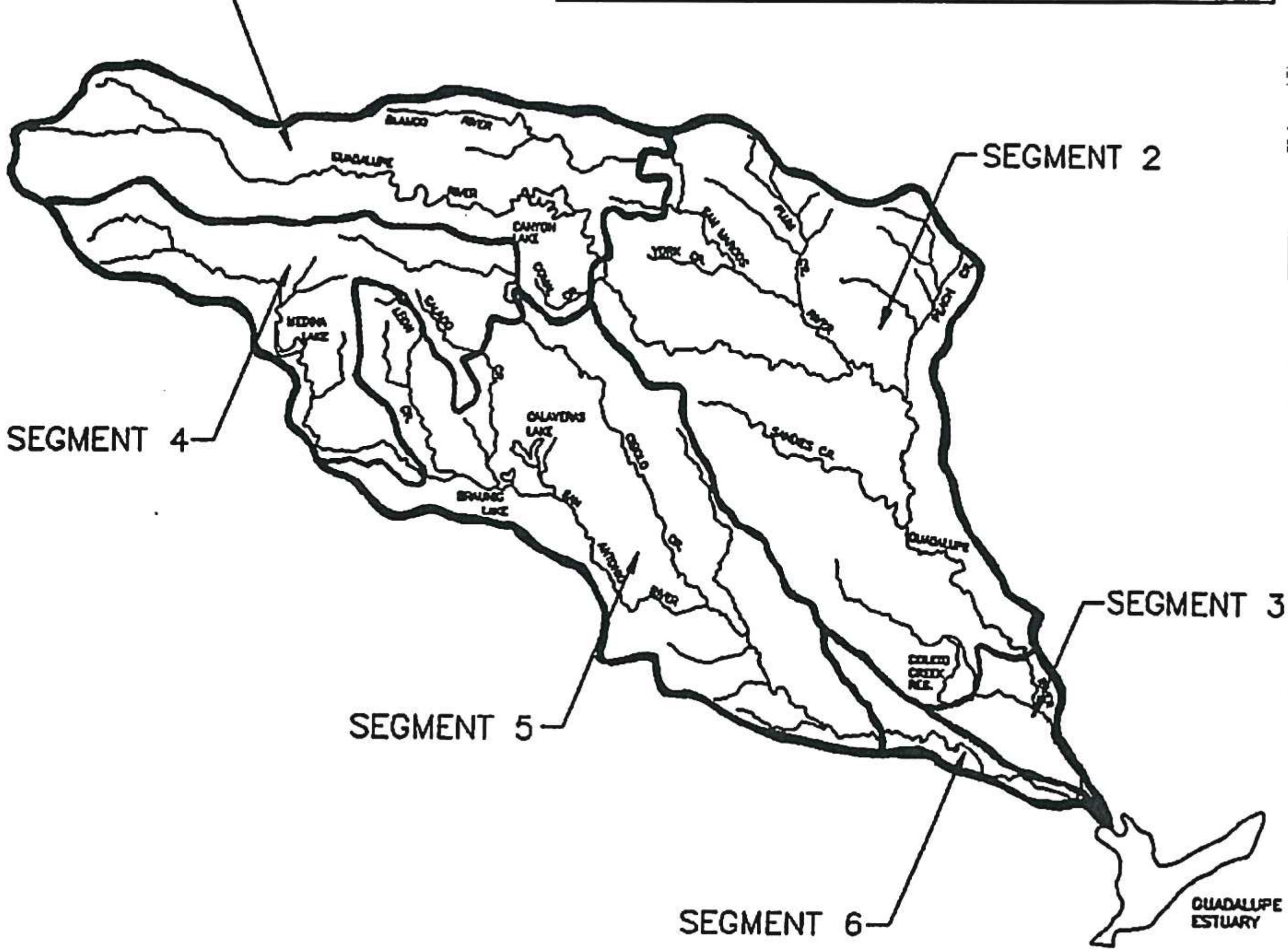
Detailed analyses of surface water use were performed as a part of this study in order to adjust gaged streamflow records for historical diversions to obtain natural streamflow. Natural streamflow is defined as that which would have occurred historically exclusive of human influences. In addition, monthly water use patterns for each type of use were needed to accurately model diversions for water rights.

For this study, the Guadalupe - San Antonio River Basin was subdivided into six major segments in order to develop regionally applicable monthly water use patterns. These segments and associated drainage areas are presented in Figure 2-2 and are described as follows:

Segment 1 - Extends from the headwaters of the Guadalupe River Basin to the downstream edge of the Edwards Aquifer recharge zone including areas upstream of the USGS streamflow gaging stations on the Guadalupe River at New Braunfels (ID# 1685), San Marcos River at San Marcos (ID# 1700), and Blanco River at Kyle (ID# 1713).

Segment 2 - Extends from the lower edge of Segment 1 to the USGS streamflow gaging stations on the Guadalupe River at Victoria (ID# 1675) and Coleto Creek near Victoria (ID# 1775).

DRAINAGE AREAS OF MODEL SEGMENTS			
SEGMENT		DRAINAGE AREA (SQ.MI.)	PERCENT OF TOTAL BASIN
	1	2,153	21.3%
GUADALUPE RIVER BASIN	2	3,539	34.9%
	3	256	2.5%
	4	1,420	14.0%
SAN ANTONIO RIVER BASIN	5	2,501	24.7%
	6	259	2.6%
TOTAL		10,128	100.0%



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

BASIN MODEL SEGMENTS

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FIGURE 2-2

Segment 3 - Extends from the lower edge of Segment 2 to the Gulf of Mexico.

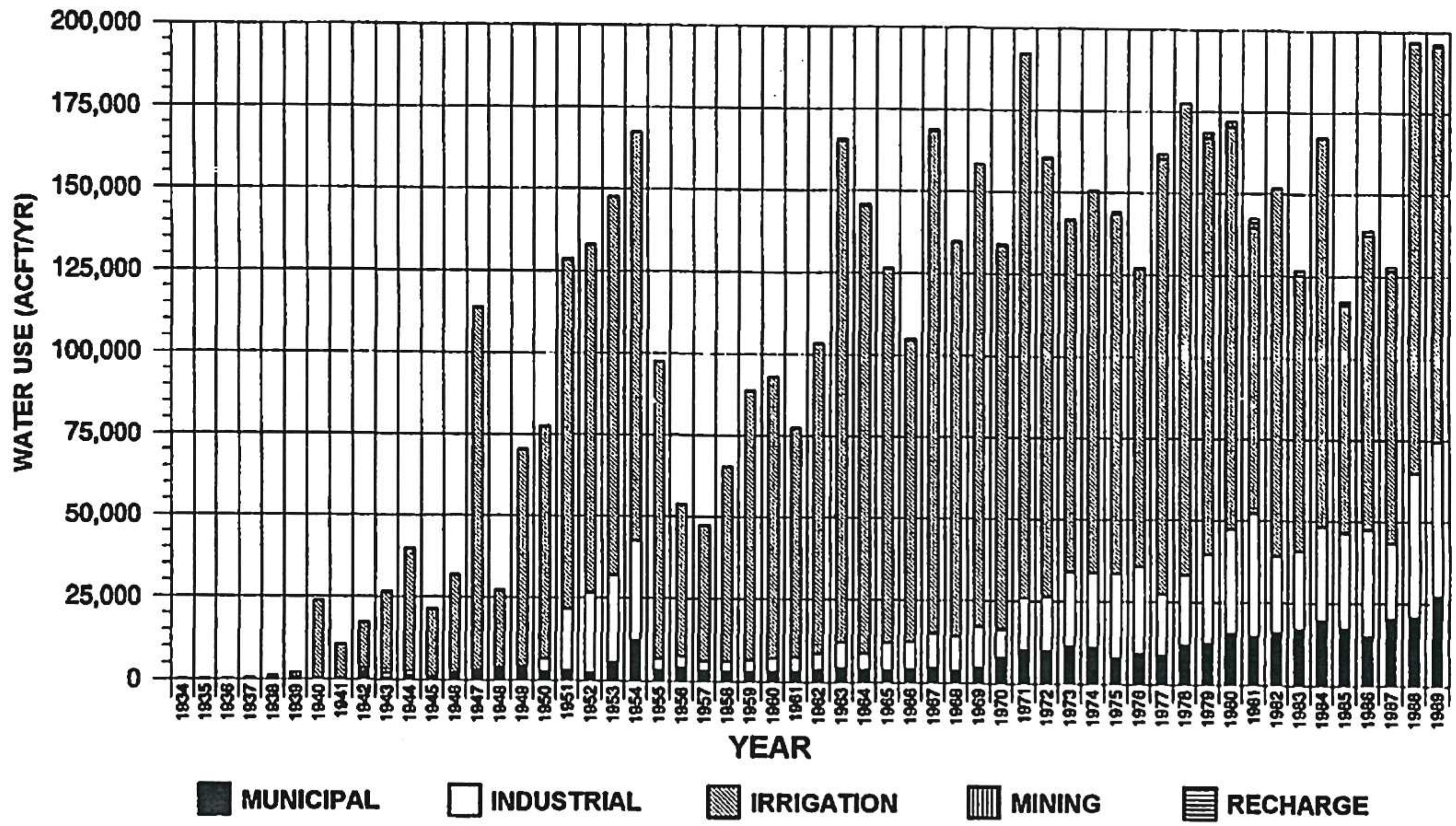
Segment 4 - Extends from the headwaters of the San Antonio River Basin to the downstream edge of the Edwards Aquifer recharge zone, including the areas upstream of the nearby USGS streamflow gaging stations on the Medina River at Somerset (ID# 1808), San Antonio River at San Antonio (ID# 1780), Salado Creek at San Antonio (ID# 1787), and Cibolo Creek at Selma (ID# 1850).

Segment 5 - Extends from the lower edge of Segment 4 to the USGS streamflow gaging station on the San Antonio River at Goliad (ID# 1885).

Segment 6 - Extends from the lower edge of Segment 5 to the confluence of the San Antonio and Guadalupe Rivers.

Records of historical surface water use as reported by individual water rights owners for the 1915-89 period were obtained from the TWC in digital format. These records are comprised of annual totals from 1915 to 1955 and available monthly totals from 1955 through 1989 and are categorized by designated type of use including municipal, industrial, irrigation, mining, and recharge. Figure 2-3 and Table 2-2 summarize historical surface water use by type of use for the entire Guadalupe - San Antonio River Basin. Table 2-3 summarizes historical surface water use according to the type of use for each segment within the basin. Comprehensive tables of reported annual surface water use, which are broken down by type of use for each reach and the entire basin, are included in Appendix B (Volume III).

As shown in Table 2-2 and Figure 2-3, the maximum historical use was 196,866 ac-ft/yr in 1988 which represents only 35 percent of the total consumptive water rights in the Guadalupe - San Antonio River Basin. A comparison of the total consumptive water rights by river basin and the corresponding 1988 water usage, is presented in Figure 2-4.



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

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GUADALUPE - SAN ANTONIO RIVER BASIN HISTORICAL SURFACE WATER USE

FIGURE 2-3

Table 2-2
Historical Consumptive Use of Surface Water
Guadalupe - San Antonio River Basin

Type of Use	Average Use[1] (Ac-Ft/Yr)	Percentage of Average Use	Maximum Use (Ac-Ft/Yr)	Year of Maximum Use
Municipal	18,371	12.0%	27,183	1989
Industrial	31,974	20.8%	47,357	1989
Irrigation	102,235	66.5%	166,218	1971
Mining	635	0.4%	1,535	1980
Recharge	474	0.3%	1,407	1981
Total	153,689	100.0%	196,866	1988

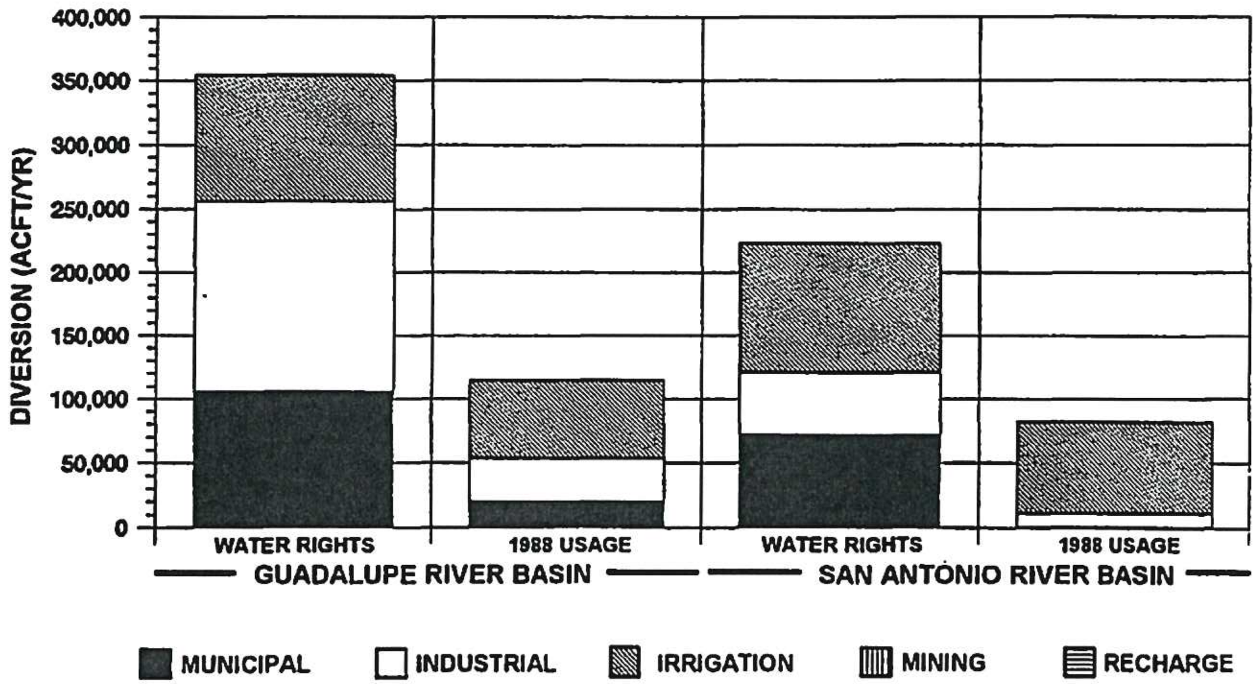
Notes:
1) Average use based on 1980-89 period.

Table 2-3
Historical Consumptive Use of Surface Water By Model Segment
Guadalupe - San Antonio River Basin

Type of Use	Percentage of Basin Average Use[1]							
	Guadalupe River Basin				San Antonio River Basin			
	Segment 1	Segment 2	Segment 3	Total	Segment 4	Segment 5	Segment 6	Total
Municipal	2.7%	5.0%	4.0%	11.7%	0.3%	0.0%	0.0%	0.3%
Industrial	0.4%	4.5%	10.0%	14.9%	0.0%	5.9%	0.0%	5.9%
Irrigation	1.7%	2.6%	27.8%	32.1%	29.5%	4.9%	0.0%	34.4%
Mining	0.0%	0.2%	0.0%	0.2%	0.1%	0.1%	0.0%	0.2%
Recharge	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.3%
All Uses	4.8%	12.3%	41.8%	58.9%	30.2%	10.9%	0.0%	41.1%

Notes:
1) Based on average use for 1980-89 period.

Type of Usage	Guadalupe River Basin		San Antonio River Basin		Total	
	Full Water Rights (Ac-Ft/Yr)	1988 Usage (Ac-Ft/Yr)	Full Water Rights (Ac-Ft/Yr)	1988 Usage (Ac-Ft/Yr)	Full Water Rights (Ac-Ft/Yr)	1988 Usage (Ac-Ft/Yr)
Municipal	105,800	20,428	71,862	493	177,662	20,921
Industrial	149,912	33,072	48,925	10,874	198,837	43,946
Irrigation	98,648	61,286	102,180	70,444	200,828	131,730
Mining	153	0	5	269	158	269
Recharge	0	0	961	0	961	0
Total	354,513	114,786	223,933	82,080	578,446	196,866



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

COMPARISON OF FULL WATER RIGHTS AND 1988 WATER USAGE

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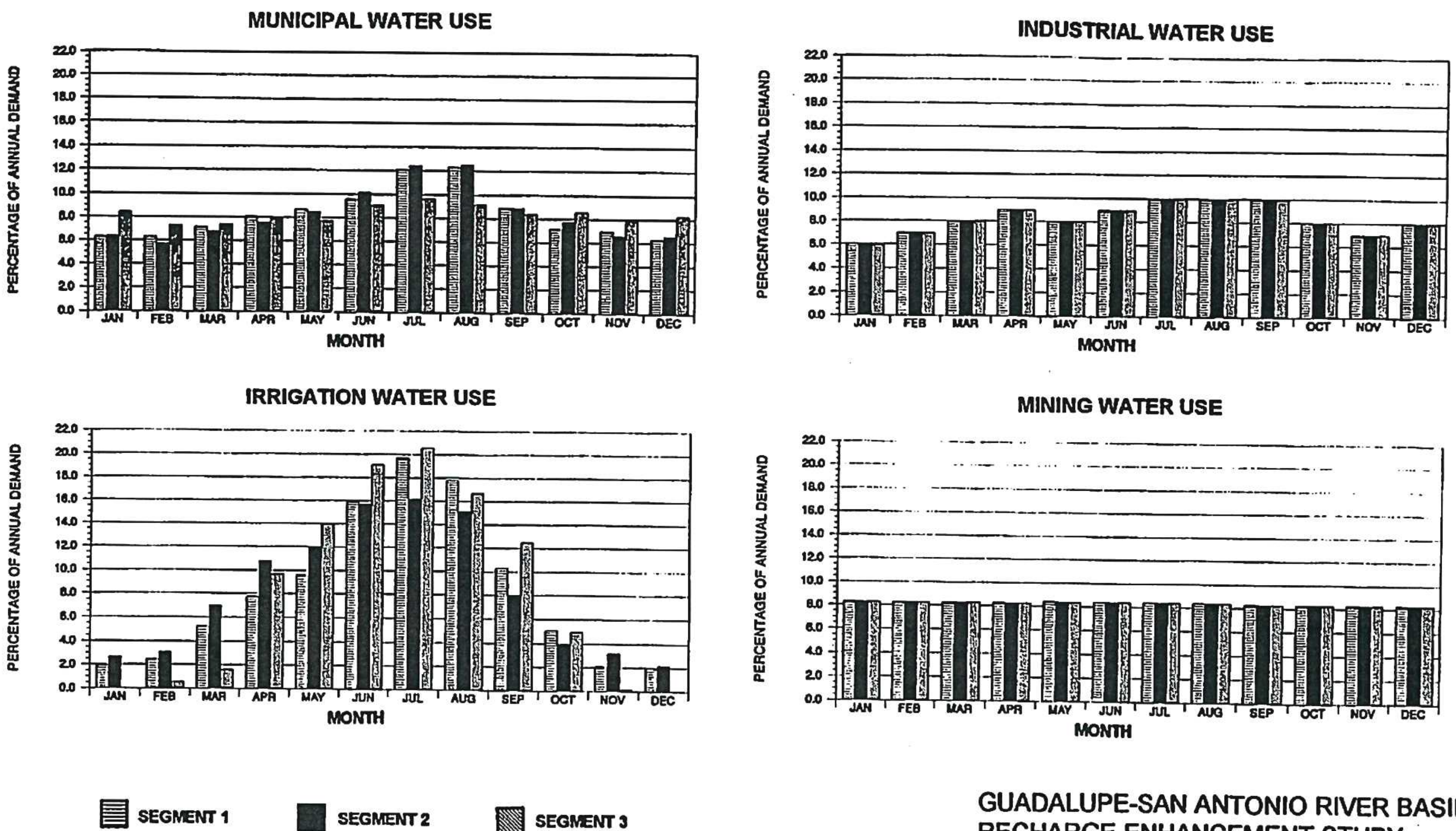
FIGURE 2-4

Irrigation accounted for 67 percent of total surface water use in 1988 representing about 62 percent and 69 percent of the total authorized irrigation rights in the Guadalupe and the San Antonio River Basins, respectively. Municipal use accounted for 11 percent of total surface water use in 1988, representing about 19 percent and less than 1 percent of the total authorized municipal rights in the Guadalupe and San Antonio River Basins, respectively. Municipal surface water rights in the San Antonio River Basin total 71,862 ac-ft/yr, of which 70,000 ac-ft/yr is associated with Applewhite Reservoir, which is currently incomplete. Industrial use accounted for 22 percent of total surface water use in 1988 representing about 22 percent of the total authorized industrial rights in both the Guadalupe and San Antonio River Basins.

Water demand can be highly variable from month to month depending on the type and geographic location of use. Typical monthly percentages of annual water demand were calculated for municipal, industrial, and irrigation use types for each of the six segments within the basin where significant use has occurred. Surface water use for mining was assumed to occur uniformly throughout the year. Reported monthly water use data for the 1955 to 1989 period was used for calculation of the monthly percentages presented in Figure 2-5 and Figure 2-6 for the Guadalupe and San Antonio River Basins, respectively.

Municipal water demand typically peaks during the summer months at between about 9 percent and 13 percent of annual demand, with summer demand percentages being higher in the upper segments of the basin. Significant industrial water use occurs primarily in the lower Guadalupe River Basin (Segment 3). Industrial demand has a more uniform monthly pattern than do municipal and irrigation demands and peaks during the summer months at



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

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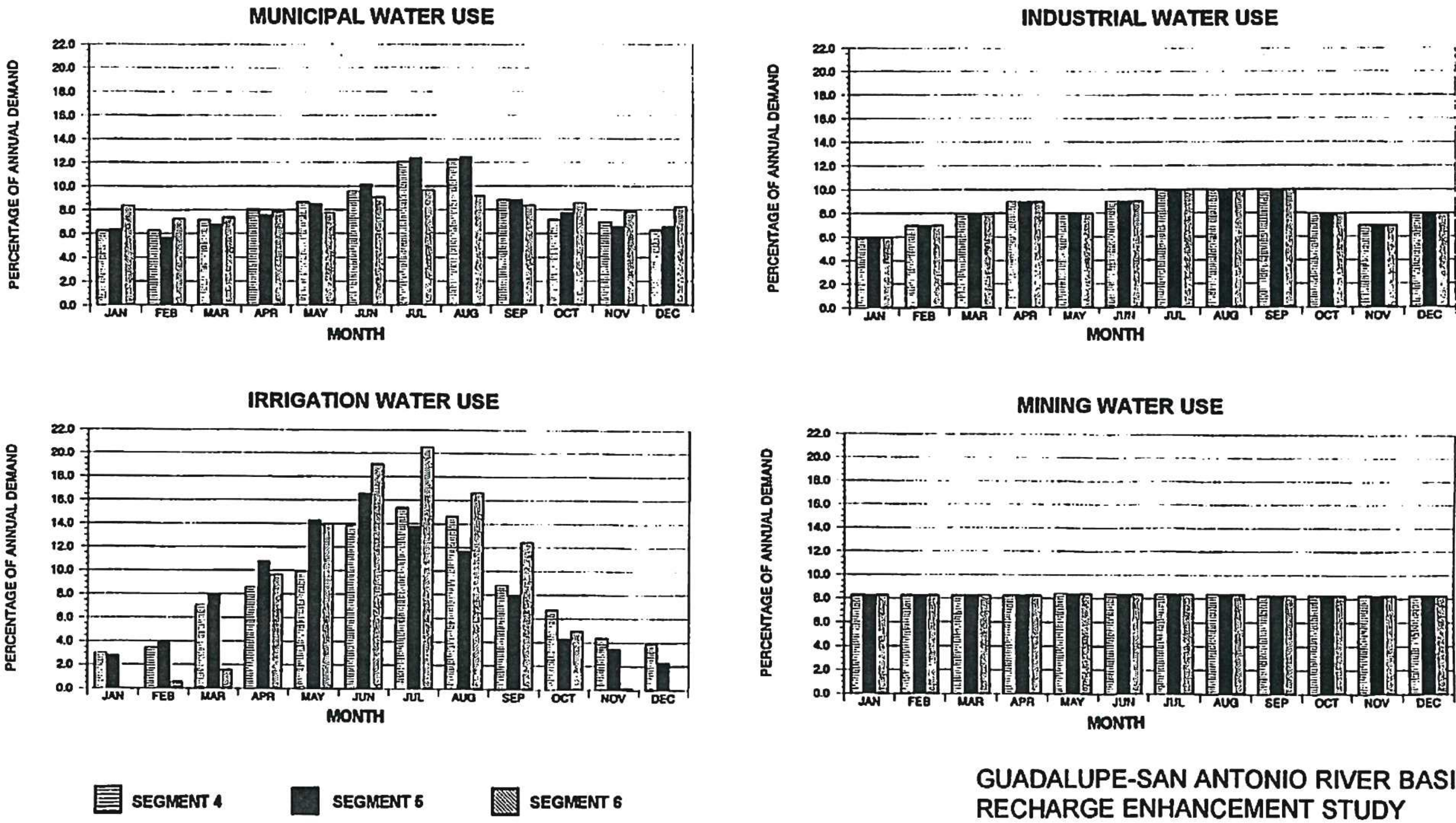
MONTHLY PERCENTAGES OF ANNUAL SURFACE WATER DEMAND FOR THE GUADALUPE RIVER BASIN

FIGURE 2-5



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

HDR Engineering, Inc.

MONTHLY PERCENTAGES OF ANNUAL SURFACE WATER DEMAND FOR THE SAN ANTONIO RIVER BASIN

FIGURE 2-6

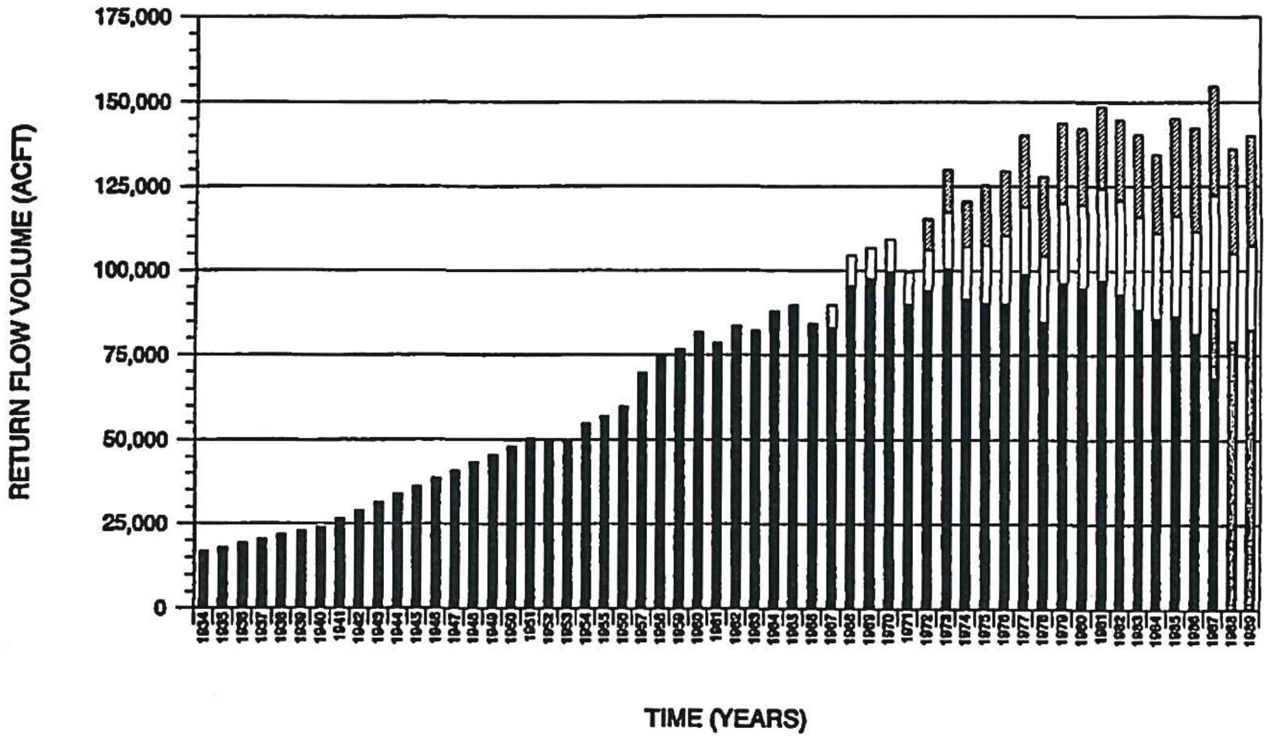
about 10 percent of the annual demand. Significant water use for irrigation purposes occurs in both the Guadalupe and San Antonio River Basins. In the Guadalupe River Basin, irrigation water use occurs primarily in the lower portion of the basin (Segment 3) and is associated with rice irrigation. Peak monthly irrigation demands are about 21 percent of the annual water demand in Segment 3 and range from 16 percent to 20 percent of the annual demand in the upper portions of the Guadalupe River Basin (Segments 1 and 2). In the San Antonio River Basin, irrigation water use predominantly occurs in the upper portion of the basin (Segment 4). The peak monthly demand in this region is about 15 percent of the annual demand. In the central portion of the San Antonio River Basin (Segment 5), irrigation water demand peaks during the summer months at about 16 percent of the annual demand. In the lower San Antonio River Basin (Segment 6), where no historical irrigation use has been reported, a monthly demand distribution identical to the lower Guadalupe River Basin (Segment 3) was assumed.

The typical monthly percentages of annual demand presented in Figure 2-5 and Figure 2-6 were used to disaggregate reported annual diversion totals prior to 1955 in order to approximate historical monthly diversions, adjust gaged streamflows, and develop a natural streamflow database for the Guadalupe - San Antonio River Basin. The same monthly demand percentages were included in the model in order to simulate typical monthly diversion patterns for water rights according to type of use and geographic location.

2.3 Return Flows

Historical return flows in the Guadalupe - San Antonio River Basin were analyzed in this study in order to adjust gaged streamflow records and obtain estimates of natural streamflow. The TWC maintains a database of self-reporting return flows since 1972 for all wastewater discharge permits. Portions of this return flow database were obtained from the TWC in digital format and manually adjusted for apparent discrepancies or omissions. For the 1934-71 period, return flows were estimated for communities discharging in excess of 0.5 million gallons per day (mgd) in 1972. These estimates were based on the product of average per capita return flow for the available period of record and historical population figures (Ref. 2).

Historical return flows from the City of San Antonio were obtained from C. Thomas Koch, Inc. (Ref. 16) and verified for the 1972-89 using the TWC self-reporting data. Annual return flows from the four major wastewater treatment plants (Leon Creek, Salado Creek, Rilling Road, and Dos Rios) operated by the City of San Antonio are presented in Figure 2-7. City of San Antonio return flow accounted for about 77 percent of all return flows in the Guadalupe - San Antonio River Basin in 1988. A summary of annual return flows used in the Guadalupe - San Antonio River Basin model is provided in Appendix C (Volume III).



NOTE:

INCLUDES CITY OF SAN ANTONIO RETURN FLOWS FROM THE FOLLOWING WASTEWATER TREATMENT PLANTS: RILLING ROAD, DOS RIOS, LEON CREEK AND SALADO CREEK.

LEGEND:
- RILLING ROAD
- DOS RIOS
- LEON CREEK
- SALADO CREEK

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

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HISTORICAL RETURN FLOWS FOR THE CITY OF SAN ANTONIO

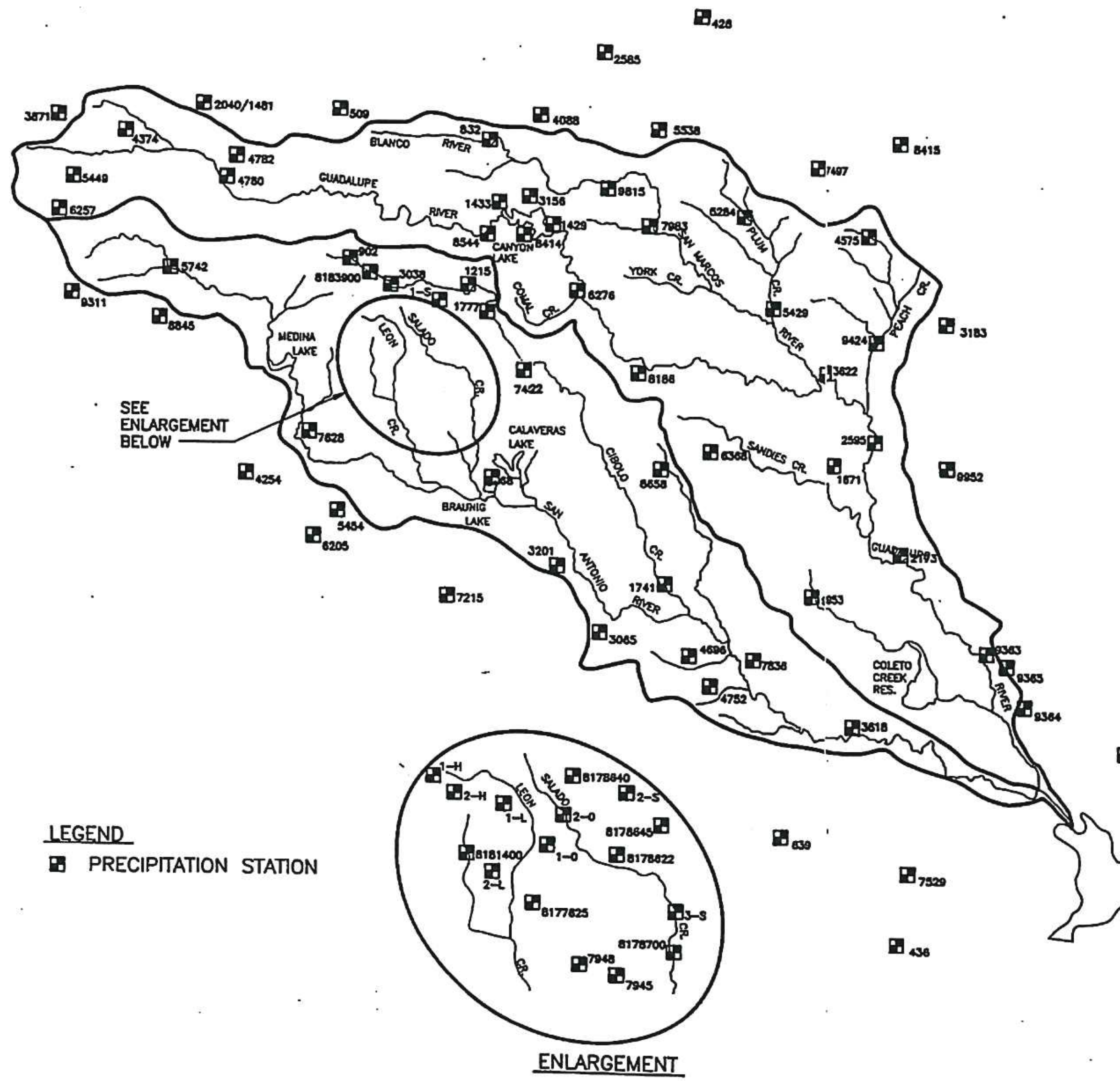
FIGURE 2-7

3.0 CLIMATOLOGICAL DATA

3.1 Precipitation

Annual precipitation in the Guadalupe - San Antonio River Basin generally increases from west to east with the westernmost portion receiving about 27 inches and the easternmost portion about 40 inches (Ref. 20). Precipitation data from approximately 90 stations was used in the development of areal precipitation for the 1923-89 historical period for each of 38 subwatersheds comprising the Guadalupe - San Antonio River Basin. The geographical location of each of these stations is presented in Figure 3-1. Inset in Figure 3-1 is a table summarizing the station name, identification number, and portion of the period of record used in this study for each precipitation station. The primary source of historical precipitation data was the National Weather Service (NWS); however, supplementary records were obtained from the U.S. Geological Survey (USGS) and the Texas Water Development Board (TWDB). Monthly areal precipitation for each of the 38 subwatersheds in the Guadalupe - San Antonio River Basin is summarized for reference in tables included in Appendix D (Volume III).

Areal precipitation for each subwatershed was developed by applying the Thiessen Polygon Method (Ref. 46) in which individual stations become the centers of polygonal areas constructed by drawing the perpendicular bisectors of lines connecting the stations. Subwatershed boundaries are superimposed on the polygons and Thiessen weights are calculated for each station and subwatershed, based on the percentage of the subwatershed area within the polygonal subarea. Monthly areal precipitation was then computed as the sum of the products of the measured station precipitation and the associated Thiessen weight.



STATION NUMBER	STATION NAME	PERIOD OF RECORD USED IN STUDY	STATION NUMBER	STATION NAME	PERIOD OF RECORD USED IN STUDY
GUADALUPE AND SAN ANTONIO RIVER BASINS PRECIPITATION STATIONS					
428	AUSTIN WSO AP	1923-89	7140	POINT COMFORT	1957-89
436	AUSTWELL	1923-60	7182	PORT LAVACA #2	1940-88
509	BANKERSMITH	1940-89	7215	POTEET	1941-89
639	BEEVILLE 5NE	1923-89	7422	RANDOLPH FIELD	1941-89
832	BLANCO	1923-89	7497	RED ROCK	1965-89
902	BOERNE	1923-89	7529	REFUGIO	1948-65
1215	BULVERDE	1940-89	7628	RIOMEDINA 2N	1923-89
1429	CANYON DAM	1961-89	7706	ROCKSPRINGS	1932-56
1433	CANYON DAM 3	1961-89	7836	RUNGE	1923-89
1481	CARR RANCH	1923-61	7945	SAN ANTONIO WSFO	1947-89
1671	CHEAPSIDE	1940-89	7948	SAN ANTONIO NURSERY	1923-61
1741	CIBOLO CREEK	1948-82	7983	SAN MARCOS	1923-89
1777	CLASSENS RANCH	1947-72	8186	SEGUIN	1923-72
2040	COTTONWOOD	1982-89	8414	SMITHSONS VALLEY	1947-56
2173	CUERO	1923-89	8415	SMITHVILLE	1923-89
2585	DRIPPING SPRINGS 6E	1984-89	8544	SPRING BRANCH	1956-89
2595	DRYER 1 NW	1940-75	8658	STOCKDALE 4N	1978-89
3038	FAIR OAKS RANCH	1947-73	8845	TARPLEY	1938-89
3065	FALLS CITY 4WSW	1946-89	9311	VANDERPOOL	1979-89
3156	FISCHERS STORE	1941-89	9363	VICTORIA WSO AP	1946-61
3183	FLATONIA	1923-89	9364	VICTORIA WB AP	1961-89
3201	FLORESVILLE	1923-89	9365	VICTORIA HWY 77 BR	1923-48
3618	GOLIAD	1923-89	9424	WAELDER 7SSW	1947-89
3622	GONZALES	1940-89	9815	WIMBERLEY 2	1984-89
3871	HALL RANCH	1940-78	9952	YOAKUM	1923-89
4088	HENLEY	1948-65	9953	YORKTOWN	1947-89
4254	HONDO	1923-75	68	BRAUNIG LAKE	1977-82
4374	HUNT	1947-89	8183900	CIBOLO CREEK	1988-89
4575	JEDDO 1SW/2NNE	1947-89	8178700	SALADO CREEK	1986-89
4696	KARNES CITY	1923-89	8177625	OLMOS CREEK	1987-89
4752	KENEDY	1949-77	8181400	HELOTES CREEK	1987-89
4780	KERRVILLE	1923-74	8185000	CIBOLO CREEK	1988-89
4782	KERRVILLE 3NNE	1974-89	8178645	EAST ELM CREEK	1987-89
5284	LOCKHART	1947-89	8178622	LORENCE CREEK	1988-89
5429	LULING	1923-89	8178640	WEST ELM CREEK	1987-89
5449	LYNDHAVEN RANCH	1951-78	1-H	HELOTES CREEK	1971-81
5454	LYTLE 3 W	1977-89	2-H	HELOTES CREEK	1971-81
5538	MANCHACA	1948-65	1-L	LEON CREEK	1971-81
5742	MEDINA	1966-89	2-L	LEON CREEK	1971-81
6205	NATALIA	1923-77	1-O	OLMOS CREEK	1971-81
6257	NELSON RANCH	1962-83	2-O	OLMOS CREEK	1971-81
6276	NEW BRAUNFELS	1923-89	1-S	SALADO CREEK	1971-81
6368	NIXON	1923-89	2-S	SALADO CREEK	1971-77
			3-S	SALADO CREEK	1971-81

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

PRECIPITATION STATION LOCATION MAP

HDR Engineering, Inc.

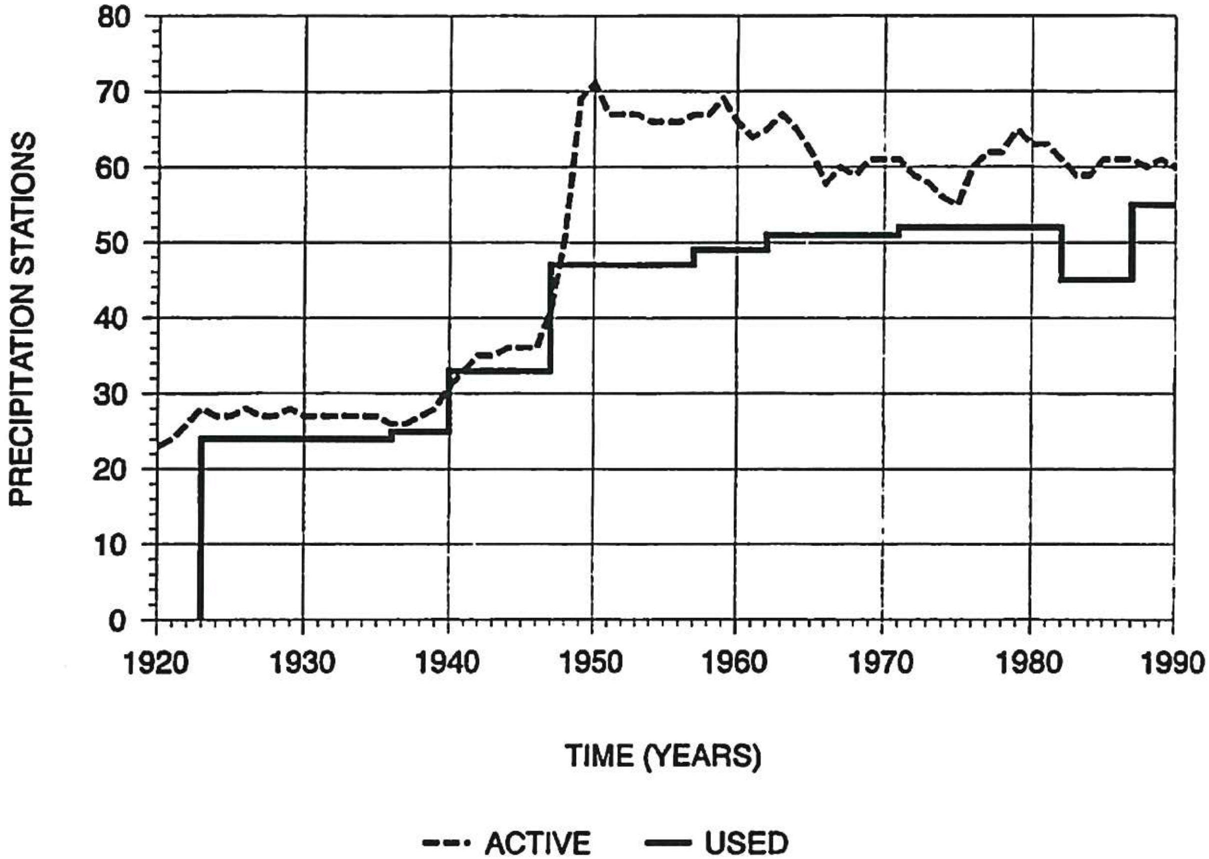
FIGURE 3-1

Missing monthly precipitation totals for some stations were estimated using available daily records. A computer program was developed for computation of missing daily precipitation values which operates in accordance with the following steps: 1) Establish a Cartesian (XY) coordinate system with the origin located at the station with a missing daily value; 2) Locate and calculate the distance to the nearest station in each quadrant with a record for that day; and 3) Apply a standard inverse distance ratio procedure to obtain a weighted average daily precipitation estimate based on the four surrounding stations. Once the missing daily values were estimated, they were summed along with the available daily records to obtain a reasonable estimate of monthly precipitation.

Because computed Thiessen weights for a given subwatershed can change significantly with the addition or deletion of precipitation stations, the 1923-89 historical period was divided into nine subperiods based on the availability of records at key stations. Figure 3-2 presents the number of stations used in each subperiod as well as the total number of precipitation stations which were active in each year of the 1920-89 period. As is apparent in Figure 3-2, records for several stations were extended during 1940 and 1947 based on geographically proximate stations using the computer program described in the previous paragraph. The actual number of stations used to compute areal precipitation during a particular subperiod ranged from a minimum of 24 during the 1923-35 period up to a maximum of 55 during the 1987-89 period.

3.2 Net Evaporation

Net evaporation is generally defined to be the difference between gross evaporation and direct precipitation at the free water surface of a reservoir and is typically expressed in



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RECHARGE ENHANCEMENT STUDY

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PRECIPITATION STATION UTILIZATION

FIGURE 3-2

inches or feet. Because evaporation is a function of many factors, including wind speed, temperature, and relative humidity, it is a rather difficult quantity to measure. Evaporation rates have historically been estimated by recording changes in water level in evaporation pans and adjusting the readings using pan coefficients to reflect differences between evaporation from a pan and evaporation from the surface of a reservoir. Since the turn of the century, evaporation pans have been maintained at various locations throughout the state by numerous federal and state agencies, municipalities, and local interests. The TWDB has compiled much of the available historical pan evaporation data (Ref. 31) and has developed monthly reservoir evaporation rates for the entire state by one degree quadrangles of latitude and longitude (Ref. 32) for the 1940-90 period. Annual net evaporation in the Guadalupe - San Antonio River Basin generally decreases from west to east with the westernmost portion experiencing about 40 inches and the easternmost portion about 20 inches (Ref. 20).

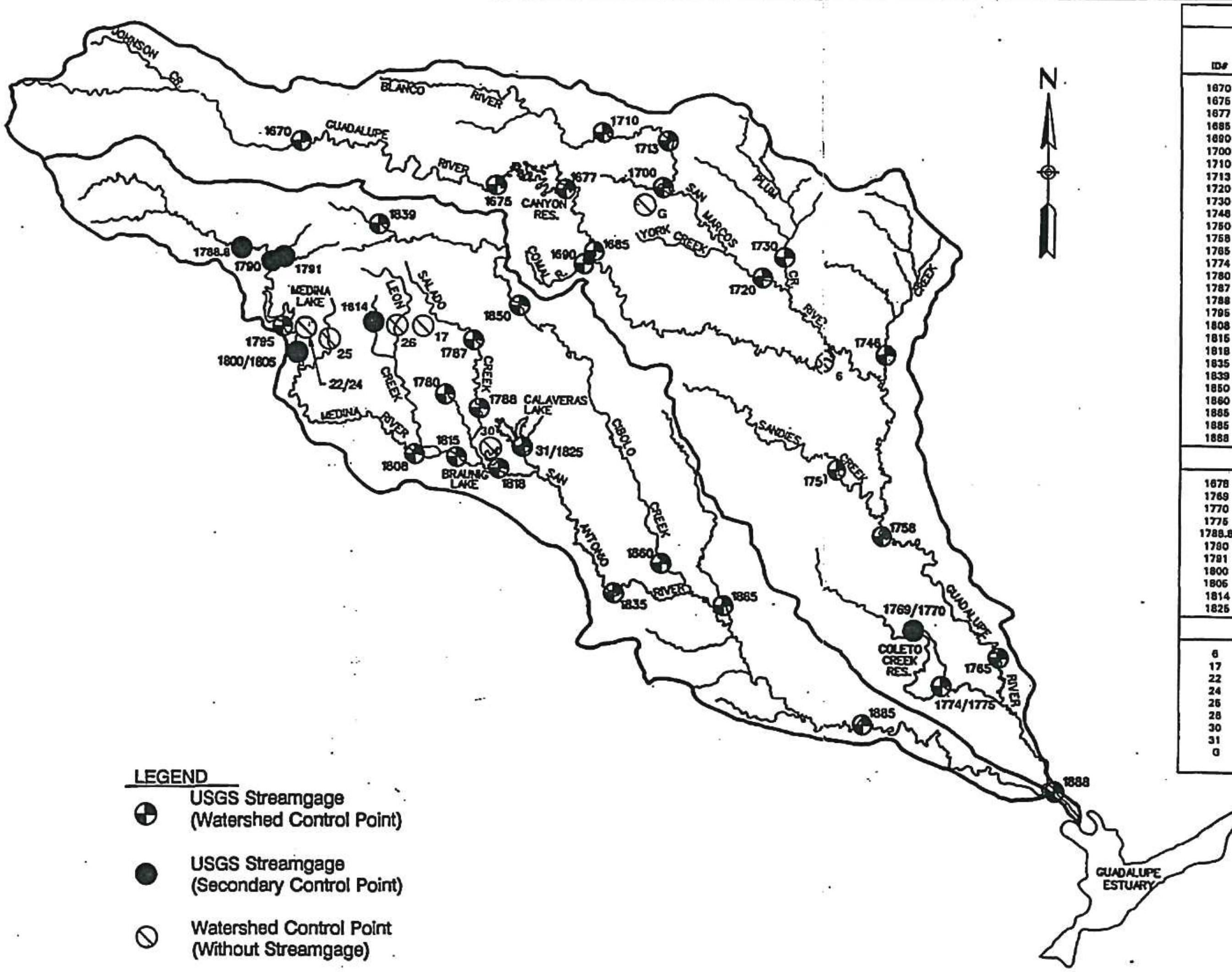
Monthly net evaporation rates for the 1934-89 period were needed in this study to calculate historical inflows to Canyon and Calaveras Lakes and to simulate lake level fluctuations in these reservoirs and other existing and/or potential reservoir projects including Medina, Diversion, and Braunig Lakes and Coleto Creek, Applewhite, Cloptins Crossing, and Lower Blanco Reservoirs. The evaporation rates used in this study for the 1940-89 period were calculated from the TWDB quadrangle data using a standard inverse distance ratio procedure to convert values typical of the centroids of adjacent quadrangles to values representative of a specific reservoir site. TWDB net evaporation data was used directly for Applewhite Reservoir, potential recharge enhancement projects, and existing reservoir sites prior to dam construction. Net evaporation rates for existing reservoirs after dam construction were calculated from TWDB gross evaporation data and locally measured precipitation. Net evaporation rates for the 1934-39 period were computed from available pan evaporation records adjusted by pan coefficients recommended by the TWDB (Ref. 32) and by coincident measured precipitation. Tables summarizing historical net evaporation rates used in this study are included in Appendix E (Volume III).

4.0 NATURAL STREAMFLOW DEVELOPMENT

The compilation of accurate estimates of historical natural streamflow is a key prerequisite to the development of a useful model of the Guadalupe - San Antonio River Basin. As previously defined in Section 2.2, natural streamflow is that which would have occurred historically exclusive of human influences. In this study, natural streamflow was computed by adjustment of monthly gaged streamflow for historical water supply diversions, municipal and industrial return flows, and reservoir operations. The effects of pumpage from the Edwards Aquifer on historical springflow, and hence, on streamflow were not addressed in the naturalization process, but were considered in the application of the GSA Model. Once an historical natural streamflow database is complete, the potential effects of future diversions and/or additional recharge reservoir construction can be accurately quantified. The steps involved in the development of natural streamflows for selected locations throughout the basin are discussed in this section. Natural streamflow summary tables for each control point in the model are included in Appendix F (Volume III).

4.1 Streamflow Data Collection

Records of streamflow in the Guadalupe - San Antonio River Basin have been collected at numerous streamflow gaging stations maintained by the U.S. Geological Survey (USGS). Figure 4-1 indicates the location, drainage area, and period of record of each streamflow gaging station used in this study, including those selected as watershed control points for the Guadalupe - San Antonio River Basin Model. Several streamflow gaging stations were considered secondary control points in this study and used to extend records



ID#	STREAM NAME, LOCATION	DRAINAGE AREA (SQ.MI.)	PERIOD OF RECORD
STREAMGAGES USED AS WATERSHED CONTROL POINTS			
1670	GUADALUPE R., COMFORT	839	6/39-12/89
1675	GUADALUPE R., SPRING BRANCH	1315	7/22-12/89
1677	CANYON LAKE	1432	7/62-12/89
1685	GUADALUPE R., ABOVE COMAL R.	1518	1/28-12/89
1690	COMAL R., NEW BRAUNFELS	130	1/28-12/89
1700	SAN MARCOS SPR., SAN MARCOS	N/A	6/56-12/89
1710	BLANCO R., WIMBERLEY	355	7/28-12/89
1713	BLANCO R., KYLE	412	6/56-12/89
1720	SAN MARCOS R., LULING	838	5/39-12/89
1730	PLUM C., LULING	309	4/30-12/89
1748	PEACH C., DILWORTH	460	6/59-9/79
1750	SANDIES C., WESTHOFF	549	8/59-12/89
1758	GUADALUPE R., CUERO	4934	9/20-11/35, 1/64-12/89
1765	GUADALUPE R., VICTORIA	5198	12/34-12/89
1774	COLETO CREEK RESERVOIR	494	2/80-12/89
1780	SAN ANTONIO R., SAN ANTONIO	41.8	3/39-12/89
1787	SALADO C., SAN ANTONIO, UPPER	137	10/60-12/89
1788	SALADO C., SAN ANTONIO, LOWER	189	10/60-12/89
1795	MEDINA LAKE	634	4/13-12/89
1808	MEDINA R., SOMERSET	867	10/70-12/89
1815	MEDINA R., SAN ANTONIO	1317	8/39-12/89
1818	SAN ANTONIO R., ELMENDORF	1743	10/62-12/89
1835	SAN ANTONIO R., FALLS CITY	2113	5/25-12/89
1839	CIBOLO C., BOERNE	68.4	3/62-12/89
1850	CIBOLO C., SELMA	274	4/46-12/89
1860	CIBOLO C., FALLS CITY	827	10/30-12/89
1865	ECLETO C., RUNGE	239	4/62-12/89
1885	SAN ANTONIO R., GOLIAD	3921	3/39-12/89
1888	GUADALUPE R., TIVOLI	10128	9/65-12/89
STREAMGAGES USED AS SECONDARY CONTROL POINTS			
1678	GUADALUPE R., SATTLER	1436	3/60-12/89
1769	COLETO C., SCHROEDER	357	10/78-12/89
1770	COLETO C., SCHROEDER	369	10/52-9/79
1775	COLETO C., VICTORIA	514	7/39-9/54, 6/78-12/89
1788.8	MEDINA R., BANDERA	427	10/82-12/89
1790	MEDINA R., PIPE CREEK	474	10/22-6/35, 10/52-9/82
1791	RED BLUFF C., PIPE CREEK	58.3	4/56-11/81
1800	MEDINA CANAL	N/A	4/22-4/34, 7/57-12/89
1805	MEDINA R., RIOMEDINA	650	2/53-9/73
1814	HELOTES C., HELOTES	15	6/68-12/89
1825	CALAVERAS C., ELMENDORF	77.2	10/54-9/71
WATERSHED CONTROL POINTS WITHOUT STREAMGAGES			
6	LAKE WOOD (H-5)	2103	1/80-12/89
17	OLMOS C., EDWARDS	8.3	N/A
22	DIVERSION LAKE SUBWATERSHED	15.6	N/A
24	DEEP C., EDWARDS	13.1	N/A
25	SAN GERONIMO C., EDWARDS	68.3	N/A
26	LEON C., EDWARDS	99.7	N/A
30	BRAUNIG LAKE	9.4	2/63-12/89
31	CALAVERAS LAKE	65.0	1/71-12/89
G	SINK, PURGATORY, YORK, AND ALLIGATOR CREEKS	94.0	N/A

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WATERSHED CONTROL POINT AND STREAMGAGE LOCATION MAP

FIGURE 4-1

at selected watershed control points. Additional watershed control points for ungaged watersheds were adopted to facilitate calculation of Edwards Aquifer recharge and are also shown in Figure 4-1. Summaries of monthly streamflow records were obtained from the Texas Water Commission (TWC) and directly from the USGS. Records from these gaging stations, with few exceptions, are classified by the USGS (Ref. 45) as "good" which means that 95 percent of the published daily discharges are within 10 percent of their true values.

An additional watershed control point was established at Lake Wood (H-5) because of its key location on the Guadalupe River just upstream of the San Marcos River confluence. Streamflow records at this location were estimated for the 1980-89 period using reports of water use for hydroelectric power generation and microfilmed spill logs maintained by the Guadalupe Blanco River Authority (GBRA). These spill logs contain detailed records of gate settings and headwater and tailwater depths during flood events which exceeded the turbine capacity and resulted in flow over the gates. Using a spillway rating table provided by GBRA with appropriate adjustments for tailwater levels (Ref. 34) and leakage, HDR developed a computer program which was applied to calculate monthly spill volumes. Combining these computed spill volumes with reported flows through the turbines, estimated gaged flows were obtained for the Guadalupe River at Lake Wood (H-5).

4.2 Reservoir Inflows

Historical reservoir inflows were computed for Canyon Lake (July, 1962 - December, 1989) and Calaveras Lake (February, 1971 - December, 1989) to supplement gaged streamflow records for the Guadalupe River and Calaveras Creek, respectively. Computation of historical inflow was based on the principle of continuity as formulated in the following simplified equation:

$$I_t = (Z_{t+1} - Z_t) + E_t + D_t + S_t - P_t \qquad (4\text{-}1)$$

where:

I_t	=	Inflow
Z_{t+1}	=	End-of-Month Storage
Z_t	=	Beginning-of-Month Storage
E_t	=	Net Evaporation
D_t	=	Direct Diversion
S_t	=	Spill and/or Release
P_t	=	Imported Inflow

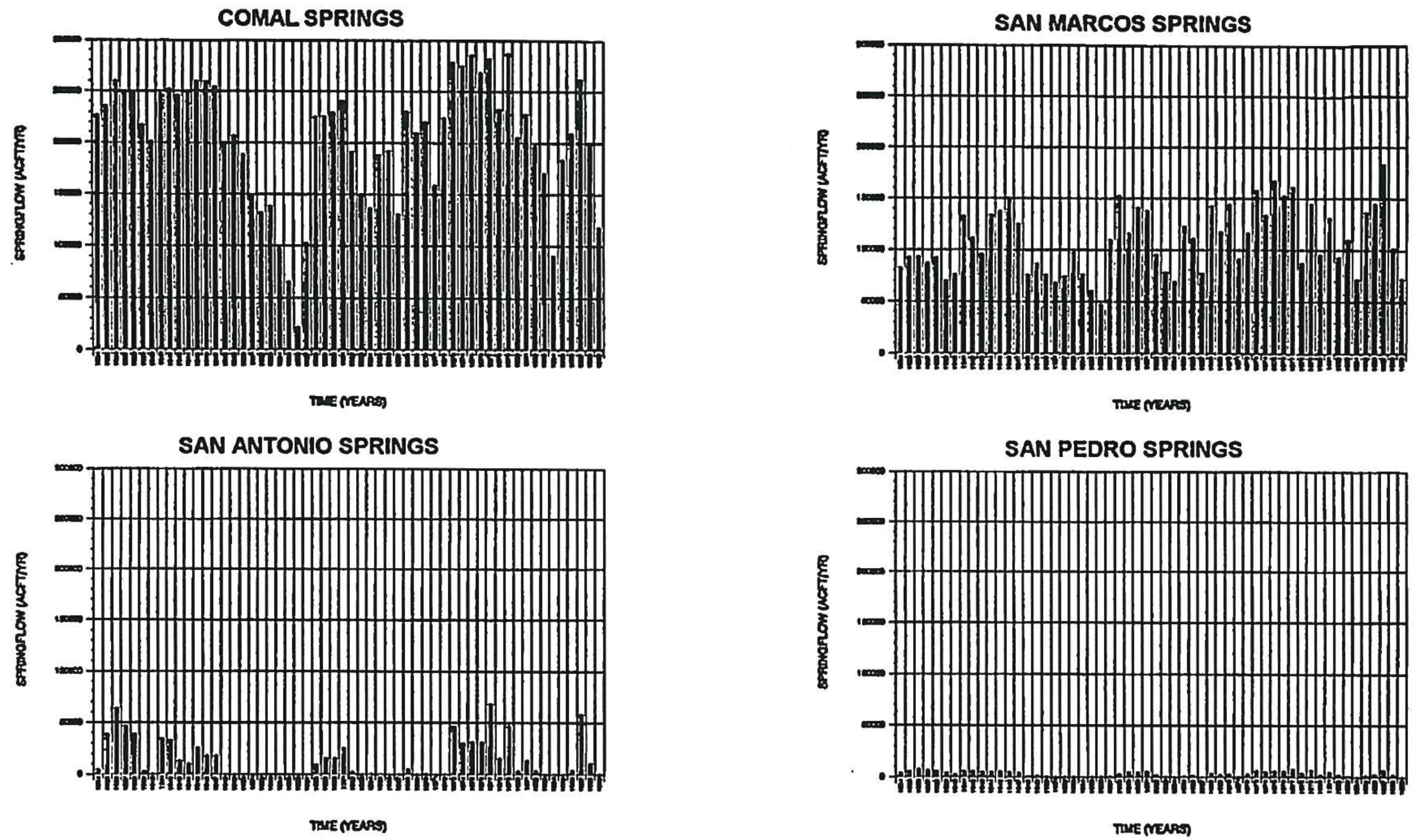
An utility program was developed to solve this equation for monthly inflow assuming the monthly storage change due to net evaporation is based on the surface area associated with the average storage volume for the month. Computed monthly inflow estimates less than zero were set equal to zero. The resultant historical reservoir inflows are comparable to gaged streamflows and were naturalized in the same manner.

Basic data for inflow computations was obtained from a variety of sources. Reservoir contents records for Canyon and Calaveras Lakes were obtained from USGS publications (Refs. 43, 44, and 45) and summary tables provided by City Public Service of San Antonio (CPS) (Ref. 5), respectively. Elevation-area-capacity tables from original reservoir mapping in 1947 and from a bathymetric survey conducted by the U.S. Army Corps of Engineers (USCE) in 1972 were used for Canyon Lake, while an elevation-area-capacity table dated 1970 (Ref. 30) was used for Calaveras Lake. Gross monthly water surface evaporation rates derived from Texas Water Development Board (TWDB) data as described in Section 3, were adjusted using records from nearby National Weather Service (NWS) or TWDB precipitation stations to obtain applicable monthly net evaporation rates. CPS provided monthly estimates of imported inflows (make-up water from the San Antonio River), releases, spills, and direct diversions (consumptive use in the form of forced evaporation) for Calaveras Lake. Gaged streamflow records for the Guadalupe River at Sattler (ID# 1678) were assumed to approximate the sum of all inflows passed through, releases from storage, and spills at Canyon Lake during the 1971-89 period.

4.3 Springflows

Four of the seven largest springs in Texas including Comal, San Marcos, San Antonio, and Hueco Springs are located within the Guadalupe - San Antonio River Basin (Ref. 1). Historical discharges from Comal, San Marcos, San Antonio, and San Pedro Springs which are located downstream of the Edwards Aquifer recharge zone were used directly in the streamflow naturalization process while flows from Hueco Springs which are located within the recharge zone were used in a different way. A more detailed discussion of the consideration of Hueco Springs is included in Section 6.1.3. Figure 4-2 provides an annual summary of historical springflow during the 1934-89 study period for four of the major springs.

Comal Springs which is the largest in Texas is located within the City of New Braunfels in Comal County and discharges an average of about 205,000 ac-ft/yr into the Comal River near the confluence with the Guadalupe River. Records provided by the USGS indicate that Comal Springs flowed continuously during the 1934-89 period with the



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HISTORICAL SPRINGFLOWS

FIGURE 4-2

exception of almost five months from June to November, 1956 during a severe drought period. Discharge from Comal Springs is highly correlated with water levels in the Bexar County Monitoring Well (J-17) as well as other regional wells in the Edwards formation. Analyses of tritium content in the water from Comal Springs reported by the Texas Department of Water Resources (TDWR) (Ref. 22) indicate that the majority of water discharging at Comal Springs entered the Edwards Aquifer as recharge more than 20 years previously.

San Marcos Springs which is the second largest in Texas is located within the City of San Marcos in Hays County and discharges an average of about 109,000 ac-ft/yr into the San Marcos River upstream of the confluence with the Blanco River. Monthly records of springflow were obtained from USGS publications (Ref. 45) for the 1956-89 period when flows were gaged. For the 1940-55 period, flow estimates were obtained from TWDB files and, for the 1934-39 period, estimated by linear interpolation between periodic USGS measurements. Springflow estimates obtained by interpolation agree reasonably well with annual values published by the USGS (Ref. 39). San Marcos Springs has flowed without interruption throughout the 1934-89 period. Analyses of tritium content indicates that "a large part of the water from San Marcos Springs did not come from the same source area as Comal Springs and that, on the average, the water from San Marcos Springs is much younger than the water from Comal Springs (Ref. 22)."

San Antonio and San Pedro Springs are both located within the City of San Antonio in Bexar County and discharge averages of about 14,400 ac-ft/yr and 3,640 ac-ft/yr, respectively, to the San Antonio River. Both of these springs have ceased to flow for extended periods during the 1934-89 study period. Periodic springflow measurements by the

USGS were correlated with water levels in the Bexar County Monitoring Wells J-17 (Fort Sam Houston, 1963-89) and 26 (Ed Steves & Sons, 1932-62) resulting in linear regression equations used to obtain estimates of historical monthly discharge from each of these springs. The regression equations based on piezometric water levels at J-17 are:

$$Q_{SA} = 6.8829(H_{J-17}) - 4629.93 \qquad \textbf{(4-2)}$$

$$Q_{SP} = 0.3511(H_{J-17}) - 229.37 \qquad \textbf{(4-3)}$$

where:

Q_{SA} = San Antonio Springflow (cfs)
Q_{SP} = San Pedro Springflow (cfs)
H_{J-17} = J-17 Well Level (ft-msl)

Coefficients of determination (r^2) for these equations ranged from 0.93 to 0.94 indicating that the equations could explain 93 to 94 percent of the variation in springflow. The J-17 water surface elevations at which the equations predict zero springflow are consistent with published spring elevations (Ref. 1) and estimated annual totals are in reasonable agreement with USGS estimates (Ref. 6).

4.4 Naturalization Methodology

Monthly natural streamflows for the 1934-89 period were developed by adjusting gaged streamflows and calculated reservoir inflows for the effects of historical water supply diversions, municipal and industrial return flows, and reservoir operations. Translation of the effects of upstream diversions and return flows to downstream locations was accomplished with the use of delivery equations representative of typical channel loss rates in each intervening reach. Derivation of delivery equations is described in Section 4.5.

The streamflow naturalization methodology applied in this study is summarized in schematic and equation form in Figure 4-3. Historical monthly diversions of all use types as well as return flows were grouped by subwatershed as delineated by control point. The natural flow at the downstream end of an headwater subwatershed, such as Subwatershed 1 in Figure 4-3, is calculated by simply adding the historical diversions to and subtracting the historical return flows from the gaged streamflow at Control Point 1 (CP1). Natural flow at the downstream end of Subwatershed 2 (CP2) is equal to the gaged streamflow adjusted for local diversions and return flows which occurred in Subwatershed 2 plus the portion of the change in flow (from gaged to natural) at CP1 which arrives at CP2. In like manner, streamflows were naturalized at consecutive control points moving upstream to downstream through the entire river basin. The methodology employed to estimate channel losses in the reach from CP1 to CP2 is described in the following section of this report.

The streamflow naturalization methodology applied in this study was originally developed by HDR in the performance of a regional water supply planning study of the Nueces River Basin (Ref. 14) and is different from the more traditional methodology incorporated in previous natural streamflow databases and river basin models (Refs. 27 and 28). Traditionally, successive downstream gaged streamflows were adjusted for historical upstream diversions and return flows on a "one-to-one" basis to obtain natural streamflows, thereby neglecting differences between historical and natural channel losses. Application of traditional methodology generally results in higher estimates of natural flow. Potential errors resulting from this traditional technique were mitigated, in part, by the "one-to-one"

$$QN_1 = QG_1 + D_1 - R_1$$

$$QN_2 = QG_2 + D_2 - R_2 + (A_{QN_1} - A_{QG_1})$$

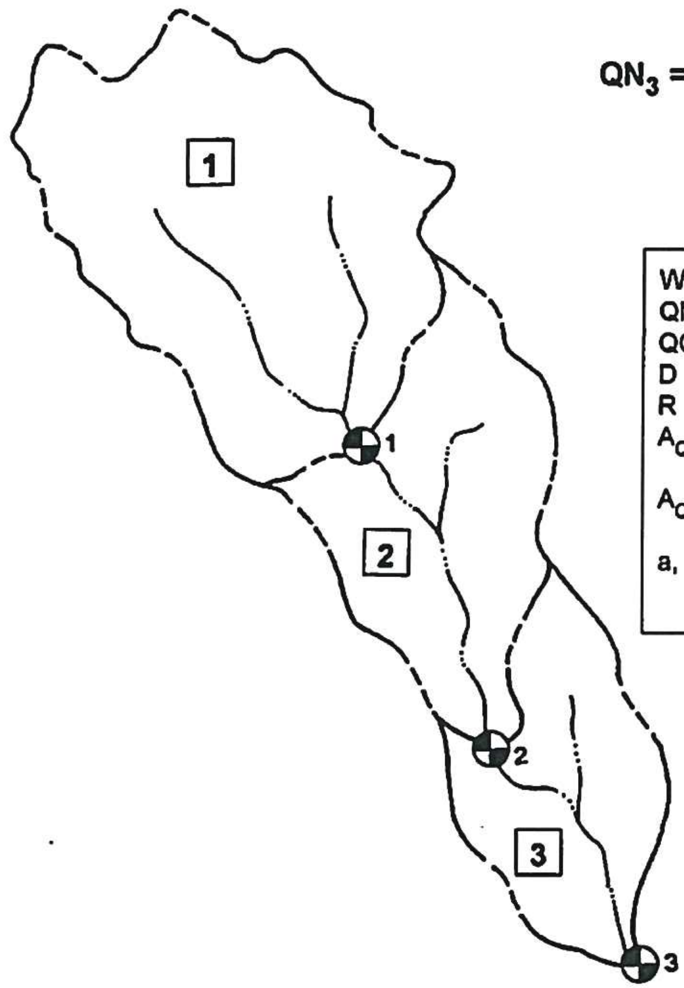
$$A_{QN_1} = QN_1 - a_2 QN_1^{b_2}$$

$$A_{QG_1} = QG_1 - a_2 QG_1^{b_2}$$

$$QN_3 = QG_3 + D_3 - R_3 + (A_{QN_2} - A_{QG_2})$$

$$A_{QN_2} = QN_2 - a_3 QN_2^{b_3}$$

$$A_{QG_2} = QG_2 - a_3 QG_2^{b_3}$$



WHERE:

QN	=	NATURAL STREAMFLOW
QG	=	GAGED STREAMFLOW
D	=	DIVERSIONS
R	=	RETURN FLOWS
A_{QN}	=	UPSTREAM NATURAL FLOW DELIVERED
A_{QG}	=	UPSTREAM GAGED FLOW DELIVERED
a, b	=	CHANNEL LOSS EQUATION COEFFICIENTS

LEGEND

- STREAMGAGE/CONTROL POINT
- WATERSHED BOUNDARY
- STREAM

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STREAMFLOW NATURALIZATION METHODOLOGY

HDR

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FIGURE 4-3

adjustment of natural flows to account for full water rights diversions and applicable return flows in the evaluation of water available for appropriation. However, if full water rights use significantly exceeds historical water use (which is often the case), application of the traditional methodology can significantly underestimate both water availability and remaining downstream flows. In this study, quantitative assessment of the potential impacts of upstream recharge enhancement projects, and/or changes in historical release patterns from Canyon Lake, necessitated the application of a methodology incorporating the effects of intervening losses. Simply stated, impoundment and recharge of one acre-foot of runoff in the headwaters of the basin does not reduce inflow to the Guadalupe Estuary by one acre-foot. Accounting for channel losses as modelled in this study more accurately reflects the natural physical processes which affect streamflows throughout the basin.

4.5 Delivery Equations and Channel Loss Rates

A streamflow delivery equation was developed for each stream reach linking control points in the Guadalupe - San Antonio River Basin in order to estimate the percentage of water passing an upstream control point that arrives at the next downstream control point. The equations were derived using gaged streamflow records at the upstream and downstream control points along with calibrated estimates of runoff from the intervening area and include adjustments for intervening diversions and return flows. Previous streamflow studies conducted by the USGS (Ref. 41) have shown a direct logarithmic relationship between channel loss and streamflow, and this type of relationship was utilized to describe the channel loss characteristics in each stream segment in the Guadalupe - San

Antonio River Basin. The channel loss equations derived for each segment illustrate that as streamflow increases, the *volume* of channel loss increases and the *percentage* of upstream flow lost decreases.

Channel loss relationships were developed for selected stream segments by performing long-term comparisons of concurrent upstream and downstream gaged streamflow records using a modified Soil Conservation Service (SCS) curve number procedure (Refs. 18 & 19) and monthly areal precipitation to estimate intervening runoff arriving at the downstream gage. The first step in the derivation of the channel loss relationships was the estimation of appropriate SCS "map" curve numbers for each subwatershed which was accomplished by detailed review of county soil surveys. The resulting map curve numbers for each of the subwatersheds are summarized in Table 4-1. Using the modified SCS procedure, monthly intervening runoff is computed from areal precipitation using the following general equation:

$$QI = \left(\frac{640}{12}\right) A \frac{\left(P - \frac{200}{CN} + 2\right)^2}{\left(P + \frac{800}{CN} - 8\right)} \qquad (4\text{-}4)$$

where

QI = Intervening Runoff (acre-feet/month);
A = Watershed Area (square miles);
P = Areal Precipitation (inches/month); and
CN = Calibrated SCS Curve Number.

A more detailed discussion of how the modified SCS procedure is applied for computing intervening runoff along with an example for a watershed over the recharge zone is presented in Section 6.

Table 4-1
Summary of SCS Map Runoff Curve Numbers for Watershed Control Points

Watershed Control Point		Intervening Drainage Area (Sq.Mi.)	SCS Map Runoff Curve Number
ID#	Stream Name, Location		
1670	Guadalupe River, Comfort	839	84.3
1675	Guadalupe River, Spring Branch	476	82.4
1677	Guadalupe River, Canyon Lake	117	82.7
1685	Guadalupe River, Above Comal River at New Braunfels	86	83.7
1690	Comal River, New Braunfels	130	86.5
1710	Blanco River, Wimberley	355	82.6
1713	Blanco River, Kyle	57	84.3
1720	San Marcos River, Luling	332[1]	83.4
1730	Plum Creek, Luling	309	83.7
1746	Peach Creek, Dilworth	460	76.4
1750	Sandies Creek, Westhoff	549	79.4
1758	Guadalupe River, Cuero	675	74.7
1765	Guadalupe River, Victoria	264	74.8
1774	Coleto Creek Reservoir, Victoria	494	73.8
1780	San Antonio River, San Antonio	41.8	83.0
1787	Salado Creek, San Antonio Upper Station	137	85.4
1788	Salado Creek, San Antonio Lower Station	52	78.0
1795	Medina Lake	634	83.6
1808	Medina River, Somerset	246[1]	80.7
1815	Medina River, San Antonio	242[1]	80.8
1818	San Antonio River, Elmendorf	195.2[2]	75.1
1835	San Antonio River, Falls City	305[3]	75.9
1839	Cibolo Creek, Boerne	68.4	82.9
1850	Cibolo Creek, Selma	205.6	83.1
1860	Cibolo Creek, Falls City	553	79.4
1865	Ecleto Creek, Runge	239	77.8
1885	San Antonio River, Goliad	742	76.4
1888	Guadalupe River, Tivoli	515	78.2
6	Guadalupe River, Lake Wood (H-5)	455	80.2
17	Olmos Creek, Edwards	8.3	85.6
22	Diversion Lake	15.6	85.6
24	Deep Creek, Edwards	13.1	85.6
25	San Geronimo Creek, Edwards	58.3	86.7
26	Leon Creek, Edwards	99.7	86.4
31	Calaveras Lake	65.0	81.5
G	Sink, Purgatory, York, Alligator Creeks	94.0	86.4

Notes:
1) Intervening area below the downstream edge of the recharge zone.
2) Includes Braunig Lake (ID# 30) drainage area.
3) Excludes Calaveras Lake drainage area.

The amount of channel loss in a given stream segment was computed for each month of concurrent record for the upstream and downstream gaging stations. Channel loss for each month was computed as:

$$Q_{Loss} = QG_1 + QI - QNH_2 \qquad (4\text{-}5)$$

where:

Q_{Loss} = Channel Loss;
QG_1 = Upstream Gaged Flow;
QI = Intervening Runoff; and
QNH_2 = Downstream Flow Adjusted for Intervening Diversions and Return Flows.

Channel loss equations for each of the stream segments were derived based on the monthly estimates of channel loss as a function of monthly upstream flow. Months when losses were calculated to be less than zero or greater than the upstream flow were not included in the derivations. Calculated losses in these months represent extreme or impossible conditions which generally result from inaccuracies in estimating runoff for large intervening watersheds from monthly areal precipitation. The channel loss equations were derived using linear regression techniques for a log-log relationship of channel loss as a function of upstream flow. The standard form of the channel loss equation is expressed as:

$$Log_{10}(Q_{Loss}) = b\ Log_{10}(QG_1) + Log_{10}(a) \qquad (4\text{-}6)$$

or

$$Q_{Loss} = a(QG_1)^b \qquad (4\text{-}7)$$

where:

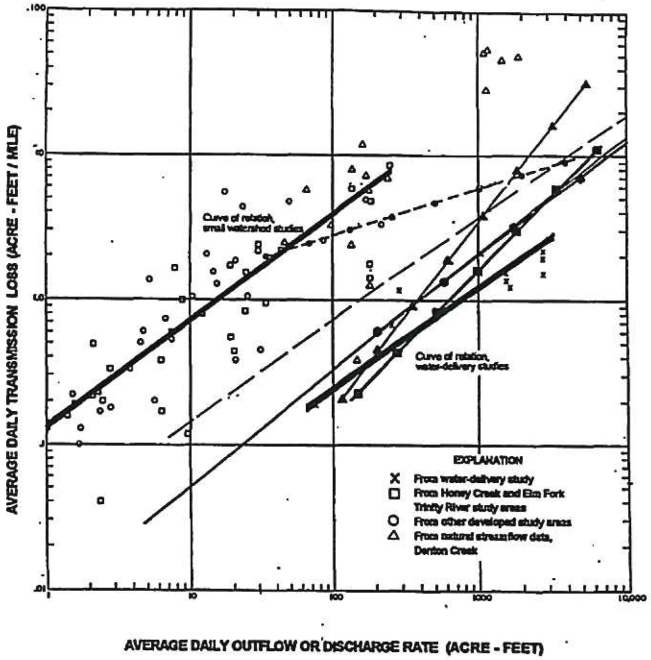
Q_{Loss} = Channel Loss (acre-feet/month);

QG_1 = Upstream Gaged Flow (acre-feet/month); and
a,b = Regression Coefficients.

For purposes of this study, the regression coefficients in the channel loss equation were retained only if they were significantly different from zero at the 90 percent confidence level based on the Students t Test (Ref. 12). The resulting regression equations for selected stream segments had coefficients of determination (r^2) ranging from 0.16 for the Blanco River at Wimberley to 0.37 for the San Antonio River at Goliad. For stream reaches where insufficient gaged data was available to compute meaningful channel loss equations, equations developed for nearby stream reaches were utilized with adjustments for median upstream flow.

Table 4-2 summarizes the channel loss equations applied for all stream segments in the Guadalupe - San Antonio River Basin. Figure 4-4 shows all channel loss equations computed with actual gaged data for the range of flows from which each was developed. Comparable regression lines for small watershed and water delivery studies conducted by the USGS (Ref. 41) are also presented for reference in Figure 4-4. The channel loss equations developed for stream segments in the Guadalupe - San Antonio River Basin, to a large extent, fall within the range of channel loss relationships found in the USGS studies. Generally, channel loss rates were found to be in the lower range for those stream segments upstream of the Edwards Aquifer recharge zone and in the plains and coastal prairies, while higher channel loss rates were found to occur in those segments crossing aquifer outcrops.

GUADALUPE RIVER BASIN

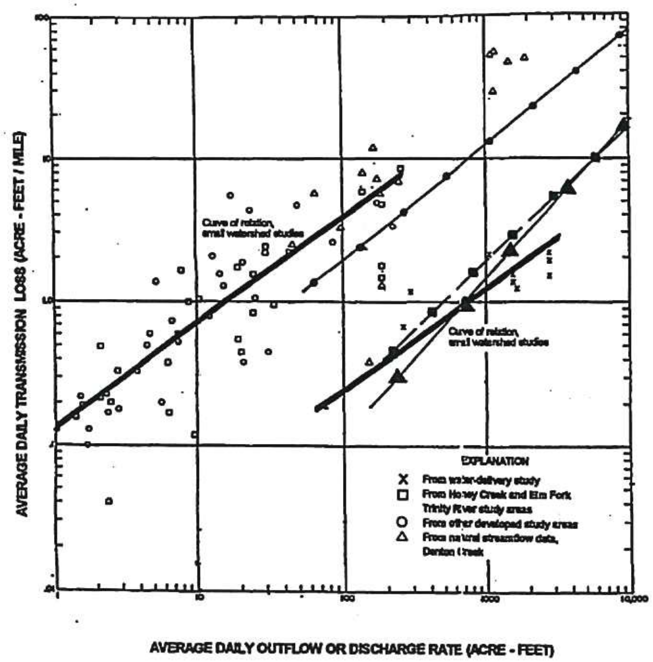


LEGEND:

- GUADALUPE RIVER: COMFORT TO SPRING BRANCH ID# 1670 TO ID# 1675 (70 MILES)
- GUADALUPE RIVER: SPRING BRANCH TO CANYON LAKE ID# 1675 TO ID# 1677 (14 MILES)
- GUADALUPE RIVER: NEW BRAUNFELS TO LAKE WOOD (H-5) ID# 1685 TO ID# 6 (78 MILES))
- GUADALUPE RIVER: CUERO TO VICTORIA ID# 1758 TO ID# 1766 (50 MILES)
- BLANCO RIVER: WIMBERLEY TO KYLE ID# 1710 TO ID# 1713 (16 MILES)
- SAN MARCOS RIVER: SAN MARCOS TO LULING ID# 1700 TO ID 1720 (42 MILES)

REFERENCE: U. S. GEOLOGICAL SURVEY, "HYDROLOGIC EFFECTS OF FLOODWATER - RETARDING STRUCTURES ON GARZA - LITTLE ELM RESERVOIR, TEXAS," WATER - SUPPLY PAPER 1984, 1970.

SAN ANTONIO RIVER BASIN



LEGEND:

- MEDINA RIVER: SOMERSET TO SAN ANTONIO ID# 1808 TO ID# 1815 (10 MILES)
- SAN ANTONIO RIVER: ELMENDORF TO FALLS CITY ID # 1818 TO ID# 1835 (42 MILES)
- SAN ANTONIO RIVER: FALLS CITY TO GOLIAD ID# 1835 TO ID #1885 (81 MILES)

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

SUMMARY OF CHANNEL LOSS ANALYSES

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FIGURE 4 - 4

Table 4-2
Summary of Channel Loss Equations

River Basin	Stream Segment Description	Upstream Control Point(s) ID#	Downstream Control Point ID#	Channel Loss Equation Coefficients[1] a	b
Guadalupe River Basin	Guadalupe River Comfort to Spring Branch	1670	1675	1.0000	0.7979
	Guadalupe River Spring Branch to Canyon Lake	1675	1677	1.0000	0.7150
	Guadalupe River Canyon Lake to New Braunfels	1677	1685	0.0000	0.0000
	Guadalupe River New Braunfels to Lake Wood	1690 1685	6	0.0771	1.0460
	Guadalupe River Lake Wood to Cuero	6,1720,1730 1746,1750	1758	0.4077	0.7801
	Guadalupe River Cuero to Victoria	1758	1765	1.0000	0.7801
	Guadalupe River Victoria to Tivoli	1765 1774	1888	0.7194	0.7801
	Blanco River Wimberley to Kyle	1710	1713	92.4272	0.3314
	San Marcos River San Marcos to Luling	1700 G	1720	0.0057	1.3161
San Antonio River Basin	Medina River Diversion Lake to Somerset	1795 22/24,25	1808	1.0000	0.7980
	Medina River Somerset to San Antonio	1808 26,17	1815	1.0000	0.7980
	San Antonio River San Antonio to Elmendorf	1815,1780 1788,30	1818	1.0111	0.7980
	San Antonio River Elmendorf to Falls City	1818 31/1825	1835	0.1727	0.9278
	San Antonio River Falls City to Goliad	1835 1860,1865	1885	0.0490	1.0880
	San Antonio River Goliad to Tivoli	1885	1888	0.0379	1.0880
	Cibolo Creek Boerne to Selma	1839	1850	1.0000	1.0000
	Cibolo Creek Selma to Falls City	1850	1860	0.5509	1.0000
	Salado Creek Upper Sta. to Lower Sta.	1787	1788	0.2944	1.0000

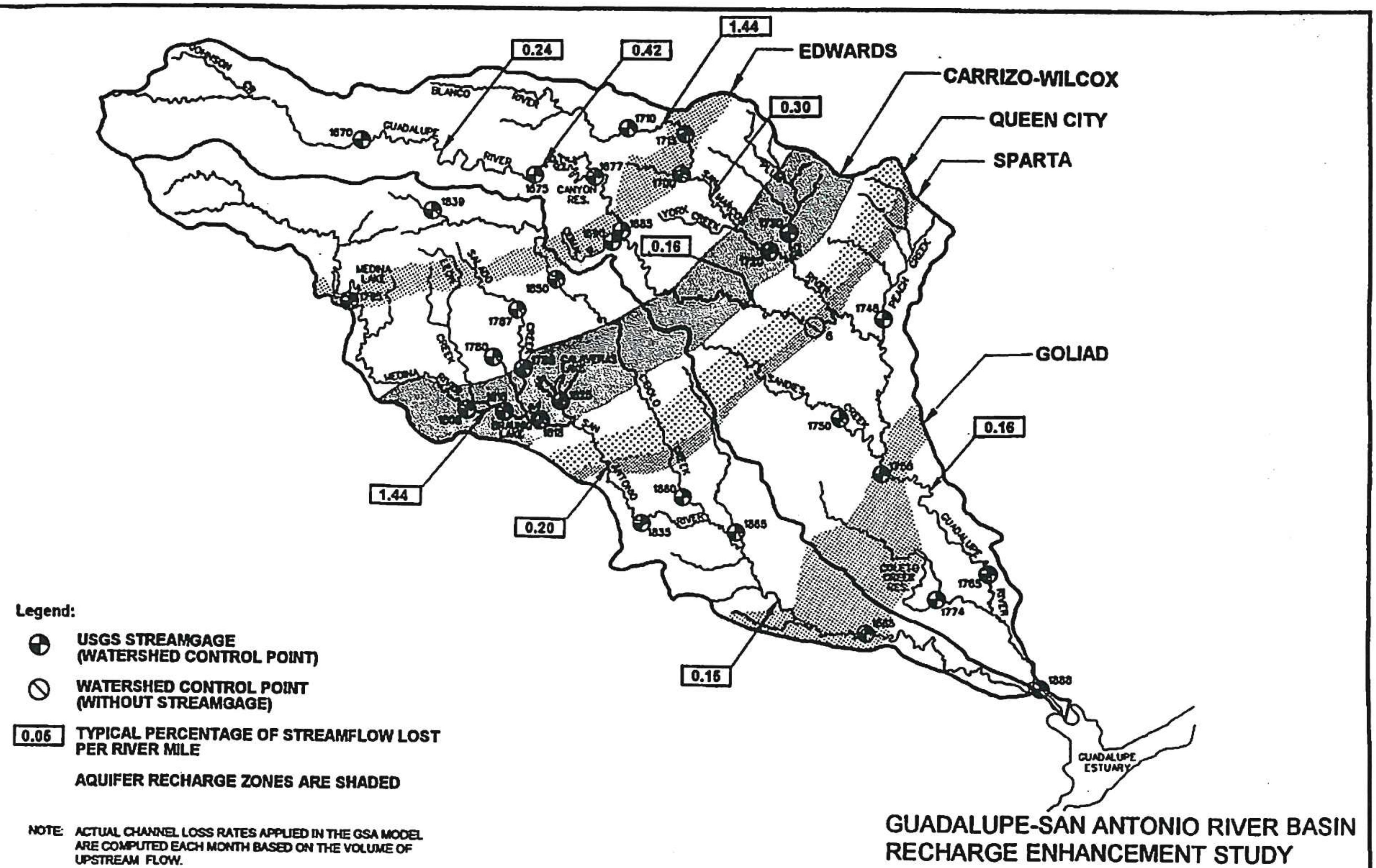
Notes:
1) Coefficients "a" and "b" for Channel Loss Equation expressed as: $Q_{Loss} = a(QG_i)^b$, where Q_{Loss} is the monthly channel loss in acre-feet and QG_i is the total monthly flow at the upstream control points in acre-feet.

Figure 4-5 presents a summary of typical channel loss rates in percent per mile, based on average flow conditions for all stream segments where losses were calculated from gaged records. Channel loss rates outside of the Edwards Aquifer recharge zone ranged from 0.15 percent per mile to 1.44 percent per mile with the highest for the Medina River segment which crosses the Carizzo-Wilcox Aquifer outcrop. Generally, the lower channel loss rates were found to occur in those stream segments which do not traverse major aquifer outcrops or have short travel distances across these outcrop areas. Overall, channel loss rates downstream of the Edwards Aquifer recharge zone averaged 0.22 percent per mile in the Guadalupe - San Antonio River Basin as compared to 0.48 percent per mile in the Nueces River Basin (Ref. 14).

4.6 Completion of Streamflow Records

Streamflow records missing during the 1934-89 historical period were estimated for 24 streamflow gaging stations or control points located throughout the Guadalupe - San Antonio River Basin. Records were completed using multiple linear regression techniques based on available streamflow records, calibrated estimates of local runoff based on areal precipitation and curve number, or drainage area ratio based on available streamflow records in the same or an adjacent watershed. The equations used to estimate these missing monthly streamflow records are summarized in Table 4-3.

Generally, regression equations were developed to calculate missing flows from available upstream or downstream flows and estimates of intervening runoff. When suitable upstream or downstream flow records were not available, however, regression equations



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

TYPICAL CHANNEL LOSS RATES

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FIGURE 4-5

Table 4-3
Estimation of Missing Streamflow Records

Control Point with Missing Records	Period of Missing Records	Equation	Length of Concurrent Records (Years)	Coefficient of Determination (r^2)
1670	1/34-5/39	$QG_{1670} = (QNH_{1675} - 0.8851\ QI_{1675})/1.0829$	50	.93
1677	1/34-6/62	$QNH_{1677} = 0.9274\ QG_{1675} + 0.8980\ QI_{1677} + 1225.5800$	27	.99
H-5	1/34-12/59	$QNH_{H-5} = 0.8002\ QG_{1685} + 1.2624\ QG_{1690} - 2254.6391$	10	.97
H-5	1/60-12/79	$QNH_{H-5} = 0.7646\ QG_{1685} + 1.2020\ QG_{1690} - 0.2587\ QI_{H-5}$	10	.98
1713	1/34-5/56	$QNH_{1713} = 1.0289\ QG_{1710} + 0.3844\ QI_{1713} + 1360.1090$	33	.98
1720	1/34-4/39	$QNH_{1720} = 1.1776\ QG_{1710} + 0.7441\ QG_{1730} + 1.1762\ QG_{1700} - 2673.7705$	50	.94
1746	1/34-7/59,10/79-12/89	$QN_{1746} = QI_{1746}$	---	---
1750	11/34-7/59	$QN_{1750} = 0.9596\ QN_{1860}$	31	.52
1758	12/35-12/63	$QG_{1758} = (QNH_{1765} - 1239.8739)/1.0461$	26	.99
1765	1/34-11/34	$QNH_{1765} = 1.0461\ QG_{1758} + 1239.8739$	26	.99
1774	1/34-6/39	$QN_{1774} = 770.9900\ P_{1774}^2 - 2657.9253\ P_{1774} + 3424.5904$	50	.78
1774	7/39-9/54	$QN_{1774} = QN_{1775}\ (494/514)_{D.A.R.}$	---	---
1774	10/54-9/78	$QN_{1774} = QN_{1770}\ (494/369)_{D.A.R.}$	---	---
1774	10/78-12/89	$QN_{1774} = QN_{1769}\ (494/357)_{D.A.R.}$	---	---

Definition of Terms: QG = Gaged Flow QN = Natural Flow P = Areal Precipitation
QNH = Gaged Flow Adjusted for Local Diversions and Return Flows
QI = Intervening or Potential Runoff Calculated Using Modified SCS Procedure
D.A.R. = Drainage Area Ratio R_N = Natural Recharge

Units: Acre-Feet/Month: QG, QN, QNH, QI, R_N Inches/Month: P

Table 4-3
Estimation of Missing Streamflow Records

Control Point with Missing Records	Period of Missing Records	Equation	Length of Concurrent Records (Years)	Coefficient of Determination (r^2)
1780	1/34-2/39	$QN_{1780} = 1.0910\ QG_{S.A.SPRING} + 6.6831\ QG_{RECHARGE\ ZONE} + 0.3556\ QI_{1780} + 1206.3234$	51	.87
1788	1/34-2/39	$QN_{1788} = 1.6024\ QN_{1787} + 0.1319\ QI_{1788} + 1479.5876$	29	.84
1788	3/39-9/60	$QNH_{1788} = 0.7510\ QN_{1780}$	29	.52
1790	7/35-9/42	$QN_{1790} = 0.4325\ QN_{1675}$	30	.75
1790	10/42-9/52	$QN_{1790} = 0.4443\ QN_{1670} + 1.1155\ QN_{1980}$	30	.87
1795	1/34-3/56,12/81-9/82	$QN_{1795} = QN_{1790}\ (634/474)_{D.A.R.}$	---	---
1795	4/56-11/81	$QN_{1795} = (QN_{1790} + QN_{1791})\ [634/(474+56.3)]_{D.A.R.}$	--	---
1795	10/82-12/89	$QN_{1795} = QN_{17888}\ (634/427)_{D.A.R.}$	---	---
1805	1/34-12/89	$QN_{1805} = QN_{1795} + QI_{1805} - R_{N1805} - 10\hat{}(0.3314\ \log QN_{1795} + 1.9658)$	---	---
1808	1/34-7/39	$QNH_{1808} = 1.1787\ QG_{1805} + 0.2179\ QI_{1808} + 2787.7344$	19	.90
1808	8/39-9/70	$QG_{1808} = (QNH_{1815} - 959.2566 - 0.1303\ QI_{1815})/1.0833$	19	.99
1815	1/34-7/39	$QNH_{1815} = 1.3496\ QG_{1805} + 4650.5164$	50	.83
1818	1/34-9/54	$QG_{1818} = QNH_{1835}/1.0942$	27	.97

Definition of Terms: QG = Gaged Flow QN = Natural Flow P = Areal Precipitation
QNH = Gaged Flow Adjusted for Local Diversions and Return Flows
QI = Intervening or Potential Runoff Calculated Using Modified SCS Procedure
D.A.R. = Drainage Area Ratio R_N = Natural Recharge

Units: Acre-Feet/Month: QG, QN, QNH, QI, R_N Inches/Month: P

Table 4-3
Estimation of Missing Streamflow Records

Control Point with Missing Records	Period of Missing Records	Equation	Length of Concurrent Records (Years)	Coefficient of Determination (r^2)
1818	10/54-9/62	$QG_{1818} = (QNH_{1835} - 5.3685\ QG_{CL} - 1839.0573)/0.9960$	27	.98
Braunig Lake	1/34-12/89	$QN_{BL} = QN_{CL}(9.4/65)$ D.A.R.		
Calaveras Lake	1/34-9/54,1/69-12/70	$QG_{CL} = 0.0527\ QNH_{1825} - 555.0354$	14	.61
Calaveras Lake	10/54-12/68	$QN_{CL} = QN_{1825}\ (65/77.2)$ D.A.R.	---	---
1839	1/34-6/35,10/52-2/62	$QN_{1839} = 0.1772\ QI_{1675} + 0.0122\ QN_{1790} - 367.9174$	21	.80
1839	7/35-9/52	$QN_{1839} = 0.1466\ QI_{1675}$	28	.76
1850	1/34-3/46	$QNH_{1850} = 0.3768\ QG_{1839} + 0.4070\ QI_{1850} - 1701.6080$	28	.64
1865	1/34-2/39	$QN_{1865} = 0.2875\ QN_{1860}$	27	.42
1865	3/39-3/62,10/89-12/89	$QG_{1865} = (QNH_{1885} - 1.0815\ QG_{1835} - 0.3649\ QG_{1860})/4.0338$	27	.93
1885	1/34-2/39	$QNH_{1885} = 0.9962\ QG_{1835} + 1.7361\ QG_{1860} + 2622.1322$	51	.83

Definition of Terms: QG = Gaged Flow QN = Natural Flow P = Areal Precipitation
QNH = Gaged Flow Adjusted for Local Diversions and Return Flows
QI = Intervening or Potential Runoff Calculated Using Modified SCS Procedure
D.A.R. = Drainage Area Ratio R_N = Natural Recharge

Units: Acre-Feet/Month: QG, QN, QNH, QI, R_N Inches/Month: P

were developed from available natural flows in one or more adjacent watersheds or by other means. Table 4-3 indicates the length of concurrent record on which each regression equation was based which averaged 2.2 times the length of missing records. Coefficients of determination (r^2) for the regression equations ranged from 0.42 to 0.99, with the average, weighted by dependent mean, being about 0.94.

Runoff estimates for the ungaged coastal area in the Guadalupe - San Antonio River Basin were required to develop a natural flow record at the Saltwater Barrier near Tivoli (ID# 1888). The ungaged area includes the 515 square mile intervening area upstream of the Saltwater Barrier, and downstream of the San Antonio River at Goliad (ID# 1885), Coleto Creek at Coleto Creek Reservoir near Victoria (ID# 1774), and the Guadalupe River at Victoria (ID# 1765). Ungaged runoff estimates for the coastal area were available from past studies by Espey, Huston & Associates, Inc. (EH&A) (Ref. 10) and the TDWR (Ref. 24) for the 1940-82 period. EH&A ungaged runoff estimates were significantly less than those developed by the TDWR but appeared more consistent with independent partial record estimates developed by HDR using drainage area ratios and modified SCS procedures. Hence, the EH&A ungaged runoff estimates were adopted for use in this study. For the period prior to 1940, monthly ungaged runoff estimates were computed using areal precipitation and a linear regression relationship based on EH&A ungaged runoff and areal precipitation during the 1940-82 period. Ungaged runoff after 1982 was estimated by application of modified SCS procedures (discussed in Section 4.5) using the Coleto Creek watershed above Coleto Creek Reservoir (ID# 1774) as a partner area. Estimated runoff for the ungaged, 515 square mile intervening area above the Saltwater Barrier averaged

221,734 ac-ft/yr for the 1934-89 period. Although this area drains about five percent of the basin, it contributes about 11.4 percent of the average annual natural flow for the entire Guadalupe - San Antonio River Basin.

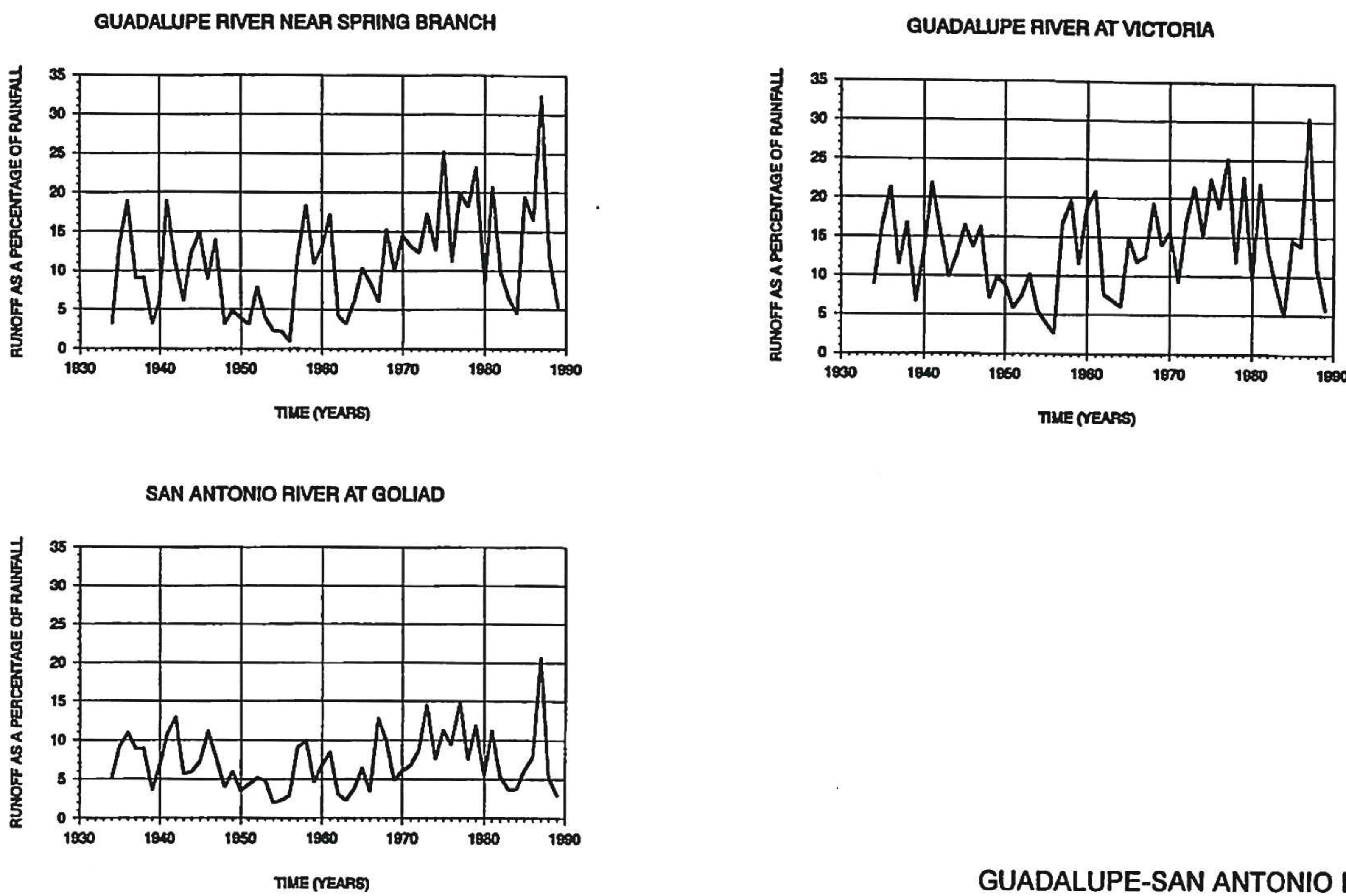
4.7 Trends in Annual Streamflow

It is not uncommon for streamflows to be influenced over time by various changes occurring within a river basin which are not directly considered in the streamflow naturalization process. Examples of these types of changes potentially applicable to the Guadalupe - San Antonio River Basin include: 1) Increasing use of groundwater from the Edwards Aquifer which, in turn, may reduce the discharge of certain springs; 2) Urbanization which may increase surface runoff; and 3) Changes in land use, vegetative cover, or farming techniques which may either increase or decrease runoff. While changes in springflow are considered in the application of the GSA Model, urbanization and other land use changes are generally assumed to be of insufficient magnitude on a basin-wide scale to warrant similar consideration. Climatic changes such as global warming may also affect the frequency and intensity of precipitation events and other factors which may influence streamflows. This section summarizes statistical analyses of long-term rainfall and natural streamflow data conducted to detect the presence of potentially significant trends.

The detection of historical trends in streamflow is an inexact science, as is estimation of future trends. Although numerous physical and statistical methods exist, none are truly deterministic due to the stochastic nature of variations in rainfall and runoff in a watershed the size of the Guadalupe - San Antonio River Basin. In order to evaluate possible changes in the relationship between streamflow and areal precipitation with respect to time, standard statistical tests were performed on the annual series of natural runoff as a percentage of rainfall at three locations. These locations included the Guadalupe River near Spring Branch (ID# 1675), Guadalupe River at Victoria (ID# 1765), and San Antonio River at Goliad (ID# 1885). These locations were selected to be somewhat representative of inflows to Canyon Lake, Guadalupe River Basin runoff, and San Antonio River Basin runoff, respectively. Figure 4-6 presents annual runoff expressed as a percentage of rainfall at each of these locations.

The statistical tests applied included the non-parametric Kendall Tau (Ref. 15) and Turning Points (Ref. 47) tests, as well as linear regression of runoff percentage versus time and sample partitioning which are classified as parametric tests. Sample partitioning, in this case, simply involved subdivision of the 56-year historical period into halves so that the means and variances from the earlier and later subperiods could be compared to one another. Review of the series for each of the selected locations indicates that the annual values may reasonably be assumed normally distributed. Statistical significance was assumed at the 90 percent confidence level for these tests. Table 4-4 summarizes the results of the trend tests for selected watersheds.

A trend which could be statistically significant was detected for the Guadalupe River near Spring Branch, while no significant indications of trend were detected for the Guadalupe River at Victoria or the San Antonio River at Goliad. It is interesting that no truly significant indications of trend were noted for the Victoria and Goliad locations as pumpage and urbanization in the San Antonio area increased dramatically during the



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GUADALUPE-SAN ANTONIO RIVER BASIN
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ANNUAL RUNOFF/RAINFALL FOR SELECTED WATERSHEDS

FIGURE 4-6

Table 4-4
Statistical Trend for Selected Watersheds[1]

Statistical Test	Test Type	Indication of Statistically Significant Trend[2]		
		Guadalupe River, Spring Branch	Guadalupe River, Victoria	San Antonio River, Goliad
Kendall Tau	Non-parametric	Yes	No	No
Turning Points	Non-parametric	No	No	Yes[5]
Linear Regression[3], t Distribution	Parametric	Yes	No	No
Sample Partitioning[4], Mean Comparison, t Distribution	Parametric	Yes	No	No
Sample Partitioning[4], Variance Comparison, F Distribution	Parametric	No	No	Yes[6]

[1]Tests based on annual series of natural streamflow as a percentage of areal precipitation.
[2]Statistical significance assumed at the 90% confidence level.
[3]Linear regression of natural streamflow as a percentage of areal precipitation versus time. These percentages are assumed to be normally distributed.
[4]56-year historical period partitioned into 1934-61 and 1962-89 sub-periods
[5]Affirmative indication more likely a result of serial correlation than long-term trend.
[6]Affirmative indication a result of including maximum (1987) observation.

1934-89 historical period. Indications were detected that runoff, as a percentage of rainfall upstream of Canyon Lake, has been increasing with time based on the Kendall Tau, linear regression, and mean comparison tests. For example, runoff as a percentage of rainfall for the Guadalupe River near Spring Branch averaged almost 9 percent for the 1934-61 period and more than 13 percent for the 1962-89 period. While this difference can be explained, in part, by greater average areal precipitation in the later period, it is interesting to note that average natural runoff for the later period exceeded that for the earlier period by an amount greater than the difference in average annual rainfall assuming that 100 percent of the difference in average rainfall became runoff. Without a full understanding of the physical causes of apparently increasing runoff above Canyon Lake, whether they be changes in land use practices, climate (including the magnitude and frequency of extreme events), or other factors, there is no reasonable assurance that the historical trend will continue into the future. For these reasons, no adjustments to natural streamflows for apparent trends in runoff were made in this study.

5.0 RIVER BASIN MODEL DEVELOPMENT

The development of the Guadalupe - San Antonio River Basin (GSA) *Model* included building selected features into a computer code to accomplish the following tasks:

- Estimation of natural and enhanced Edwards Aquifer recharge;
- Simulation of the operations of existing and proposed reservoirs subject to various Edwards Aquifer pumpage/springflow and surface water rights scenarios; and
- Calculation of water potentially available at selected locations subject to various Edwards Aquifer pumpage/springflow and surface water rights scenarios.

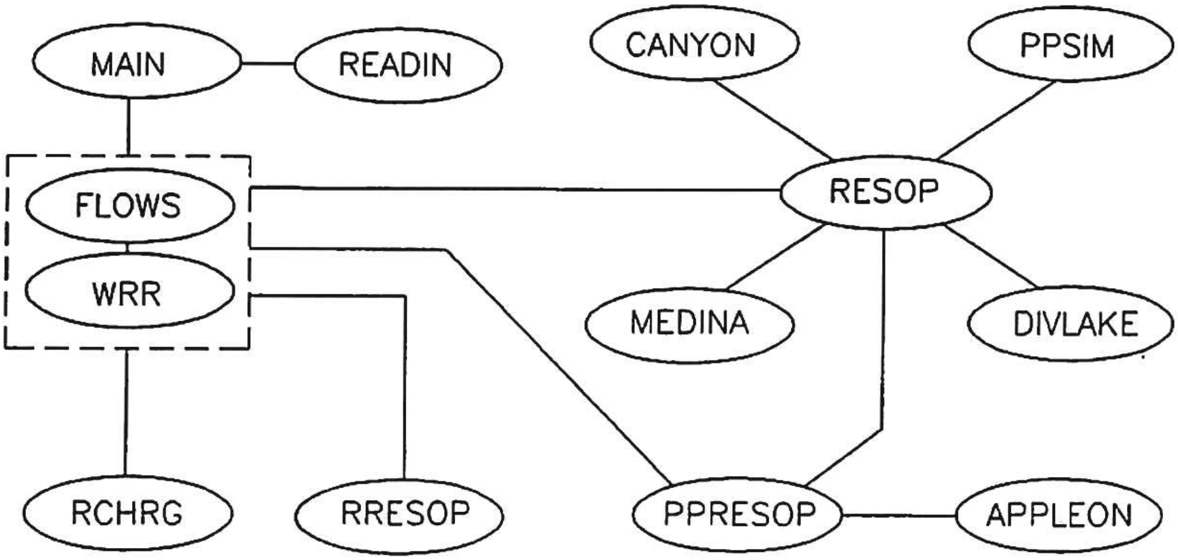
The structure of the model is based on the physical characteristics, water rights, and hydrologic phenomena which exist within the basin with monthly computations simulating the movement of water throughout the basin. The GSA Model was completed in two primary stages: 1) Development of input databases such as natural streamflows which are described in the preceding sections; and 2) Computer program code development and pertinent assumptions which are addressed in this section.

5.1 General Organization

The computer program code for the GSA Model is in the FORTRAN programming language as are many similar models currently in use such as RESOP-II (Ref. 26) and SIMYLD-II (Ref. 29) and is compatible with the Nueces River Basin Models previously developed by HDR (Refs. 13 and 14). The GSA Model was compiled and debugged using Microsoft FORTRAN, Version 5.1 (Ref. 17) and is sufficiently generic that it can be compiled and executed on mainframe, micro, and many personal computers. The program code was written in subroutines which are program segments intended to simulate a specific process or perform a related sequence of calculations. Thirteen of the most significant subroutines in the GSA Model are shown in Figure 5-1 along with connecting lines indicating their relationships and a brief definition of the function of each subroutine. Comments and variable definitions were interspersed throughout the program code to facilitate understanding of computational logic and sequencing. A listing of the FORTRAN code for the GSA Model is included in Appendix G (Volume III).

5.2 Basic Computational Procedures

The GSA Model employs a monthly time step proceeding with flow calculations in an upstream to downstream order simulating recharge, channel losses, water rights, return flows, and reservoir operations. Changes in upstream flow from the natural flow at each control point are translated to the next downstream control point using the delivery equations described in Section 4.5. Calculations are performed at each of the 38 Watershed Control Points located throughout the river basin as shown in Figure 4-1 beginning in the headwaters of the Guadalupe River near Comfort (ID# 1670), continuing downstream to Victoria (ID# 1765), moving to the headwaters of the San Antonio River Basin near Medina Lake (ID# 1795), continuing downstream to Goliad (ID# 1885), and finally combining flows from both the Guadalupe and San Antonio Rivers at the Saltwater Barrier near Tivoli (ID# 1888). These control points were generally established at streamflow gaging stations, existing reservoirs, and other locations near the downstream limits of the Edwards Aquifer recharge zone.



SUBROUTINE	PRIMARY FUNCTION
MAIN	Input/Output File Management
READIN	Control Parameters and Data Input
FLOWS	Streamflow and Water Delivery Simulation
WRR	Water Rights Release Determination
RCHRG	Natural Recharge Calculation
RRESOP	Recharge Reservoir Operations and Recharge Calculation
RESOP	Reservoir Operations
CANYON	Canyon Lake Contents Simulation
PPSIM	Power Plant Reservoir Contents Simulation
MEDINA	Medina Lake Contents Simulation and Recharge Calculation
DIVLAKE	Diversion Lake Contents Simulation and Recharge Calculation
PPRESOP	Power Plant Reservoir Operations
APPLEON	Leon Creek to Applewhite Reservoir Diversion

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

KEY MODEL SUBROUTINES

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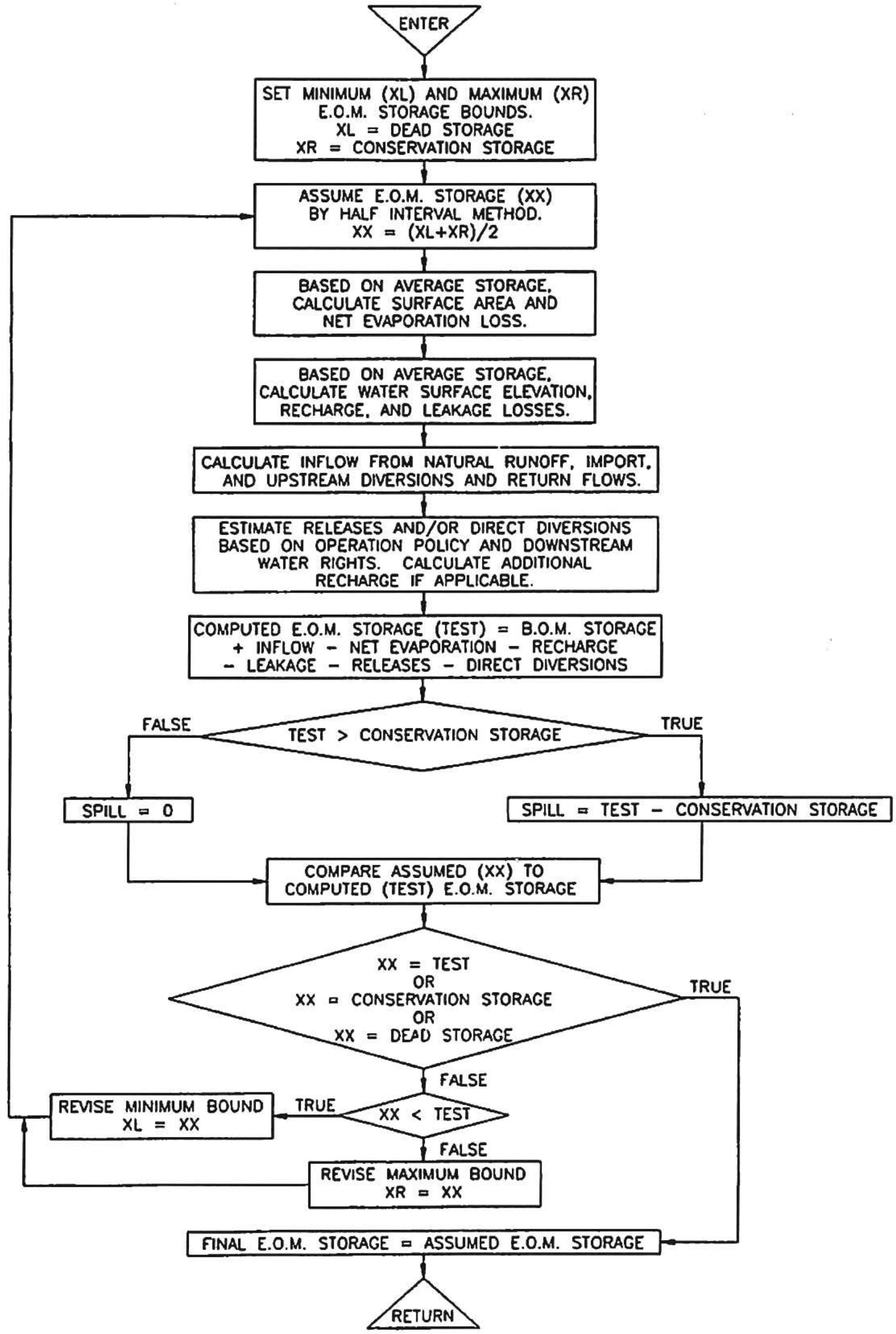
FIGURE 5-1

Monthly simulation of reservoir contents can be somewhat more complicated than estimation of streamflow and recharge for control points without reservoirs. Volume fluxes affecting reservoir storage include inflow, net evaporation, recharge, leakage, direct diversions, releases, and spills. As net evaporation, recharge, and leakage are calculated from the water surface area or elevation associated with the average storage for a given month, a simultaneous solution for these fluxes is necessary to obtain an accurate estimate of end-of-month storage. This solution is obtained using the Half-Interval Method (Ref. 3) as illustrated in Figure 5-2 which depicts the reservoir contents simulation procedure employed by the GSA Model in the form of a flowchart. Elevation-area-capacity relationships for existing reservoirs and potential recharge enhancement projects were obtained from published sources or developed from available topographic mapping. Tables summarizing these relationships are included in Appendix H (Volume III).

5.3 Water Rights

The GSA Model is capable of simulating diversion rights for consumptive water use and non-consumptive hydropower generation rights as well as reservoir storage rights. Diversion rights were grouped according to use type between control points and exercised in accordance with typical monthly percentages of the authorized annual diversion depending on water availability. River diversions for power plant cooling reservoir make-up were assumed to be exercised only when needed to maintain a desired cooling surface and were limited to authorized annual amounts. In order to accurately determine monthly inflow passage and/or releases from Canyon Lake, it was necessary to group diversion rights



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

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RESERVOIR CONTENTS SIMULATION PROCEDURE

FIGURE 5-2

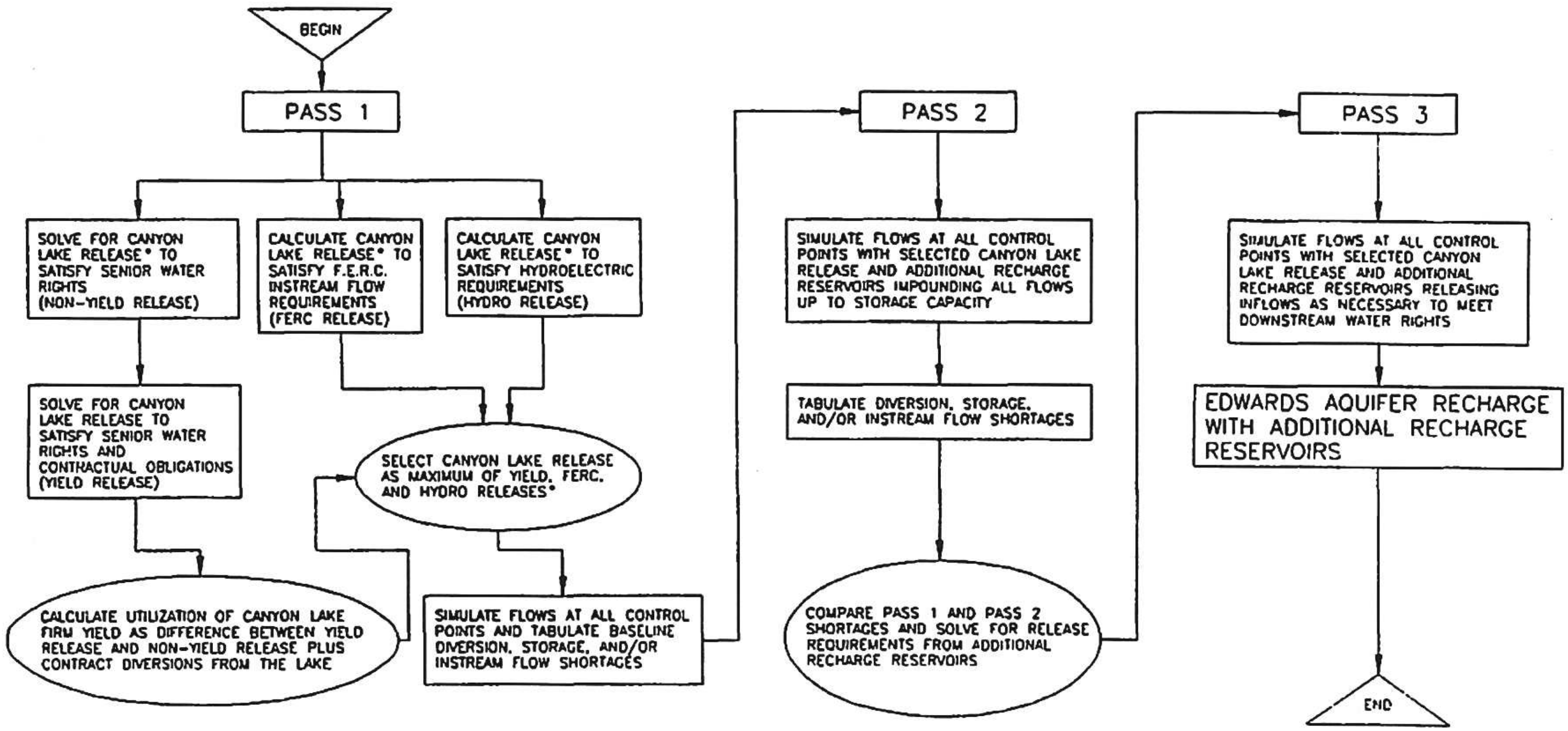
throughout the Guadalupe - San Antonio River Basin into three classes: 1) Rights senior to Canyon Lake; 2) Contractual obligations under Guadalupe-Blanco River Authority (GBRA) rights in Canyon Lake; and 3) Rights junior to Canyon Lake. The senior industrial diversion rights (300 cfs) held by Central Power & Light (CP&L) for non-consumptive, once-through cooling were modelled as an instream flow requirement to meet all nonconsumptive rights in the lower basin at or below the control point located on the Guadalupe River near Victoria.

A desired hydropower flowrate in cubic feet per second (cfs) representative of streamflow entering Lake Dunlap on the Guadalupe River is an interactive input for each execution of the GSA Model. Non-consumptive hydropower rights other than those held by GBRA for a series of small dams on the Guadalupe River between New Braunfels and the San Marcos River confluence were not included in the GSA Model. It was assumed that the hydropower rights of Seguin Municipal Utilities which are generally satisfied by GBRA hydropower operations would be subordinated to the same extent as those held by GBRA based on inflows to Lake Dunlap. Rights held by New Braunfels Utilities downstream of Comal Springs and Aquarena Springs Corporation downstream of San Marcos Springs were not included because surface water availability at neither of these locations would be significantly affected by any of the identified recharge enhancement projects. Major hydropower rights held by the City of Gonzales and John L. McNeill were neglected because their Certificates of Adjudication specify that they would be subordinated to any future rights to use the waters of the Guadalupe River for municipal, industrial, irrigation, and/or mining purposes. Rights held by Hydraco Power Inc. on the San Marcos

River were officially abandoned by permit amendment issued August 20, 1990.

Major reservoir storage rights are handled in the GSA Model much as they have traditionally been handled in river basin models developed by the Texas Department of Water Resources (Refs. 27 and 28). Monthly reservoir inflows are required to be passed to the extent necessary to satisfy senior downstream water rights, but flows impounded in previous months may remain in storage. No reservoir inflows are passed for junior water rights. Similarly, potential recharge enhancement reservoirs or diversion projects are not allowed to impound or divert, respectively, unless the downstream reservoir is full and spilling.

Computation of water potentially available for recharge or diversion for other purposes from selected locations without adversely affecting downstream water rights is accomplished by the GSA Model using a three-pass process. A flowchart summarizing this three-pass process is presented in Figure 5-3. In the first pass, operational releases from Canyon Lake (which may include both inflow passage and release from storage) and make-up diversions for Coleto Creek, Braunig, and Calaveras Lakes are determined, flows are simulated at all control points, and any shortages (failures to satisfy diversion or storage rights or any specified instream flow requirements) are tabulated. Operational releases from Canyon Lake, make-up diversions for power plant cooling reservoirs, and operational guidelines assumed for Medina Lake are presented in Sections 5.4, 5.5, and 5.6, respectively. In the second pass, additional recharge or diversion projects are included and shortages are tabulated for the entire river basin assuming full impoundment or diversion of inflows and



* NON-YIELD, FERC, AND/OR HYDRO RELEASES ARE LIMITED TO CANYON LAKE INFLOWS.

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GUADALUPE-SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

RIVER BASIN MODEL FLOWCHART

FIGURE 5-3

considering applicable evaporation losses at the additional project locations. If these shortages exceed those determined in the first pass, the GSA Model solves for the portion of inflow at each additional project which must be passed in order to satisfy all downstream water rights to the extent they were satisfied in the first pass. Any inflows which may be impounded or diverted without impacting downstream water rights are assumed to be available for recharge enhancement or other purposes. In the third and final pass, flows are simulated at all control points with the selected Canyon Lake release and additional projects passing inflows as necessary for downstream water rights and enhanced recharge of the Edwards Aquifer is computed.

5.4 Canyon Lake

One of the most critical and complicated aspects of GSA Model development was the determination of operational releases (inflow pass through and/or releases from storage) from Canyon Lake in order to satisfy senior water rights, contractual obligations, hydropower requirements, and Federal Energy Regulatory Commission (FERC) guidelines. Simulation of these operational releases is important so that the GSA Model can compute reasonably accurate estimates of recharge enhancement with identified projects or water potentially available for diversion at selected stream locations.

As indicated in Figure 5-3, the first step in evaluating Canyon Lake operations is the calculation of firm yield utilization by determination of the arithmetic difference between monthly "non-yield" and "yield" releases. The non-yield release is limited to monthly inflow at Canyon Lake and represents the quantity of water which would have to be passed to satisfy senior water rights only. The yield release may include both inflows and storage and represents the quantity of water which would have to be released to satisfy contractual obligations in full (with the exception of CP&L at Coleto Creek which is delivered only as needed) and senior water rights to the extent they could be satisfied with the non-yield release. It is assumed in the GSA Model that releases must be sufficient to deliver full contracted amounts to the points of diversion so that any losses in delivery are a part of the utilization of the firm yield or authorized diversion rights at Canyon Lake. Hydropower requirements and FERC guidelines are not considered in the calculation of yield utilization because they result in essentially non-consumptive use of water.

The firm yield of Canyon Lake is a complex function of many interrelated assumptions including hydropower subordination, Edwards Aquifer pumpage and resultant springflow, reservoir operation policy, point(s) of diversion, channel losses incurred in delivery, and type of use in addition to the highly variable hydrologic factors of inflow and net evaporation. . Although calculation of Canyon yield was not within the scope of this study, it was necessary to account for the full utilization of senior rights associated with Canyon Lake in order to determine quantities of water potentially available for recharge enhancement with the implementation of new projects. Hence, GBRA contractual obligations were honored in full and any portion of the firm annual yield which remained unutilized was removed from Canyon Lake in December of each year simulated. When calculating firm yield utilization specifically for the estimation of water potentially available at Canyon Lake, however, unutilized firm annual yield was not removed from Canyon Lake. Yield estimates used in this study were obtained from a study sponsored by GBRA and completed in 1993 by EH&A (Ref. 7). While the yield estimates from the GBRA study do not reflect the effects of channel losses on water deliveries or the effects of some future drought management plan for the Edwards Aquifer on springflows, they are the best presently available.

The second step in the modelling of Canyon Lake operations is the calculation of inflow passage necessary to comply with FERC guidelines (Ref. 11). These guidelines specify instream flow minima of 100 cfs (June-January) and 120 cfs (February-May) to be maintained in non-drought conditions to the extent inflows as measured at the USGS streamflow gage located near Spring Branch (ID# 1675) are available. In the event of two consecutive months of inflow less than 90 cfs, drought conditions apply and the instream flow requirement is reduced to passage of inflows up to 90 cfs until the end-of-month reservoir level exceeds 909.0 ft-msl. For consistency with respect to water rights, the GSA Model uses inflows to the lake rather than those measured near Spring Branch. The remaining provisions of the FERC guidelines are included in the GSA Model and the required volume of inflow passed is referenced in Figure 5-3 as the "FERC" release.

The third step in the modelling of Canyon Lake operations is calculation of inflow passage for hydropower generation which is referenced in Figure 5-3 as the "hydro" release. The GSA Model determines Canyon Lake inflow passage necessary to maintain a user-specified desired flowrate near Lake Dunlap based on the sum of monthly flows at control points located on the Guadalupe and Comal Rivers near New Braunfels. There are no releases from Canyon Lake storage strictly for the purpose of hydropower generation.

Ultimately, the maximum of the yield, FERC, and hydro releases is selected as the monthly operational release from Canyon Lake and flows are simulated at all control points throughout the river basin. These flows and any observed diversion, storage, and/or instream flow shortages become the baseline relative to which the potential impacts of recharge enhancement or diversion projects are measured using the GSA Model. Guidelines for the release of flood storage in Canyon Lake were not incorporated in the GSA Model. Rather, it was assumed that all flood flows would be discharged during the same month in which they entered Canyon Lake to ensure a conservative estimate of water potentially available for recharge enhancement.

5.5 Power Plant Reservoirs

Coleto Creek Reservoir, Calaveras Lake, and Braunig Lake serve as sources of circulating flow for the dissipation of heat resulting from the operations of three existing power plants. Consumptive use of water at these power plant reservoirs or cooling ponds is the result of forced evaporation due to heat loading. Forced evaporation is a volume of water loss typically calculated from the megawatt hours of electricity generated and is accounted for separately from natural evaporation occurring at the free water surface. Each of these reservoirs is located on a stream tributary to the Guadalupe or San Antonio River and has an estimated or permitted annual consumptive use rate which is supplemented by permitted annual make-up diversions from the nearby river.

It is generally desirable to maintain power plant reservoirs at or near the normal pool level because the efficiency of heat dissipation increases with the size of the available mixing volume. Therefore, the power plant reservoir operation policy coded into the GSA Model first solves for the desired monthly volume of make-up water in addition to local inflows necessary to maintain a full reservoir subject to forced and natural evaporation losses and any required instream flow releases. The GSA Model then calculates flow available in the river after satisfying instream flow requirements at the specified source location for make-up diversions and transfers the necessary portion of this available flow to the reservoir. Cumulative annual make-up diversions associated with each power plant reservoir are tracked in the GSA Model and these river diversions are suspended for the remainder of the calendar year when the permitted annual maximum has been withdrawn.

Consumptive use by Central Power and Light (CP&L) at Coleto Creek Reservoir was assumed equal to the permitted rate of 12,000 ac-ft/yr distributed in accordance with the typical monthly industrial water use pattern presented in Figure 2-5. Make-up diversions are made from the Guadalupe River between Cuero (ID# 1758) and Victoria (ID# 1765) and are obtained under a permitted run-of-the-river right of 20,000 ac-ft/yr supplemented, when necessary, by a contractual agreement with GBRA for water from Canyon Lake averaging about 6,000 ac-ft/yr. As the run-of-the-river rights were obtained through a purchase and transfer of West Side Calhoun County Navigation District rights, originally located near Tivoli, make-up diversions under these rights are not permitted unless there is concurrent flow over the Saltwater Barrier (ID# 1888). It was assumed that CP&L rights for make-up water for Coleto Creek Reservoir would take precedence over the CP&L rights to use the waters of the Guadalupe River near Victoria up to approximately 300 cfs for non-consumptive, once-through cooling purposes. These provisions are included in the GSA Model along with the required passage of Coleto Creek inflows up to 5 cfs. The contractual agreement with GBRA for supplementary make-up water is rather complex and all provisions therein were not included in the GSA Model. Make-up diversions made under the GBRA contract are, however, reflected in the monthly utilization of the firm yield of Canyon Lake as computed by the GSA Model. The simulated maximum annual make-up diversion under the GBRA contract was approximately 19,000 ac-ft in 1956 which is consistent with the results of the original study in support of the CP&L permit application (Ref. 33).

For Braunig and Calaveras Lakes, respective maximum consumptive use rates of 10,500 ac-ft/yr and 16,000 ac-ft/yr (based on future plant expansions) as well as maximum make-up diversion rates of 12,000 ac-ft/yr and 36,900 ac-ft/yr provided by San Antonio City Public Service were used in the GSA model. Make-up diversions for both lakes are made from the San Antonio River upstream of the control point (ID# 1818) located near Elmendorf and are limited by a minimum instream flow requirement of 10 cfs. Return flows from the City of San Antonio which enter the river upstream of Elmendorf are typically sufficient to satisfy both the make-up water needs of the power plant reservoirs and the instream flow requirements.

Although the construction of Applewhite Reservoir has been abandoned, the associated diversion and storage rights are still held by the City of San Antonio and were included in the GSA Model. Rights associated with Applewhite Reservoir were modelled similarly to the power plant reservoirs with a consumptive use of 70,000 ac-ft/yr at the lake and an annual maximum make-up diversion of 12,300 ac-ft from Leon Creek. In accordance with the Certificate of Adjudication, Applewhite inflows up to 4 cfs were passed downstream and make-up diversions from Leon Creek were not allowed to impair the desired instream flow of 10 cfs for the Medina River at San Antonio (ID# 1815).

5.6 Medina and Diversion Lakes

Medina Lake and Diversion Lake storage is simulated on a monthly timestep in the GSA Model in accordance with the reservoir contents simulation procedure detailed in Figure 5-2. Recharge and leakage curves developed by EH&A (Ref. 9) for each of the reservoirs were expressed mathematically and included in the program code. Estimates of recharge and leakage at each lake are calculated by the GSA Model using these curves and the water surface elevation associated with average contents for each month simulated. The majority of the water rights associated with the lakes including the 67,830 ac-ft/yr irrigation rights held by Bexar-Medina-Atascosa Water Control and Improvement District (BMA) were assumed to be diverted from Diversion Lake into the Medina Canal. Releases from Medina to Diversion Lake were based on the operational objective of sustaining a Diversion Lake level about five feet below the spillway during irrigation season to minimize losses and maintain diversion efficiency. In all simulations, full or partial water rights were assumed to be exercised in every year to the extent storage was available in Medina and Diversion Lakes to satisfy those rights.

5.7 Pumpage/Springflow Simulation

Pumpage or withdrawal of water from the Edwards Aquifer affects storage and water levels within the formation which, in turn, affect springflows. The GSA Model does not directly simulate this process, however, it is capable of simulating the effects of changes in aquifer pumpage and historical springflows on streamflows throughout the Guadalupe - San Antonio River Basin below the springs. Changes from historical springflows were determined for a range of pumpage scenarios through application of the Texas Water Development Board (TWDB) Edwards Aquifer Model (Ref. 23) using historical monthly recharge calculated by HDR. The assistance of TWDB Staff in geographical distribution of HDR historical recharge estimates; modification of the Edwards Model to include new relationships for estimation of San Antonio and San Pedro springflows and Edwards Aquifer flux in the Hueco Springs area; and generation of springflow sequences subject to historical and to three fixed annual pumpage rates is acknowledged and appreciated.

5.8 Recharge Reservoirs

The operations of recharge reservoirs with respect to water rights are simulated in the GSA Model in a manner consistent with that described in Section 5.3. Recharge reservoir inflows are passed to the extent necessary to satisfy downstream rights to the extent they would have been satisfied without the new recharge enhancement projects. When multiple recharge enhancement projects are considered, the user specifies the sequence of projects from which inflows will be passed to mitigate any additional downstream shortages.

Recharge occurring with reservoirs is calculated in the GSA Model by the specification of a recharge release rate and/or a direct recharge rate. The recharge release rate is generally specified for reservoirs located upstream of the recharge zone and is equal to the threshold rate at which the Edwards Aquifer will accept recharge from the streambed across the outcrop. The direct recharge rate may be the percolation rate through the bottom of a reservoir and/or the diversion rate for injection to the Edwards Aquifer in an adjacent watershed. Evaporation losses are computed at all recharge reservoirs with the exception of smaller projects located atop the recharge zone which have monthly direct percolation rates in excess of reservoir storage capacity.

For recharge reservoirs located upstream of the outcrop, recharge is calculated as the sum of the losses across the recharge zone and diversions for injection. For recharge reservoirs located over the outcrop, recharge is calculated as the sum of natural recharge (without the reservoir), percolation, and diversions for injection. All estimates of recharge are limited to the monthly volume of runoff physically available at or above the project site plus any carryover storage from previous months.

The GSA Model calculates recharge in basins where Soil Conservation Service Flood Retardation Structures (SCS/FRS) are present as the sum of natural recharge adjusted for water rights and return flows plus recharge enhancement components associated with the normal and active pools of the SCS/FRS. As described in greater detail in Section 6.2.1 of this report, 100 percent and 70 percent of the volume of water impounded in the respective normal and active pools of the SCS/FRS is assumed to recharge the Edwards Aquifer. Under scenarios in which the principal spillway outlets are closed, it is assumed that 100 percent (rather than 70 percent) of the water impounded in the former active pool (between the principal and emergency spillway levels) contributes to recharge. Evaporation losses are not simulated for SCS/FRS because data collected on these structures indicates that they drain in a matter of days or a few weeks.

5.9 Verification

Verification of the GSA Model and the natural streamflow sequences was accomplished through reproduction of historical gaged flows and recharge estimates for each control point. More specifically, the GSA Model was verified by simulating the effects of historical diversions and return flows on the natural streamflows developed for each control point. The result of this simulation should be reproduction of the gaged streamflows and historical recharge estimates, if the model is functioning correctly. Agreement with the gaged flows and historical recharge estimates was virtually exact with some very minor discrepancies arising from the limited use of integer variables in the model. Further verification of all model simulation capabilities was accomplished through extensive manual checking of intermediate computations and final output summaries.

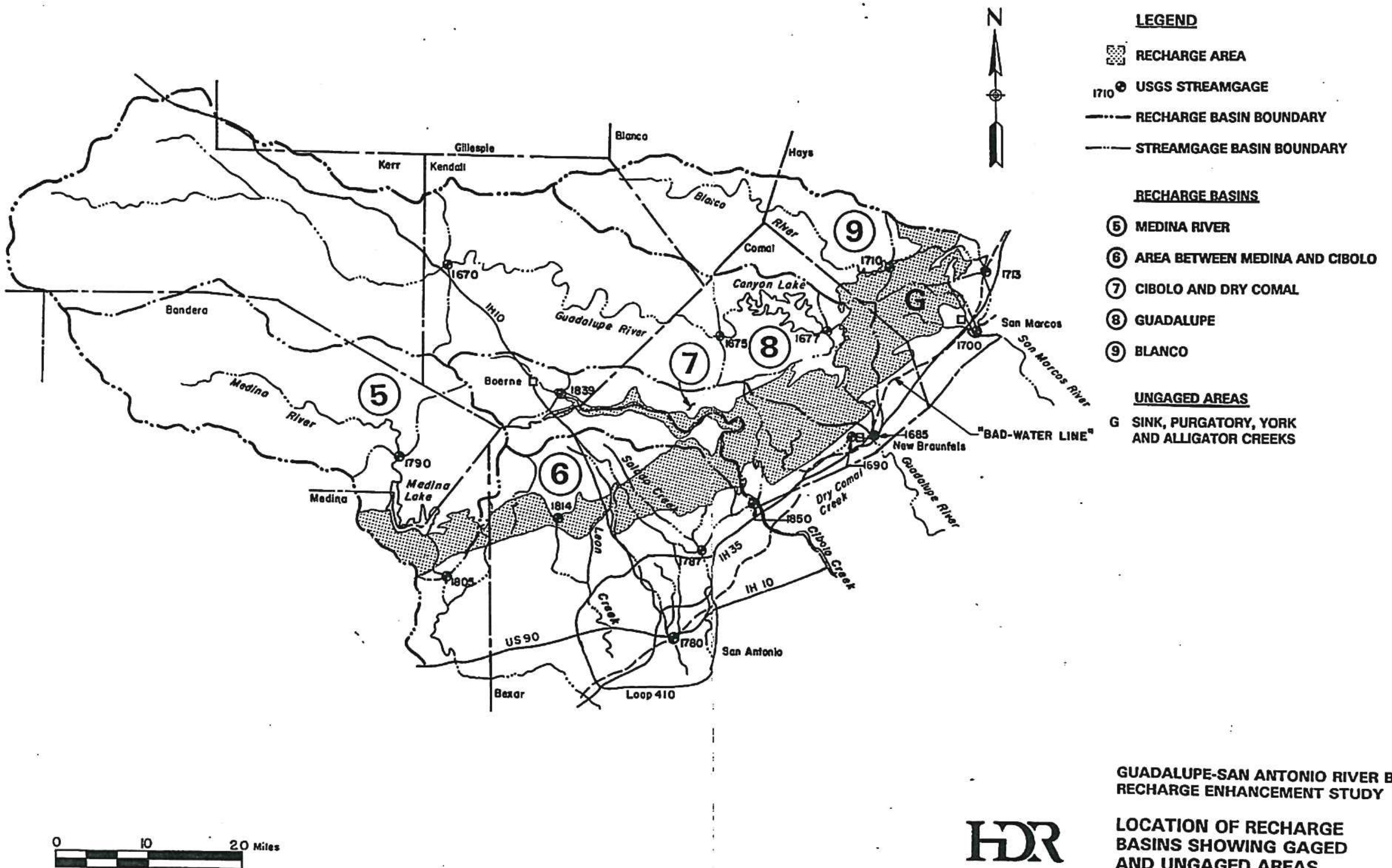
6.0 HISTORICAL RECHARGE

Estimates of recharge to the Edwards Aquifer for the five major recharge basins in the Guadalupe - San Antonio River Basin were calculated for the 56-year period from 1934 through 1989. The boundaries of the five recharge basins are shown in Plate 1. These recharge basin boundaries are the same as those utilized by the U.S. Geological Survey (USGS) in their annual report (Ref. 39) prepared in cooperation with the Edwards Underground Water District (EUWD). Drainage areas and corresponding percentages of the total drainage area included in each recharge basin are summarized in Table 6-1. Gaged areas total about 2,838 square miles above and within the recharge zone, and partially gaged and ungaged areas total about 554 square miles. Methodologies applied in the calculation of recharge in gaged, partially gaged, and ungaged areas are detailed in the following sections.

Table 6-1
Recharge Basin Drainage Areas

Recharge Basin[1]	Drainage Area (square miles)	Percent of Total
5. Medina River	634	18%
6. Area between Medina River and Cibolo Creek	330	10%
7. Cibolo Creek and Dry Comal Creek	404	12%
8. Guadalupe River	1,518	45%
9. Blanco River and Upper San Marcos River	506	15%
Total	3,392	100%

Notes:
1. Recharge Basins 1 through 4 are located in the Nueces River Basin (Refs. 39 and 45).



GUADALUPE-SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

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LOCATION OF RECHARGE BASINS SHOWING GAGED AND UNGAGED AREAS

PLATE 1

6.1 Recharge in Gaged Areas

In the Guadalupe - San Antonio River Basin, there are three streams that recharge the Edwards Aquifer which are gaged both upstream and immediately downstream of the recharge zone. These streams include the Blanco River, Cibolo Creek, and the Guadalupe River. Figure 6-1 is a schematic diagram showing typical gage locations relative to the recharge zone.

Historical recharge in gaged areas was calculated on a monthly time step in accordance with the following equation:

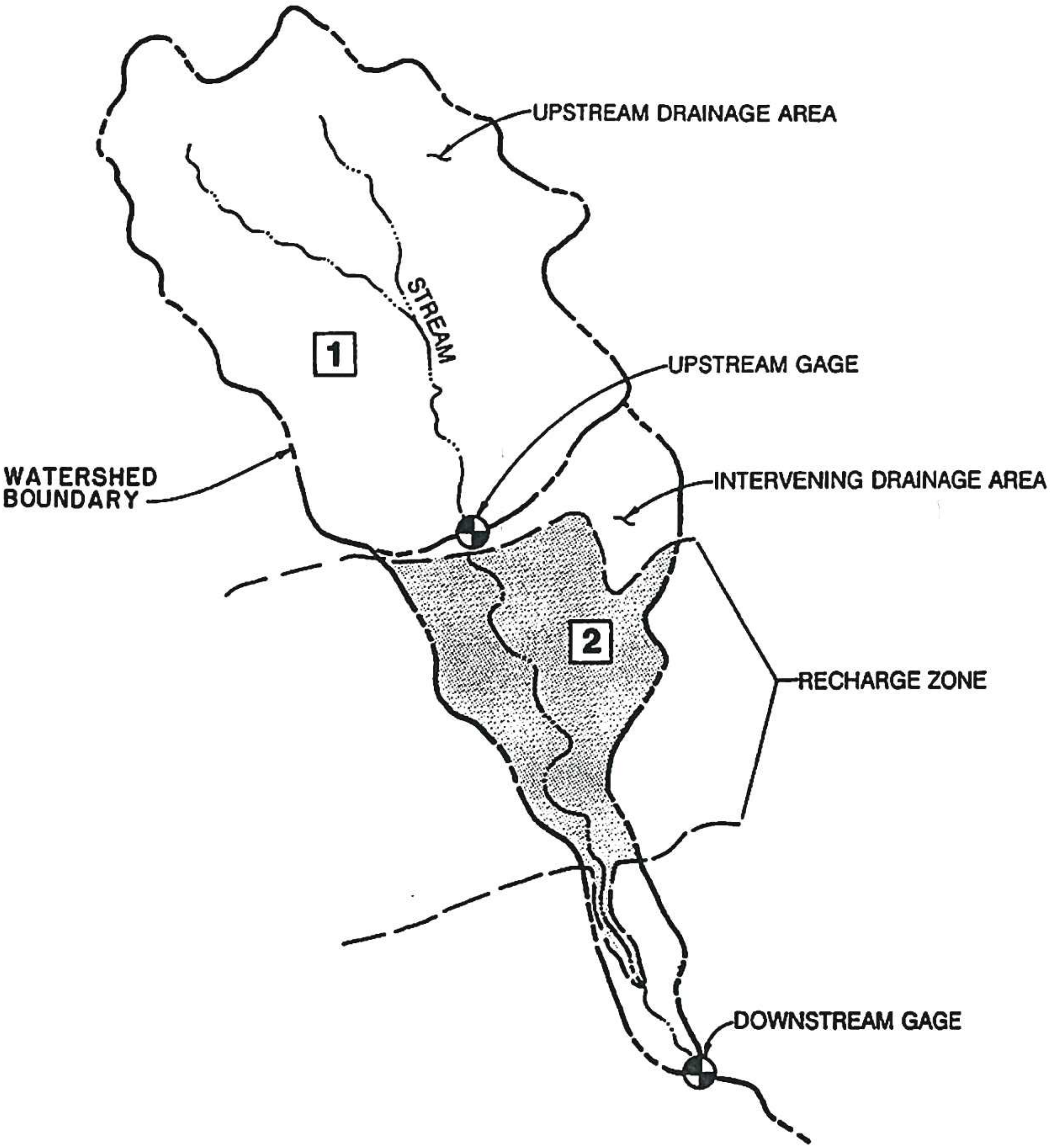
$$R = QG_1 + QI - QNH_2 \qquad (6\text{-}1)$$

where:

R = Recharge;
QG_1 = Upstream Gaged Flow;
QI = Intervening Runoff; and
QNH_2 = Downstream Flow Adjusted for Intervening Diversions and Return Flows.

Intervening runoff is the most difficult parameter to quantify in the above equation because it cannot be measured directly and must be estimated from available data such as gaged streamflow, precipitation, and watershed characteristics. In the calculation of recharge, intervening runoff may also be called potential runoff as it represents the volume of runoff which would have arrived at the downstream gage if the intervening area were not over the recharge zone.

The method employed to estimate potential runoff for the intervening area is a variation of the SCS runoff curve number procedure (Refs. 18 and 19) developed by HDR



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RECHARGE ENHANCEMENT STUDY

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SCHEMATIC OF TYPICAL GAGED AREA NEAR RECHARGE ZONE

FIGURE 6-1

for the calculation of recharge in the Nueces River Basin. This procedure takes into account differences in soil-cover complexes as well as differences in precipitation between upstream gaged and intervening areas. Applying this procedure, potential intervening runoff is expressed as:

$$QI = \left(\frac{640}{12}\right) A \frac{\left(P - \frac{200}{CN} + 2\right)^2}{\left(P + \frac{800}{CN} - 8\right)} \qquad (6\text{-}2)$$

where:

QI = Potential Intervening Runoff (acre-feet/month);
A = Watershed Area (square miles);
P = Aerial Precipitation (inches/month); and
CN = SCS Curve Number.

The first step in the application of the SCS runoff curve number procedure was the selection of a runoff curve number (CN) for each major soil-cover complex in a watershed using SCS soils reports. The curve numbers were then weighted by area to arrive at a composite average CN for each watershed (see Table 4-1). Under the SCS procedure, CN also varies with antecedent moisture conditions (AMC). The average CN (AMC_{II}) increases with wet antecedent moisture conditions (AMC_{III}) and decreases with dry conditions (AMC_{I}). The higher the CN, the more runoff is produced for a given rainfall amount.

In calculating monthly intervening runoff, the CN for the intervening area was calibrated for antecedent moisture conditions as reflected in a gaged partner area. It is assumed in this methodology that AMC and storm rainfall patterns in the gaged partner area are reasonably indicative of those in the ungaged or intervening area. Using natural runoff and areal precipitation for the partner area, Equation 6-2 is solved each month for CN and the magnitude of this CN, relative to the AMC_{II} CN, is used to adjust the AMC_{II} CN and obtain a calibrated CN for the ungaged or intervening area. This calibration procedure is necessary to justify application of SCS methods on a monthly rather than storm event basis. Potential intervening runoff is then calculated using Equation 6-2 with precipitation and the calibrated CN for the intervening area.

Following is an example illustrating the procedures used for estimating potential intervening runoff and calculating recharge for July, 1987 in the Blanco River Basin (see Table 6-2). The Blanco River is gaged upstream of the recharge zone near Wimberley (ID# 1710). The watershed area at this location is 355 square miles with an average (AMC_{II}) CN of 82.6. Utilizing relationships defined by the SCS, the AMC_{I} and AMC_{III} curve numbers were computed to be 66.60 and 91.61, respectively. The Blanco River is also gaged downstream of the recharge zone near Kyle (ID# 1713). The intervening area is 57 square miles and has an estimated AMC_{II} CN of 84.3 with corresponding AMC_{I} and AMC_{III} curve numbers of 69.28 and 92.51, respectively. Natural runoff from the watershed above Wimberley, which serves as the partner area for the intervening area, was 25,978 acre-feet (25,950 acre-feet gaged) or 1.37 inches for the month of July, 1987. Areal precipitation in July, 1987 totalled 4.13 inches and 2.80 inches for the upstream and intervening areas, respectively. Based on rainfall of 4.13 inches and the corresponding runoff volume of 1.37 inches, a CN of 69.32 which is between AMC_{I} and AMC_{II}, was calculated for the upstream gaged area. By interpolation, using the AMC_{I} and AMC_{II} curve numbers for the intervening

Table 6-2 Example Calculation of Potential Intervening Runoff for the Blanco River Basin		
Data	**Blanco River near Wimberley ID# 1710 (Partner Area)**	**Blanco River near Kyle ID# 1713 (Intervening Area)**
Drainage Area	355 sq.mi.	57 sq.mi
AMC_{II} CN	82.60	84.30
AMC_{I} CN	66.60	69.28
AMC_{III} CN	91.61	92.51
July, 1987 Rainfall	4.13 inches	2.80 inches
July, 1987 Runoff	25,978 ac-ft[1]	2,086 ac-ft[2]
July, 1987 Runoff	1.37 inches	0.69 inches
July, 1987 CN	69.32[3]	71.87[4]

Notes:
1) Natural runoff at ID# 1710 of 25,978 ac-ft is the sum of 25,950 ac-ft (gaged) and 28 ac-ft (diversions).
2) Potential intervening runoff estimate. Actual gaged flow at ID# 1713, adjusted for diversions and return flows, was 26,450 ac-ft.
3) Computed CN based on rainfall and runoff of 4.13 inches and 1.37 inches, respectively.
4) Calibrated CN based on interpolation between AMC_I CN and AMC_{II} CN.

area, a CN of 71.87 was computed for the intervening area. Applying Equation 6-2 using monthly rainfall of 2.80 inches and the calibrated curve number of 71.87, a potential runoff estimate of 0.69 inches or 2,086 acre-feet was computed for the intervening area. The flow measured at the streamflow gage downstream of the recharge zone (ID# 1713) was 26,450 acre-feet after adjustments for diversions and return flows in the intervening area. This downstream flow represents the portion of total runoff originating upstream of the recharge zone and in the intervening area that did not contribute to recharge. The recharge estimate for the Blanco River Basin for July, 1987 was then computed by using Equation 6-1 expressed as:

$$R_{1713} = QG_{1710} + QI - QNH_{1713} \tag{6-3}$$

where:

R_{1713} = Recharge for Blanco River Basin;
QG_{1710} = Upstream Gaged Flow for Blanco River at Wimberley (ID# 1710);
QI = Potential Intervening Runoff for the Area Between Wimberley (ID# 1710) and Kyle (ID# 1713); and
QNH_{1713} = Downstream Flow for Blanco River at Kyle (ID# 1713) Adjusted for Intervening Diversions and Return Flows.

Inserting values for July, 1987 recharge was computed as:

$$R_{1713} = 25{,}950 + 2{,}086 - 26{,}450 = 1{,}586 \text{ ac-ft}$$

6.1.1 Blanco River Basin

Recharge in the Blanco River Basin was computed utilizing the streamflow gaging stations located upstream of the recharge zone near Wimberley (ID# 1710) and downstream of the recharge zone near Kyle (ID# 1713). The upstream gaging station was in service for the entire 1934-89 period while the downstream gaging station was in service only during the 1956-89 period. Streamflow at the downstream gaging station prior to 1956 was estimated by standard multiple linear regression techniques utilizing the upstream gaged flow and the estimated intervening runoff (see Table 4-3). Estimates of potential runoff for the 57 square mile intervening area over the recharge zone were made using the Blanco River watershed above Wimberley as a partner area.

Average annual recharge for the Blanco River Basin for the 1934-89 period was 27,018 ac-ft which represents 4.3 percent of the total average annual recharge to the Edwards Aquifer. The minimum annual recharge estimate was 12,224 ac-ft in 1956 and the maximum annual recharge estimate was 53,952 ac-ft in 1975.

6.1.2 Cibolo Creek Basin

Recharge in the Cibolo Creek Basin was computed utilizing the streamflow gaging stations located upstream of the recharge zone near Boerne (ID# 1839) and downstream of the recharge zone near Selma (ID# 1850). The upstream gaging station was in service for the 1962-89 period and the downstream gaging station was in service for the 1946-89 period. Streamflow at the upstream gaging station for the period prior to 1962 was estimated using relationships based on the intervening runoff for the Guadalupe River at Spring Branch (ID# 1765) and streamflow as measured on the Medina River near Pipe Creek (ID# 1790). Streamflow data at the downstream gaging station for the period prior to 1946 was estimated using estimated upstream gaged flow (ID# 1839) and potential runoff for the Cibolo Creek intervening area. Table 4-3 summarizes the methods used to predict the missing streamflow records. Estimates of potential runoff for the 205.6 square mile intervening area over the recharge zone were made using the Cibolo Creek watershed above Boerne as a partner area. Accuracy of recharge estimates prior to 1962 may be limited by the accuracy of estimated flows at the upstream and downstream gaging stations. The large difference in drainage area between the upstream partner area (68.4 sq.mi.) and the intervening area over the recharge zone (205.6 sq.mi.) may also affect the accuracy of recharge estimates for the Cibolo Creek Basin.

Average annual recharge for the Cibolo Creek Basin for the 1934-89 period was 63,880 ac-ft which represents 10.2 percent of the total average annual recharge to the Edwards Aquifer. The minimum annual recharge estimate was 1,683 ac-ft in 1956 and the maximum annual recharge estimate was 149,136 ac-ft in 1958.

6.1.3 Guadalupe River Basin

Recharge in the Guadalupe River Basin was computed using the streamflow gaging stations located upstream of the recharge zone near Sattler (ID# 1678) and downstream of the recharge zone at New Braunfels (ID# 1685). Streamflow records are available for the downstream gaging station for the 1934-89 period, however, records for the upstream gaging station exist only for the 1962-89 period. Streamflow at the upstream gaging station prior to 1962 was estimated using a relationship with the Guadalupe River at Spring Branch (ID# 1675) and the intervening runoff between the Spring Branch and Sattler gages (see Table 4-3). Intervening runoff estimates for the area over the recharge zone between the Sattler and New Braunfels gaging stations were developed utilizing the Blanco River watershed above Wimberley (ID# 1710) as a partner area.

In addition to upstream and downstream gaged flows and potential intervening runoff, there is an exchange of water or flux between the Edwards Aquifer and the Guadalupe River occurring in this reach which affects the calculation of recharge. Initially, it was theorized that Hueco Springs was the primary component of this flux, but literature review (Refs. 1 and 22) and preliminary regression analyses using periodic discharge measurements indicate that flows from Hueco Springs are probably influenced by a combination of local recharge, regional Edwards Aquifer levels, and possible flow from the Guadalupe River.

In order to obtain an estimate of historical and/or simulated recharge occurring in this reach, it was necessary to isolate the steady component of flux driven by regional Edwards Aquifer levels from the transient components associated with local recharge and flow from the Guadalupe River. It is expected that the regional Edwards Aquifer level flux component would be affected by changes from historical pumpage rates to a greater degree than would the transient, local components. Hence, estimates of Edwards Aquifer flux in this reach of the Guadalupe River were developed by subtracting downstream flow from upstream flow during each of the 94 months when intervening runoff was insignificant and flows in the previous month were below average. These estimates of flux were then correlated to the corresponding monthly average well level at the Bexar County Monitoring Well (J-17) resulting in a linear relationship of flux as a function of well level. A linear relationship was assumed based on similar linear relationships found for San Antonio, San Pedro, and Comal springflow as a function of J-17 level. The resulting relationship is plotted in Figure 6-2 and is expressed as:

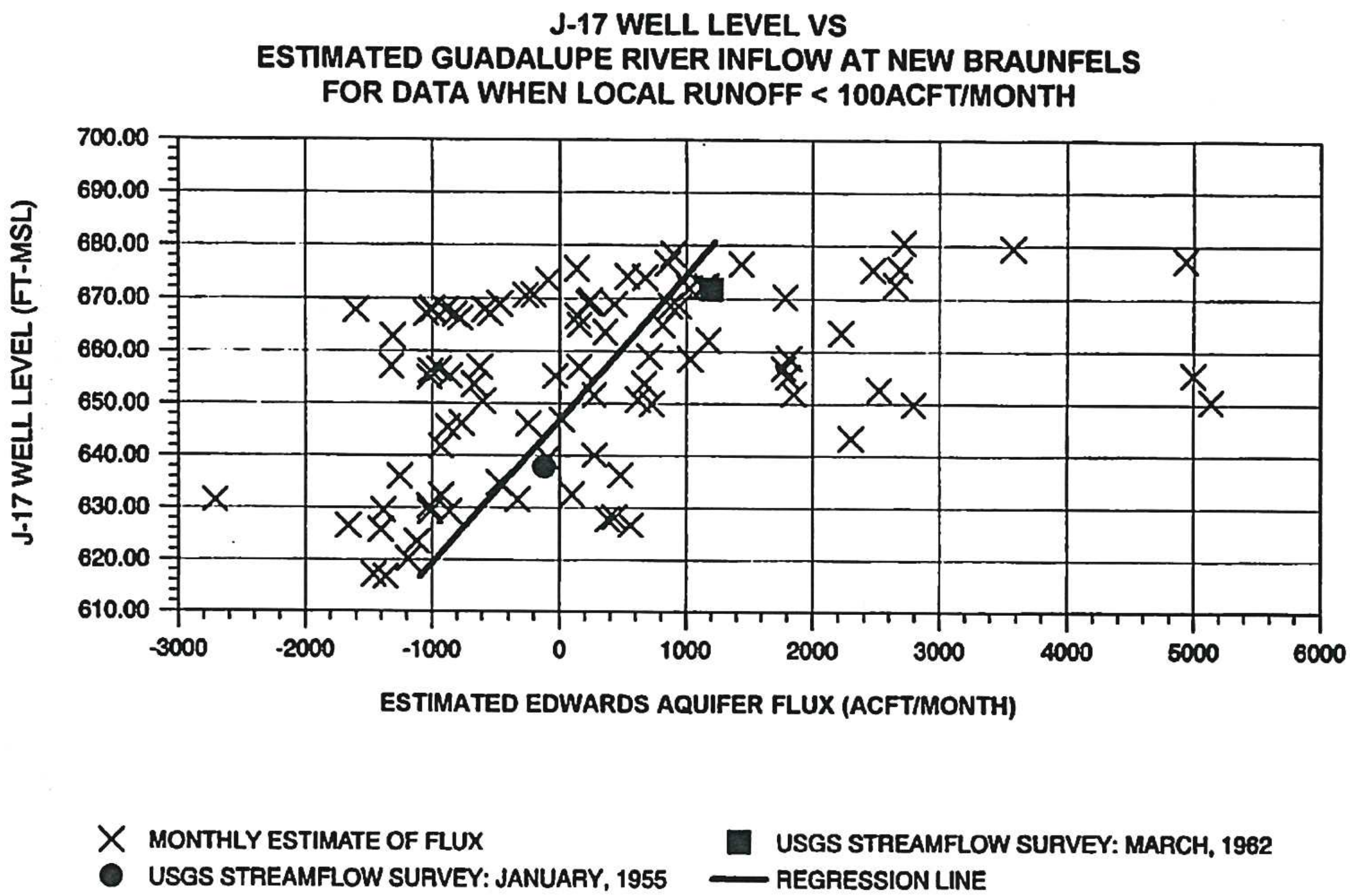
$$Q_E = 36.31 (H_{J-17}) - 23{,}486 \quad (6\text{-}4)$$

where:

Q_E = Edwards Aquifer Flux (ac-ft/month); and
H_{J-17} = Average Monthly J-17 Well Level (ft-msl).

Statistical significance of the regression equation and coefficients was confirmed by F and t tests (Ref. 4), respectively. The coefficient of determination (r^2), however, was 0.16 indicating that only 16 percent of the variation in flux is explained by the regression equation.

Streamflow surveys performed by the USGS (Refs. 38 and 40) for the reach between the Sattler and New Braunfels gaging stations were completed during January, 1955 and March, 1962. The average monthly J-17 well levels for these two periods were 637.8 ft-msl and 671.7 ft-msl, respectively. The January, 1955 streamflow survey showed a net loss



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ESTIMATED EDWARDS AQUIFER FLUX NEAR HUECO SPRINGS

FIGURE 6-2

of about 120 acre-feet per month (2 cfs) in the reach, while the March, 1962 streamflow survey showed a net gain of 1200 acre-feet per month (20 cfs). These two surveys are identified in Figure 6-2 and, in general, appear to support the derived relationship of J-17 well level versus Edwards Aquifer flux. The regression equation indicates that this segment of the Guadalupe River changes from a gaining to a losing reach with respect to water in the Edwards Aquifer when the J-17 well level falls below about 647 ft-msl.

Using the derived relationship, Edwards Aquifer flux was computed for each month during the 1934-89 period based on average monthly J-17 well levels. Recharge for the Guadalupe River Basin was then calculated using the following equation:

$$R_{1685} = QG_{1677} + QI - (QNH_{1685} - Q_E) \qquad (6\text{-}5)$$

where:

R_{1685} = Recharge for Guadalupe River Basin;
QG_{1677} = Upstream Gaged Flow for Guadalupe River at Sattler (ID# 1678);
QI = Potential Intervening Runoff for Area Between Sattler (ID# 1678) and New Braunfels (ID #1685);
QNH_{1685} = Downstream Flow for Guadalupe River at New Braunfels (ID# 1685) Adjusted for Intervening Diversions and Return Flows; and
Q_E = Edwards Aquifer Flux.

Average annual recharge for the Guadalupe River Basin for the 1934-89 period was 11,255 ac-ft which represents 1.8 percent of the total average annual recharge to the Edwards Aquifer. The minimum annual recharge estimate was 0 ac-ft in 1965 and 1977 and the maximum annual recharge estimate was 37,170 ac-ft in 1936. Accuracy of the Edwards Aquifer flux and recharge estimates for the Guadalupe River Basin may be somewhat limited by the accuracy of the flow estimates at Sattler during dry periods prior to 1962.

Even considering the maximum error possible in these flow estimates, recharge in the Guadalupe River Basin accounts for about 7.0 percent of the total recharge during 1956. Hence, the findings of this study do not support the past assumption that the Guadalupe River does not contribute recharge in significant quantities (Ref. 42). In fact, the findings of this study suggest that recharge from the Guadalupe River becomes increasingly significant when aquifer levels are lowered.

6.2 Recharge in Partially Gaged and Ungaged Basins

Partially gaged and ungaged areas which contribute to Edwards Aquifer recharge in the Guadalupe - San Antonio River Basin include portions of the Dry Comal, Salado, Leon, Helotes, Government, San Geronimo, Sink, Purgatory, York, and Alligator Creek watersheds. The last four of these areas have been grouped and are referenced herein as the Upper San Marcos River. All of these areas are headwater watersheds which lie primarily on the Edwards Aquifer recharge zone and have no gages located upstream of the recharge zone. Dry Comal and Salado Creeks are gaged at locations just below the downstream limits of the recharge zone, Helotes Creek has been gaged within the recharge zone in recent years, and the remaining watersheds listed above are ungaged in or near the recharge zone. Without upstream gage records, the calculation of recharge is highly dependent on estimates of potential runoff which reflect the soil types, slopes, and land use characteristics of each area. Hence, potential runoff in each of these areas was computed using the modified SCS procedure described in Section 6.1 which includes monthly calibration to an adjacent gaged watershed. Calculation of recharge in each of these partially gaged and ungaged watersheds is described in the following subsections.

6.2.1 Dry Comal Creek Basin

The Dry Comal Creek Basin is an area of about 130 square miles upstream of the USGS streamflow gaging station on the Comal River at New Braunfels (ID# 1690) the majority of which is located on the Edwards Aquifer recharge zone. Published records for this gaging station include the discharge of Comal Springs, however, the USGS has performed hydrograph separations on a daily basis throughout the entire 1934-89 study period to obtain estimates of surface runoff exclusive of springflow and provided these estimates to HDR. The surface runoff estimates were then adjusted by HDR to account for reported historical diversions and return flows. Potential runoff for the Dry Comal Creek Basin was estimated using the Blanco River watershed above Wimberley (ID# 1710) as a partner area and historical recharge was calculated in accordance with the following equation:

$$R_{1690} = QI_{1690} - QNH_{1690} \tag{6-6}$$

where:

R_{1690}	=	Recharge for Dry Comal Creek Basin;
QI_{1690}	=	Potential Runoff for Dry Comal Creek Basin; and
QNH_{1690}	=	Surface Runoff for Comal River at New Braunfels (ID# 1690) Adjusted for Upstream Diversions and Return Flows.

Average annual recharge for the Dry Comal Creek Basin for the 1934-89 period was 46,259 ac-ft which represents 7.2 percent of the total average annual recharge to the Edwards Aquifer. The minimum annual recharge estimate was 3,971 ac-ft in 1939 and the maximum annual recharge estimate was 121,146 ac-ft in 1973.

There are a total of five SCS/FRS located in the Dry Comal Creek Basin controlling runoff from 57.4 percent of the watershed with aggregate normal pool capacity of 709 ac-ft and active pool capacity of 18,265 ac-ft. Soil Conservation Service records indicate that these SCS/FRS were completed between June, 1956 and April, 1981. Clearly, the SCS/FRS have the effect of enhancing recharge through both direct percolation and steady release of impounded waters while performing their primary flood control function. The Dry Comal Creek Basin is the primary source of gaged surface runoff data for watersheds located directly over the Edwards Aquifer recharge zone in the Guadalupe - San Antonio River Basin and is an important partner area. For this reason, it was necessary to remove the SCS/FRS effects from the gaged data and obtain estimates of natural recharge which could be used to estimate recharge in ungaged basins. Furthermore, it was necessary to simulate the effects of these structures as if they were in place throughout the study period in order to obtain recharge and streamflow baselines for the consideration of potential recharge enhancement projects.

In order to assess the recharge characteristics of the SCS/FRS, it was postulated that historical recharge (R) is comprised of natural recharge (R_N) and additional components associated with the normal pool (R_{NP}) and active pool (R_{AP}) as defined in the following equations (in which, for clarity, the control point ID# 1690 is not shown):

$$R = R_N + R_{NP} + R_{AP} \quad \text{(6-7)}$$

$$R_{NP} = c_1(A_c/A)(QI - R_N) \leq c_{NP}\ (NP) \quad \text{(6-8)}$$

$$R_{AP} = c_2[(A_c/A)(QI - R_N) - R_{NP}] \leq c_{AP}\ (AP) \quad \text{(6-9)}$$

where:

R	=	Historical Recharge;
R_N	=	Natural Recharge;
R_{NP}	=	SCS/FRS Normal Pool Recharge;
R_{AP}	=	SCS/FRS Active Pool Recharge;
QI	=	Potential Runoff;
A_c	=	Watershed Area Controlled;
A	=	Total Watershed Area;
c_{NP}	=	Normal Pool Recharge Coefficient;
c_{AP}	=	Active Pool Recharge Coefficient;
NP	=	Aggregate Normal Pool Storage; and
AP	=	Aggregate Active Pool Storage.

Assuming that potential runoff, historical recharge, area controlled, and SCS/FRS physical characteristics were known for the 1956-89 period, reasonable estimates for natural recharge and the recharge coefficients were sought in the following manner. First, an approximation of natural monthly recharge for the 1956-89 period was obtained from a linear regression relationship between natural and potential runoff based on available data prior to SCS/FRS construction. The normal pool recharge coefficient was assumed equal to 1.0 which implies that 100 percent of water impounded within the normal pools of the SCS/FRS will contribute to recharge neglecting evaporation. Historical monthly recharge was then computed based on the postulated equations using various assumed values for the active pool recharge coefficient. An assumed active pool recharge coefficient of 0.70 resulted in the least error in estimating historical recharge during the 1981-89 period when all structures were in place. This result indicates that approximately 70 percent of the runoff temporarily impounded by the SCS/FRS ultimately contributes to recharge neglecting evaporation. Hence, normal and active pool recharge coefficients of 1.00 and 0.70, respectively, were adopted for the Dry Comal Creek Basin SCS/FRS and consistent monthly estimates of natural recharge and runoff were computed using Equations 6-6 through 6-9.

6.2.2 Salado Creek Basin

The Salado Creek Basin is an area of about 137 square miles upstream of the USGS streamflow gaging station on Salado Creek (Upper Station) at San Antonio (ID# 1787) the majority of which is located on the Edwards Aquifer recharge zone. Available gaged streamflows for the 1960-89 period were adjusted for reported upstream diversions and return flows and potential runoff was estimated using the Blanco River watershed above Wimberley (ID# 1710) as a partner area. The curve number used in the estimation of potential runoff for the Salado Creek was increased with respect to time to reflect the gradual urbanization of the watershed. Historical recharge for the 1960-89 period was computed in accordance with the following equation:

$$R_{1787} = QI_{1787} - QNH_{1787} \qquad \textbf{(6-10)}$$

where:

R_{1787} = Recharge for Salado Creek Basin;
QI_{1787} = Potential Runoff for Salado Creek Basin; and
QNH_{1787} = Surface Runoff for Salado Creek at San Antonio (ID# 1787) Adjusted for Upstream Diversions and Return Flows.

Historical recharge for the 1934-59 period when gaged streamflow records on Salado Creek are unavailable was computed using the following equation:

$$R_{1787} = QI_{1787}(R_{N\,1690}/QI_{1690}) \qquad \textbf{(6-11)}$$

where:

$R_{N\,1690}$ = Natural Recharge for Dry Comal Creek Basin; and
QI_{1690} = Potential Runoff for Dry Comal Creek Basin.

Average annual recharge for the Salado Creek Basin for the 1934-89 period was 44,014 ac-ft which represents 6.9 percent of the total average annual recharge to the Edwards Aquifer. The minimum annual recharge estimate was 6,783 ac-ft in 1955 and the maximum annual recharge estimate was 117,150 ac-ft in 1973.

As of 1989, there were a total of 12 SCS/FRS located in the Salado Creek Basin controlling runoff from 58.7 percent of the watershed with aggregate normal pool capacity of 1809 ac-ft and active pool capacity of 28,847 ac-ft. Soil Conservation Service records indicate that these SCS/FRS were completed between March, 1971 and April, 1987. These structures as well as one additional SCS/FRS completed in December, 1991 have the effect of enhancing recharge through both direct percolation and steady release of impounded waters while performing their primary flood control function. For reasons identical to those stated with respect to Dry Comal Creek (Section 6.2.1), it was necessary to quantify and remove the SCS/FRS effects and obtain monthly estimates of natural streamflow and recharge. Employing the methodology described for the Dry Comal Creek Basin, an active pool coefficient of 0.63 resulted in the least error in estimating historical recharge during the 1971-80 period before urbanization significantly affected the Salado Creek watershed. Hence, normal and active pool recharge coefficients of 1.00 and 0.63, respectively, were adopted for the Salado Creek Basin SCS/FRS and consistent monthly estimates of natural recharge and runoff were computed.

6.2.3 Upper San Marcos River Basin

The Upper San Marcos River recharge basin includes Sink and Purgatory Creeks which feed the headwaters of the San Marcos River near San Marcos Springs, as well as the portion of York and Alligator Creek watersheds over the recharge zone. No gaged streamflow data has been published for the basin, therefore, natural recharge that occurred in this basin was estimated using the relationship of natural recharge to potential runoff in the nearby Dry Comal Creek Basin. Potential runoff estimates for the Upper San Marcos River Basin were developed by application of modified SCS procedures and Equation 6-2 using the Blanco River watershed above Wimberley (ID# 1710) as a partner area. Natural recharge in the Upper San Marcos River Basin was computed using the following equation:

$$R_{N\,1700} = QI_{1700} \left(\frac{R_{N\,1690}}{QI_{1690}} \right) \tag{6-12}$$

where:

$R_{N\,1700}$ = Natural Recharge for Upper San Marcos River Basin;
QI_{1700} = Potential Runoff for Upper San Marcos River Basin;
$R_{N\,1690}$ = Natural Recharge for Dry Comal Creek Basin; and
QI_{1690} = Potential Runoff for Dry Comal Creek Basin.

Six SCS/FRS were constructed on the recharge zone in the Upper San Marcos River Basin during the 1963-89 period which provide a total of 751 ac-ft of normal pool storage and 20,926 ac-ft of active pool storage. Historical recharge enhancement due to SCS/FRS in the Upper San Marcos River Basin was estimated by application of techniques developed for assessment of SCS/FRS in the Dry Comal and Salado Creek watersheds. Normal and active pool coefficients of 1.00 and 0.70, respectively, were used. Natural recharge was combined with estimated recharge enhancement due to the SCS/FRS to obtain the total historical recharge for the Upper San Marcos River Basin.

Historical recharge in the Upper San Marcos River Basin during the 1934-89 period averaged 37,505 ac-ft/yr, comprising 5.8 percent of the total average annual recharge to the Edwards Aquifer. The minimum annual recharge estimate was 3,868 ac-ft in 1939 and the maximum annual recharge estimate was 92,668 ac-ft in 1981.

6.2.4 Leon, Helotes, Government, and San Geronimo Creeks

Recharge estimates for the portions of the Leon, Helotes, Government, and San Geronimo Creek watersheds upstream and over the recharge zone were developed for the 1934-89 period. These watersheds were ungaged during the study period, with the exception of Helotes Creek which was gaged (ID# 1814) during the 1968-89 period. Recharge estimates were developed by considering the basins as a group and included the intervening area over the recharge zone between Medina Lake and Diversion Lake and the subwatersheds over the recharge zone adjacent to the Diversion Lake watershed. The combined area totals 193 square miles of which 106 square miles is upstream of the recharge zone and 87 square miles is on the recharge zone. Composite curve numbers were determined for the areas upstream of and on the recharge zone and monthly potential runoff estimates were developed for both of these areas using the Cibolo Creek watershed near Boerne (ID# 1839) as a partner area.

For the area on the recharge zone, recharge was computing using the ratio of natural recharge to potential runoff for the Salado Creek Basin expressed as follows:

$$R_{NZ} = QI_Z \left(\frac{R_{N\,1787}}{QI_{1787}} \right) \tag{6-13}$$

where:

R_{NZ} = Natural Recharge for Area On Recharge Zone;
QI_Z = Potential Runoff for Area On Recharge Zone;
$R_{N\,1787}$ = Natural Recharge for Salado Creek Basin; and
QI_{1787} = Potential Runoff for Salado Creek Basin.

For the area upstream of the recharge zone, recharge during the 1968-89 period was computed utilizing measured data from the Helotes Creek gaging station (ID# 1814). The Helotes Creek gaging station measures runoff from an area that is predominantly upstream of the recharge zone, but overlies the recharge zone in the vicinity of the gage. Using the Cibolo Creek watershed near Boerne (ID# 1839) as a partner area, monthly potential runoff estimates were developed for the Helotes Creek watershed. Recharge for the Helotes Creek Basin was computed as the difference between potential and measured runoff at the gaging station. The monthly ratio of recharge to potential runoff for the Helotes Creek Basin was then used to compute recharge for the entire 106 square mile area upstream of the recharge zone in accordance with the following equation:

$$R_U = QI_U \left(\frac{R_{1814}}{QI_{1814}} \right) \tag{6-14}$$

R_U = Recharge for Area Upstream of Recharge Zone;
QI_U = Potential Runoff for Area Upstream of Recharge Zone;
R_{1814} = Recharge for Helotes Creek Basin; and
QI_{1814} = Potential Runoff for Helotes Creek Basin.

For the period prior to 1968, when the Helotes Creek gaging station was not in service, recharge estimates for the area upstream of the recharge zone were based on respective averages developed for the Helotes and Salado Creek Basins. For the 1968-89 period, recharge in the Helotes Creek Basin averaged about 61 percent of potential runoff while natural recharge averaged about 85 percent of potential runoff in the adjacent Salado Creek Basin. Therefore, the ratio of recharge to potential runoff for the area upstream of the recharge zone (including the Helotes Creek Basin) averaged about 71 percent (61/85) of that for the Salado Creek Basin. This percentage was used to compute monthly recharge estimates for the area upstream of the recharge zone for the 1934-67 period based on natural recharge and potential runoff in the adjacent Salado Creek Basin in accordance with the following equation:

$$R_U = 0.71\ QI_U \left(\frac{R_{N\ 1787}}{QI_{1787}} \right) \qquad (6\text{-}15)$$

where:

R_U = Recharge for Area Upstream of Recharge Zone;
QI_U = Potential Runoff for Area Upstream of Recharge Zone;
$R_{N\ 1787}$ = Natural Recharge for Salado Creek Basin; and
QI_{1787} = Potential Runoff for Salado Creek Basin.

San Geronimo Creek Dam was constructed at the downstream edge of the recharge zone by the Edwards Underground Water District for the purpose of enhancing recharge to the Edwards Aquifer. Incremental recharge provided by this structure was obtained from TWC monthly water use reports prepared by the EUWD and added to the recharge estimates computed for the areas upstream of and on the recharge zone.

Average annual recharge for the Leon, Helotes, Government and San Geronimo Creek Basins for the 1934 - 89 period was 44,260 ac-ft which represents 6.9 percent of the total average annual recharge to the Edwards Aquifer. The minimum annual recharge estimate was 2,056 acre-feet in 1955 and the maximum annual recharge estimate was 109,881 acre-feet in 1986.

6.3 Medina and Diversion Lakes

Estimation of monthly Edwards Aquifer recharge occurring at Medina and Diversion Lakes is very different from the procedures used in other watersheds as it is based on relationships with reservoir stages. Medina and Diversion Lakes have been in place throughout the 1934-89 study period and have been operated primarily to supply water for irrigation through a distribution canal beginning at Diversion Lake. In addition to diversions for water supply and net evaporation losses, storage in these reservoirs is affected by percolation or recharge as well as leakage through the dams. It was assumed that reasonable estimates of recharge, leakage, and net evaporation could be based on the elevation or water surface area associated with the average reservoir contents in each month.

Key records used in the calculation of historical recharge include Medina Lake contents (1913-89) and gaged flows for the Medina River at Riomedina (ID# 1805) (1953-73) and for the Medina Canal (1922-35, 1957-89). Additional diversion records for the Medina Canal were obtained from an Espey, Huston & Associates, Inc. (EH&A) report (Ref. 9) for the 1940-56 period and estimated by HDR for the 1935-39 period. Elevation-area-capacity tables for Medina and Diversion Lakes were obtained from published reports (Refs. 25 and 35) and are included in Appendix H (Volume III).

Calculation of historical monthly recharge at Medina Lake and leakage at Medina Dam was accomplished using the reservoir stage associated with average monthly contents and recharge and leakage curves developed by EH&A (Ref. 9). Historical recharge at Diversion Lake, however, was somewhat more difficult to calculate in the absence of contents records. When gaged streamflow records were available for the Medina River at Riomedina (ID# 1805), they were assumed equal to the sum of leakage and spills from Diversion Lake, average monthly lake level was estimated from the EH&A leakage curve, and recharge was calculated from the EH&A recharge curve using the average lake level. When gaged streamflows were not available below Diversion Dam, average monthly lake level was estimated by iterative mass balance calculations considering runoff below Medina Dam, leakage and releases from Medina Lake, Medina Canal diversions, and net evaporation losses. Releases from Medina to Diversion Lake were based on the operational objective of maintaining Diversion Lake at a level about five feet below the spillway during irrigation season to minimize losses and maintain diversion efficiency.

Average annual recharge at Medina and Diversion Lakes for the 1934-89 period was 41,833 ac-ft which represents 6.5 percent of the total average annual recharge of the Edwards Aquifer. Approximately 64 percent of the historical average recharge is attributable to Medina Lake. The minimum annual recharge estimate was 10,256 ac-ft in 1951 and the maximum annual recharge estimate was 53,275 ac-ft in 1936.

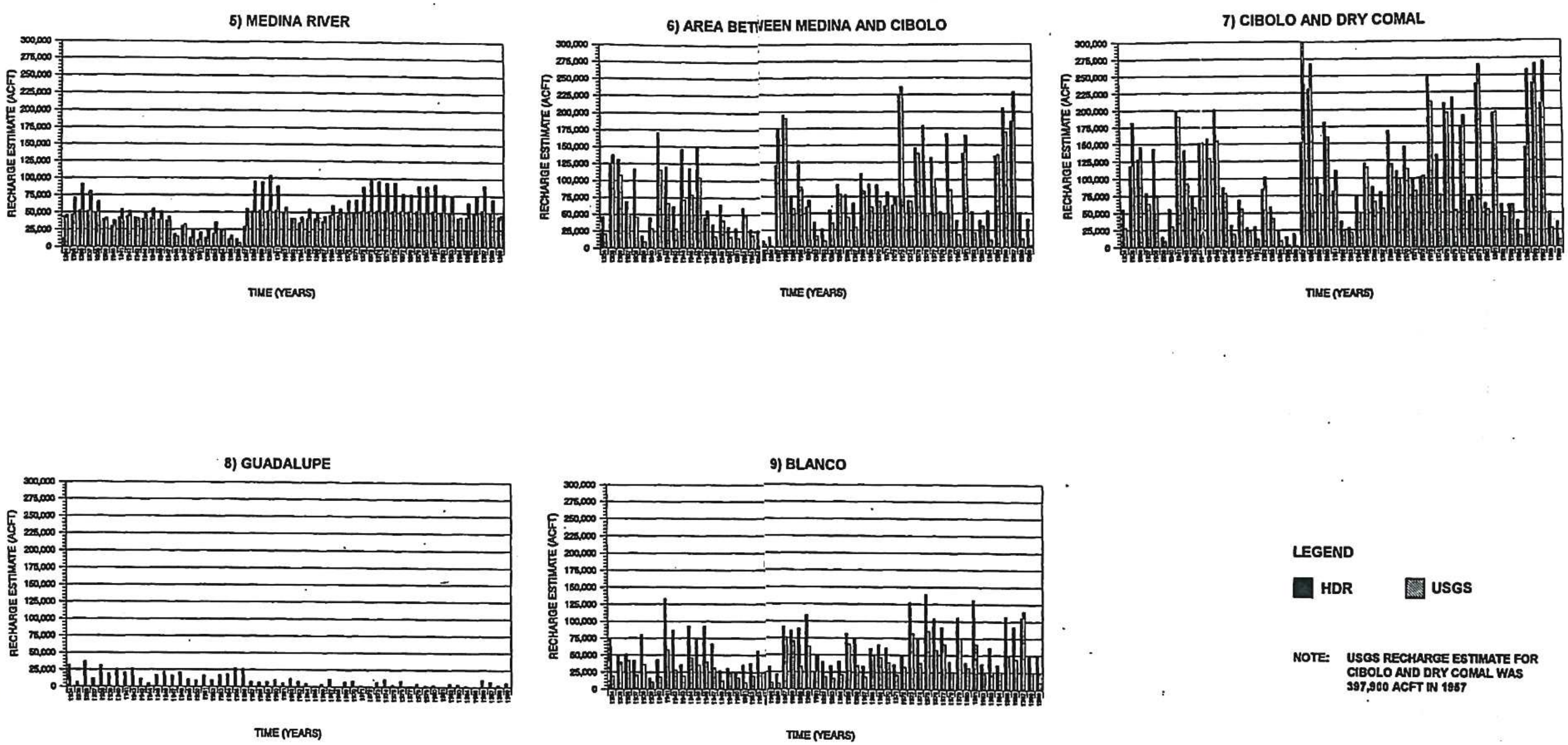
6.4 Comparison of Edwards Aquifer Recharge Estimates

Historical Edwards Aquifer recharge estimates for the watersheds within the Guadalupe - San Antonio River Basin were compared to the USGS recharge estimates for the 1934-89 period. This comparison revealed that the USGS average recharge estimate of 270,000 ac-ft/yr is about 15 percent less than the average of 316,000 ac-ft/yr computed by HDR. Although this difference in the long-term average is only marginally significant considering the complexity of the physical processes involved, important differences do exist in the geographical distribution of recharge among the various recharge basins.

In order to understand the differences between the USGS and HDR estimates, key methodologies and assumptions must be considered. The principal difference between the HDR and USGS methods of calculating recharge is in estimating potential runoff directly over the recharge zone. Reasonable estimates of flow in this area are necessary to accurately calculate recharge. The methods employed by the USGS assume that potential runoff over the recharge zone is equal to runoff from the area upstream of the recharge zone (or other partner area) adjusted for drainage area size and precipitation differences if precipitation differs by more than 20 percent. More specifically, USGS methods assume that runoff varies linearly with precipitation when adjusting for precipitation differences and that soil-cover complex is identical in both the area upstream of and the area directly over the recharge zone. Methods applied by HDR are based on Soil Conservation Service (SCS) procedures which account for differences in soil-cover complex as well as differences in rainfall regardless of relative magnitude. Other general differences between the HDR and USGS methodologies include consideration of historical diversions and return flows. HDR accounts for such diversions and return flows, while the USGS does not. Selections of partner areas for use in estimating the potential runoff for intervening or ungaged areas also differ for some recharge basins.

Figure 6-3 presents a comparison of annual HDR and USGS recharge estimates for the 1934-89 period for each of the five recharge basins identified in Plate 1. Recharge estimated by the USGS in the Medina River Basin averaged 45.3 percent higher than the average of 41,833 ac-ft/yr computed by HDR. Both sets of recharge estimates for the Medina River Basin are based on stage-recharge relationships for Medina and Diversion Lakes. The recharge estimates computed by HDR were based on stage-recharge relationships developed by Espey, Huston and Associates (Ref. 9) which have been shown to reasonably approximate historical lake levels at Medina Lake, while the USGS recharge estimates were based on stage-recharge relationships developed by Lowry (Ref. 42). USGS recharge estimates were higher than HDR estimates due to the differences in the stage-recharge relationships used.

Recharge estimated by the USGS for the area between the Medina River and Cibolo Creek averaged 23.3 percent lower than the average of 88,274 ac-ft/yr computed by HDR. This area includes the Leon, Helotes, Government, San Geronimo, and Salado Creek Basins. HDR also included the intervening area between Medina Lake and Diversion Lake in this basin which, in part, accounts for the higher recharge estimates computed by HDR. It is noted that neither HDR or the USGS (Ref. 42) included an area of about 12 square miles over the Edwards Aquifer recharge zone in the Medina Lake watershed in the recharge calculations. If this area were considered and experienced recharge comparable



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COMPARISON OF HISTORICAL RECHARGE ESTIMATES FOR FIVE RECHARGE BASINS

FIGURE 6-3

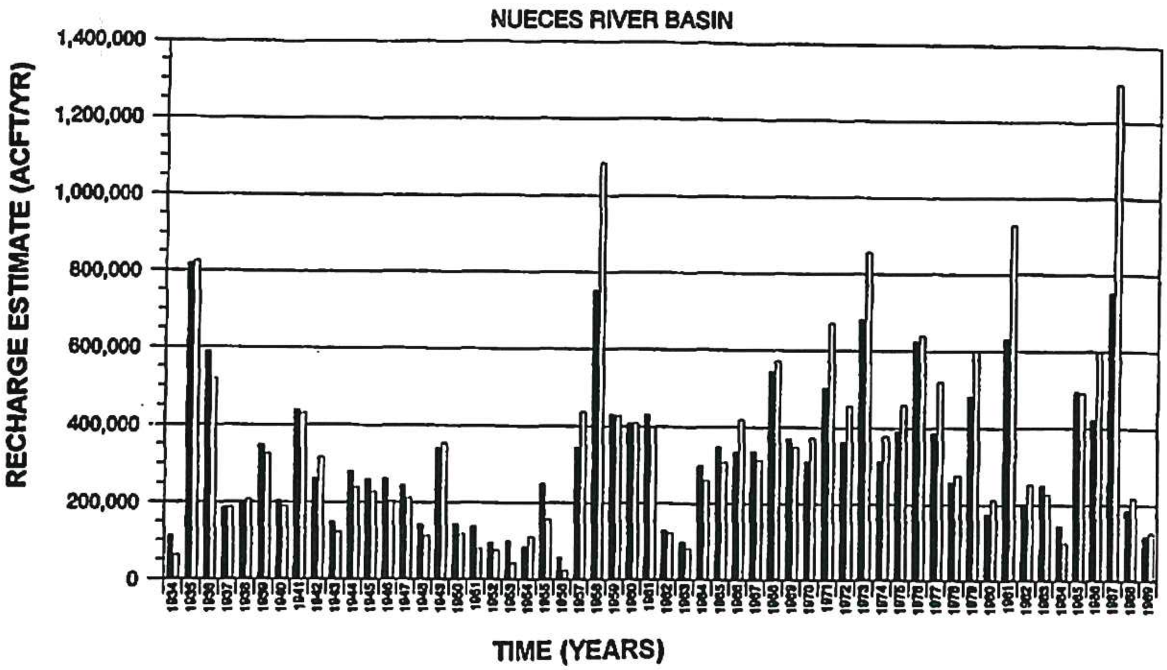
to adjacent watersheds over the recharge zone, HDR estimates of average annual recharge to the entire Edwards Aquifer might be increased by about 3,000 ac-ft (0.46 percent). Other differences in methodology include an accounting for enhanced recharge due to existing structures in the San Geronimo and Salado Creek Basins and the inclusion of urbanization effects on potential runoff in the Salado Creek Basin by HDR. All of these factors contribute to HDR producing higher average annual recharge estimates for this basin than the USGS.

HDR and USGS average annual recharge estimates for the Cibolo Creek and Dry Comal Creek Basin differ significantly, especially during drought periods. The average recharge estimate of 104,045 ac-ft/yr by the USGS was 5.5 percent lower than the 110,139 ac-ft/yr average recharge estimate computed by HDR. During the 1947 to 1956 drought period, average USGS recharge was 35,250 ac-ft/yr which is 21.8 percent less than the HDR average of 45,050 ac-ft/yr. Large differences were evident during wet years where the USGS recharge estimates were, in many cases, substantially higher than those computed by HDR. The higher HDR average recharge estimate for this basin is partially attributed to HDR accounting for enhanced recharge due to existing structures in the Dry Comal Creek Basin and due to a difference in selection of partners areas for intervening runoff estimates. For the Dry Comal Creek Basin, the USGS used the intervening area for the Guadalupe River between Canyon Lake and New Braunfels (ID# 1685) as a partner area while the Blanco River watershed near Wimberley (ID# 1710) was used in the HDR estimates. The intervening area between Canyon Lake and New Braunfels lies primarily over the recharge zone which may produce lower estimates of potential runoff resulting in lower recharge estimates for the Dry Comal Creek Basin by the USGS.

In the Guadalupe River Basin, below Canyon Lake and above New Braunfels, recharge estimates were computed only by HDR. The USGS considers recharge to be insignificant in this reach. Although, the average recharge of 11,255 ac-ft/yr in the Guadalupe River Basin is not great, it can be a significant component of Edwards Aquifer recharge when aquifer levels are low.

HDR and USGS average annual recharge estimates for the Blanco River Basin, which includes the Blanco and Upper San Marcos River Basins, were significantly different. Average recharge of 37,758 ac-ft/yr estimated by the USGS was 41.5 percent lower than the average of 64,523 ac-ft/yr computed by HDR. During the 1947-56 drought period, recharge estimated by the USGS averaged 17,030 ac-ft/yr, some 53.0 percent less than the HDR average of 36,260 ac-ft/yr. The difference in the recharge estimates is partially attributable to HDR accounting for recharge enhancement due to existing SCS/FRS and to the selection of partner areas. Similarly to the Dry Comal Creek Basin, the USGS used the intervening area for the Guadalupe River between Canyon Lake and New Braunfels (ID# 1685) as one of their partner areas, while HDR used the Blanco River Watershed near Wimberley (ID# 1710). Utilizing the Guadalupe River intervening area which is over the recharge zone is believed to produce low potential runoff estimates resulting in lower recharge estimates by the USGS.

Figure 6-4 presents a comparison of the historical Edwards Aquifer recharge computed by the USGS and HDR for the Guadalupe - San Antonio River Basin and also for the Nueces River Basin, which was previously studied by HDR (Ref 14). Table 6-3



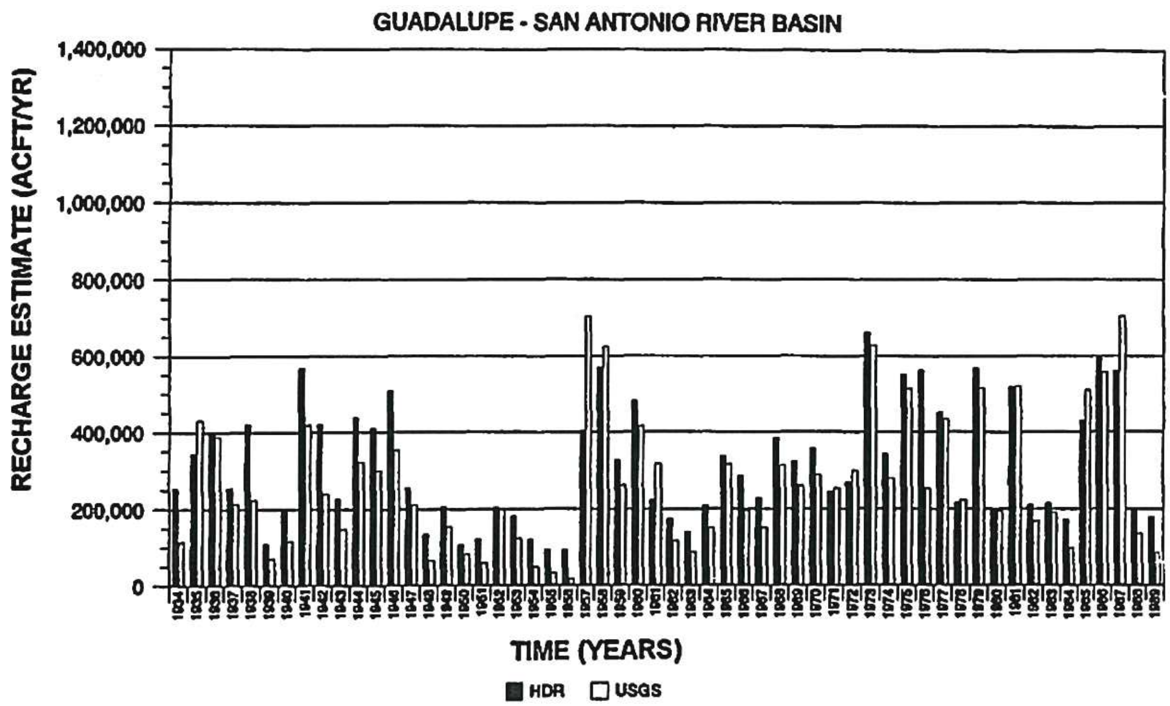


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FIGURE 6-4

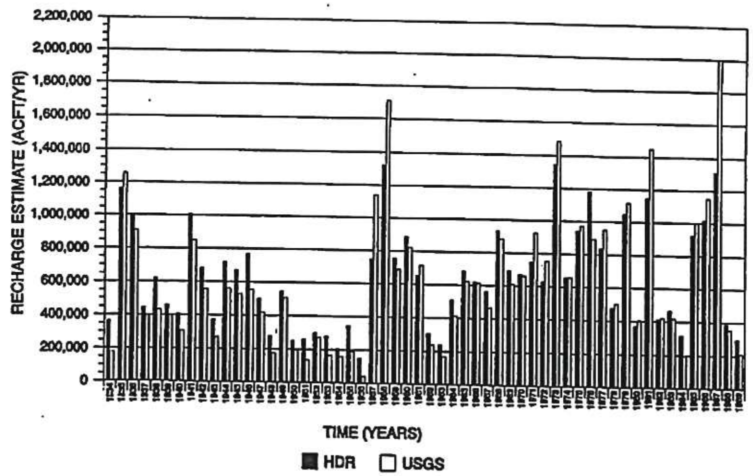
and Appendix I (Volume III) present the geographical distribution of estimated average annual recharge for various recharge basins within the Nueces, San Antonio, and Guadalupe River Basins. It is interesting to note that the recharge estimated by HDR for the Nueces River Basin proved to be consistently lower than the recharge reported by the USGS. This was also the case in the westernmost watershed of the Guadalupe - San Antonio River Basin (Medina River). However, in the eastern watersheds, the HDR recharge estimates were substantially higher than the USGS estimates.

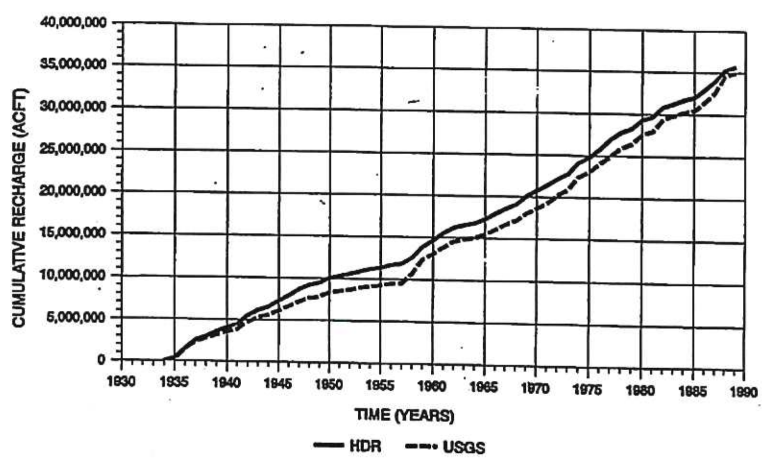
The modified geographical distribution of historical recharge reflected in the HDR estimates could have a significant effect on calibration of existing Edwards Aquifer models. The Texas Water Development Board (TWDB) used the HDR recharge estimates instead of the USGS estimates in various simulations to assess the effects of these new recharge estimates might have on the predictive capability of the TWDB Edwards Aquifer Model. Preliminary comparisons of simulated versus actual Bexar County monitoring well (J-17) levels and Comal and San Marcos springflows obtained from the TWDB model using the HDR recharge estimates generally show improved correlation as compared to simulations using the USGS recharge estimates. Additional improvement in simulated versus actual performance would be expected if the TWDB model were re-calibrated using the new recharge estimates.

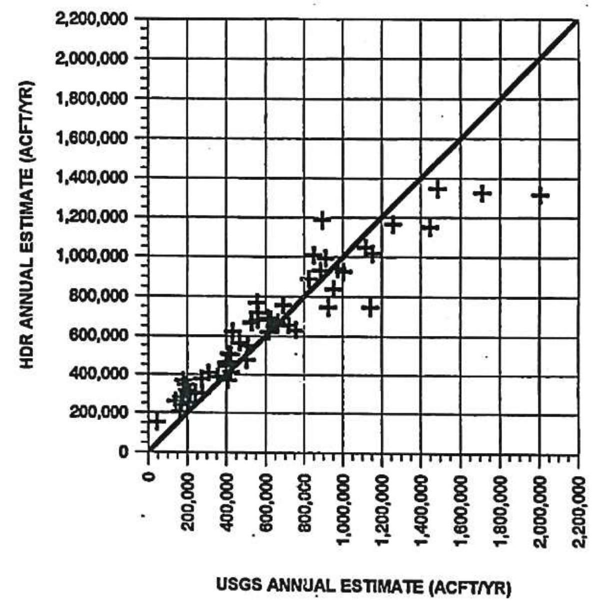
Table 6-3
Summary of Historical Edwards Aquifer Recharge by Basin

River Basin	Recharge Basin	HDR Recharge Estimate (Ac-Ft/Yr)	USGS Recharge Estimate (Ac-Ft/Yr)	Difference (Ac-Ft/Yr)	Percent Difference
Nueces	1. Nueces - W. Nueces	88,744	104,509	15,765	17.8%
	2. Frio - Dry Frio	111,739	117,454	5,715	5.1%
	3. Sabinal	32,581	38,307	5,726	17.6%
	4. Between Sabinal & Medina	92,998	97,404	4,406	4.7%
	SUBTOTAL	326,062	357,674	31,612	9.7%
San Antonio	5. Medina	41,833	60,780	18,947	45.3%
	6. Between Medina & Cibolo	88,274	67,705	-20,569	-23.3%
	7. Cibolo - Dry Comal	110,139	104,045	-6,094	-5.5%
	SUBTOTAL	240,246	232,530	-7,716	-3.2%
Guadalupe	8. Guadalupe	11,255	0	-11,255	-100.0%
	9. Blanco	64,523	37,758	-26,765	-41.5%
	SUBTOTAL	75,778	37,758	-38,020	-50.2%
	TOTAL	642,086	627,962	-14,124	-2.2%

Figure 6-5 presents three comparisons of total recharge to the Edwards Aquifer, including both the Nueces and Guadalupe - San Antonio River Basins. This comparison shows that the previous USGS estimate of about 628,000 ac-ft/yr for the entire aquifer is about two percent lower than the estimate of about 642,000 ac-ft/yr computed by HDR. However, for individual watersheds in the eastern sections of the aquifer, the differences are much more significant with the largest difference occurring in the Guadalupe and Blanco River Basins where the average USGS recharge estimate is about 50 percent less than the HDR estimate. Considering the proximity of these eastern watersheds to Comal and San Marcos Springs, the disparate recharge estimates could have a significant effect on efforts







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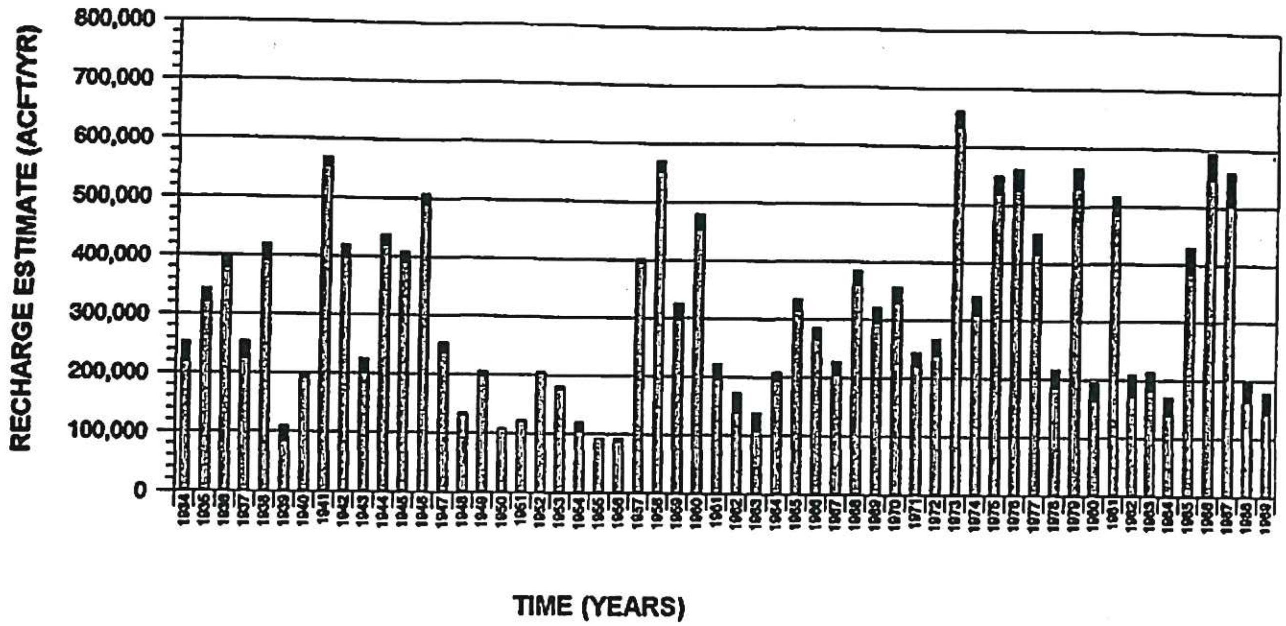
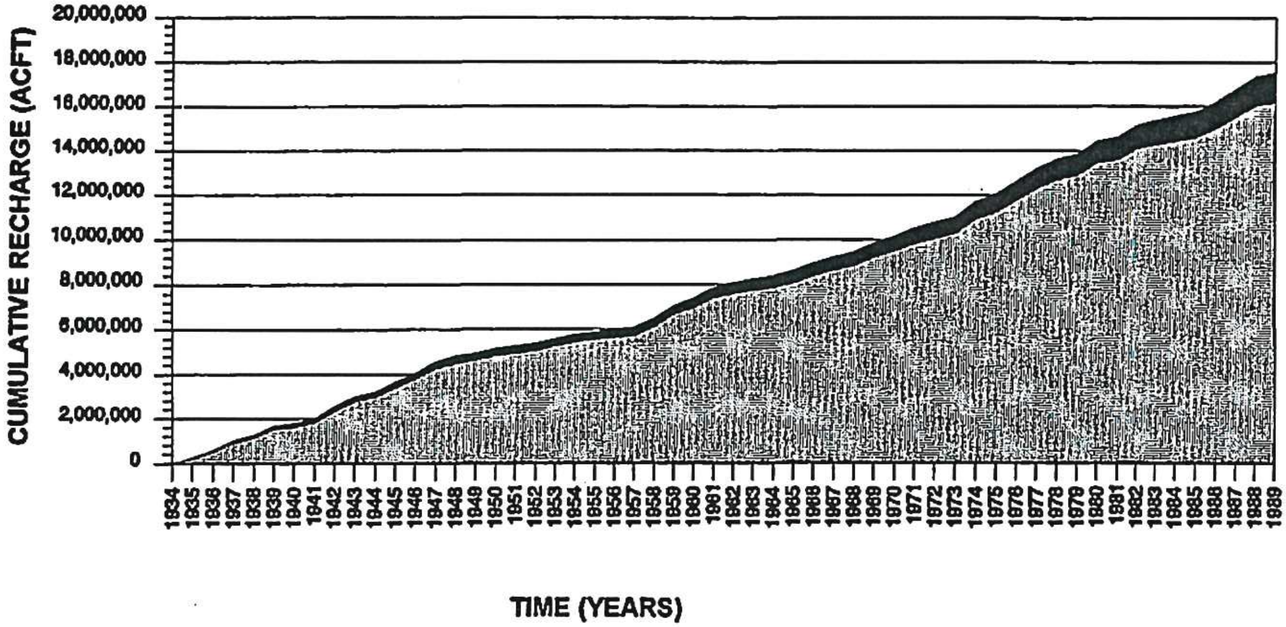
COMPARISON OF HISTORICAL EDWARDS AQUIFER RECHARGE

FIGURE 6-5

to accurately predict springflows. Overall, the USGS annual recharge estimates are lower than the estimates computed by HDR for dry and average years; however, for wet years, the USGS estimates are significantly higher than the HDR estimates.

Throughout the historical period, various reservoir structures have been constructed in the Guadalupe - San Antonio River Basin atop the Edwards Aquifer recharge zone which have enhanced the natural recharge to the aquifer. These structures include Medina Lake (constructed in 1911), San Geronimo Creek Dam, and various SCS Flood Retardation Structures (SCS/FRS) in the Salado Creek, Dry Comal Creek and Upper San Marcos River (including York Creek) watersheds. An estimate of the natural recharge to the Edwards Aquifer in the Guadalupe - San Antonio River Basin was developed in order to approximate the effects of these structures. The average annual natural recharge in the Guadalupe River Basin is estimated to be about 291,000 ac-ft as compared to the historical recharge of about 316,000 ac-ft, an 8.6 percent increase. Figure 6-6 traces the annual and cumulative historical recharge in the Guadalupe - San Antonio River Basin for the 1934-89 period and identifies the portion attributable to man-made structures in existence at the time.





NATURAL RECHARGE

HISTORICAL RECHARGE ENHANCEMENT

HDR

HDR Engineering, Inc.

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

COMPARISON OF NATURAL AND HISTORICAL EDWARDS AQUIFER RECHARGE

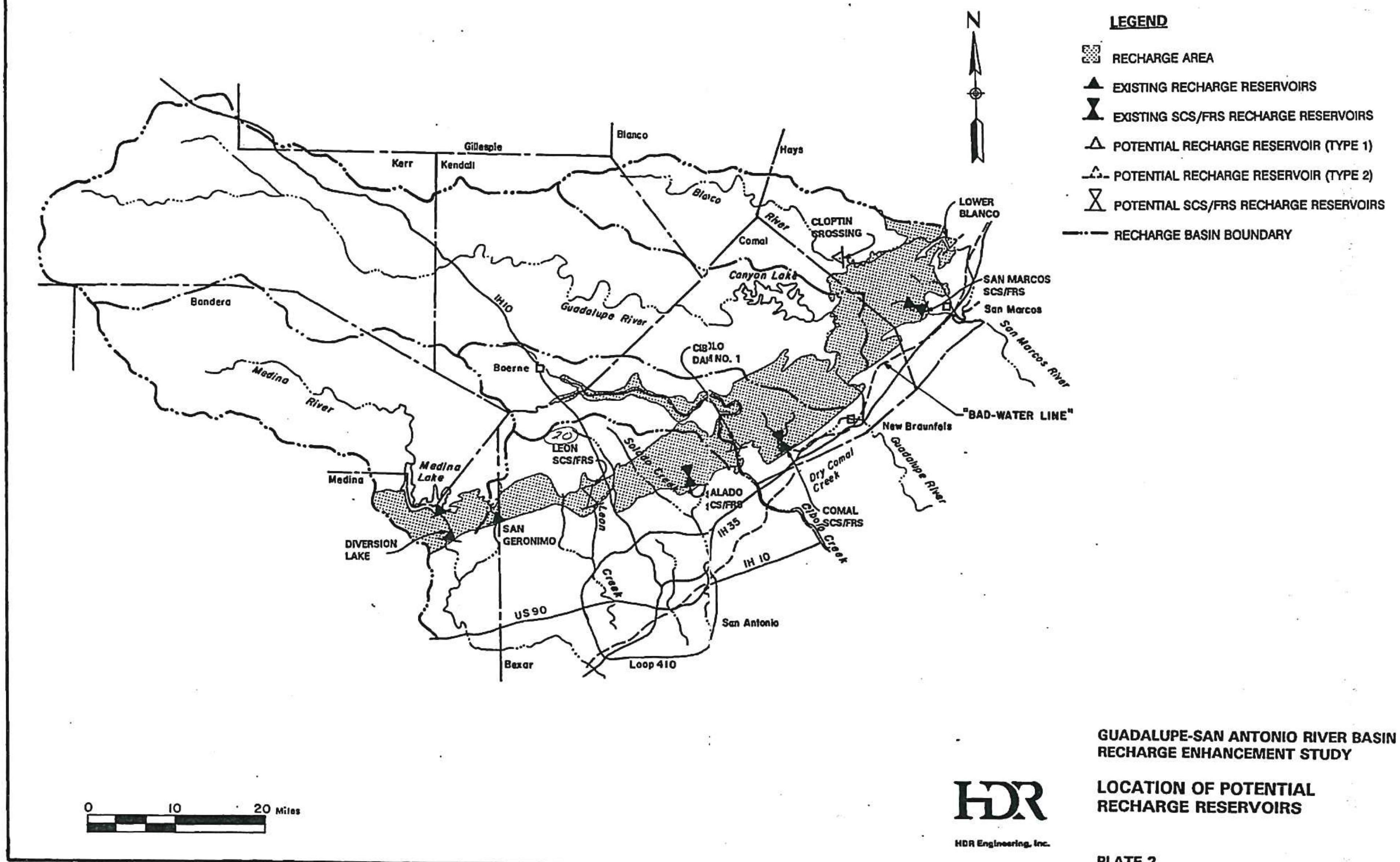
FIGURE 6-6

7.0 POTENTIAL RECHARGE ENHANCEMENT PROJECTS

7.1 Identification of Potential Projects

The approximate locations of all potential recharge reservoirs and existing reservoirs which contribute to the recharge of the Edwards Aquifer in the Guadalupe - San Antonio River Basin are shown in Plate 2. Although the Cloptin Crossing and Cibolo Dam No. 1 projects have been identified and examined in previous studies (Refs. 36 and 8, respectively), other potential recharge reservoirs were sited in the course of this study without detailed consideration of economic, geologic, environmental, or other factors of human interest. The express purpose of the projects selected for analysis in this study was the determination of the theoretical maximum additional recharge attainable. The reader is cautioned that this study was performed to assess the potential for recharge enhancement in the Guadalupe - San Antonio River Basin subject to the current state of water supply development and without regard for proposed water resource developments or environmental needs. Any use of the results of this study should be appropriately qualified in accordance with the following abbreviated list of factors, each of which, when applied, may serve to reduce the amount of recharge enhancement potential reported herein:

- Smaller projects dictated by economics;
- Water requirements for more valuable supply alternatives;
- Water requirements for environmental needs;
- Reuse of treated wastewater effluent;
- Limited recharge enhancement during severe drought;
- Site geology and/or regional hydrogeology; and



GUADALUPE-SAN ANTONIO RIVER BASIN RECHARGE ENHANCEMENT STUDY

LOCATION OF POTENTIAL RECHARGE RESERVOIRS

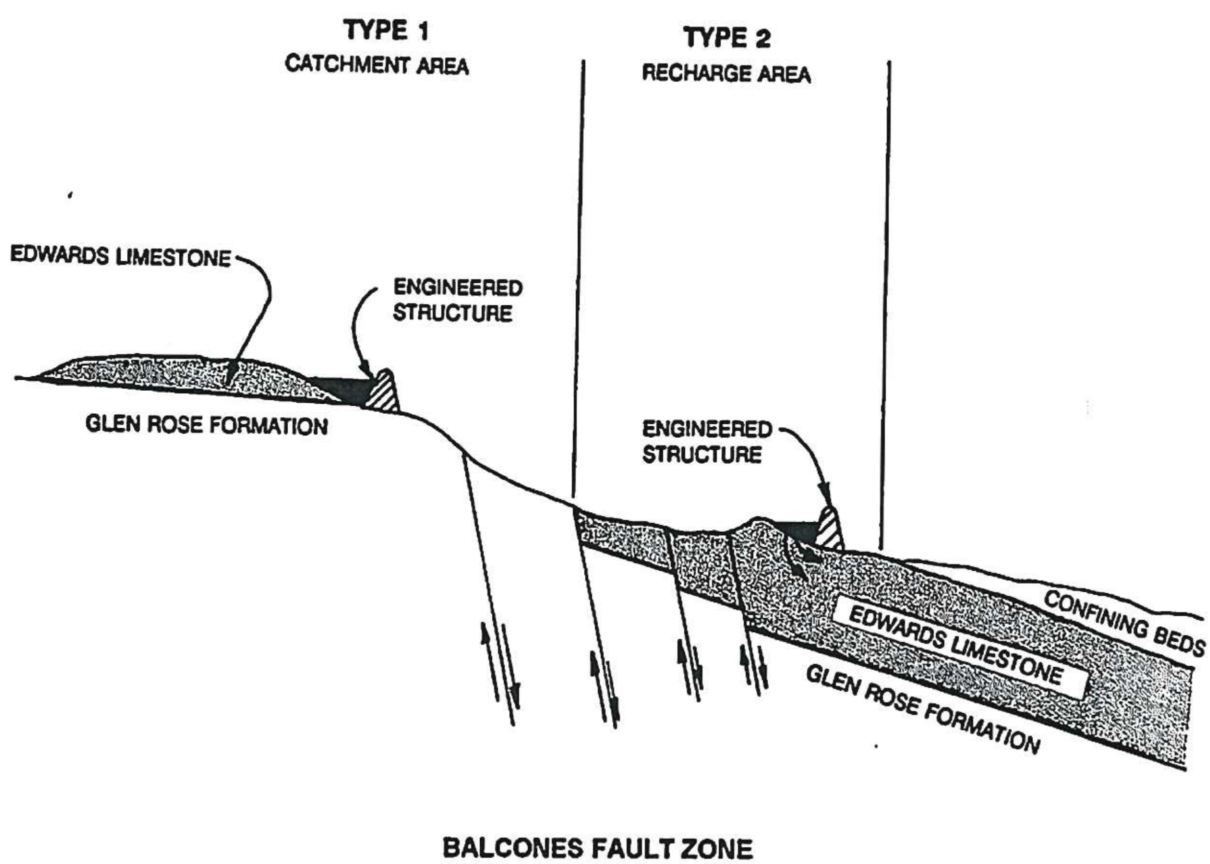
PLATE 2

- Location of recharge enhancement relative to demand centers and/or springs.

The effect of each of these factors on recharge enhancement potential may be measured in subsequent studies when suitable criteria for the application of each is established.

The two general types of recharge reservoirs considered are illustrated in Figure 7-1. Type 1 or "catch and release" reservoirs are located upstream of the recharge zone and are operated to release water at the maximum recharge rate of the downstream channel. Carryover storage from one month to the next is frequent in Type 1 reservoirs so net evaporation losses are included in the simulation of reservoir contents. Cloptin Crossing Reservoir is the only Type 1 project considered in this study. Type 2 or "direct percolation" reservoirs are located within the recharge zone and recharge directly through the bottom of the reservoir. For smaller Type 2 projects, the entire storage volume will usually drain within a period of less than one month and evaporation losses are not calculated. Cibolo Dam No. 1 and Lower Blanco Reservoir are the only Type 2 projects considered individually in this study. Due to relatively low natural recharge rates along the Blanco River, direct diversions from either the Cloptin Crossing or Lower Blanco Reservoir for injection to the aquifer and/or transfer to the adjacent upper San Marcos River watershed were modelled in order to more efficiently recharge water impounded in these reservoirs. Since the Lower Blanco Reservoir will normally have carryover storage, net evaporation losses were calculated.

Existing Soil Conservation Service Flood Retardation Structures (SCS/FRS) constructed in the recharge zone, exhibit characteristics of both Type 1 and Type 2



GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

TYPES OF RECHARGE RESERVOIRS

HDR Engineering, Inc.

FIGURE 7-1

reservoirs in that both controlled releases and direct percolation serve to drain storage which has been temporarily impounded. In this study, SCS/FRS reservoirs are grouped by watershed for calculation of recharge, and net evaporation losses are assumed negligible due to the rapid rate at which storage is typically evacuated from these reservoirs. Analyses of hydrologic data from the Salado Creek and Dry Comal Creek watersheds indicates that, on the average, approximately 100 percent and 70 percent of the water stored in the normal and active pools, respectively, contributes to recharge. If the recharge characteristics of the SCS/FRS were not incorporated in their original design, it is possible that restriction and/or closure of reservoir outlets could enhance recharge without adversely affecting the flood control function of these projects.

7.2 Scenarios and Assumptions

Potential recharge enhancement projects considered in this study have been generally classified and grouped into "Structural" and/or "Operational" programs. The various potential recharge enhancement projects have been classified and grouped in this way simply for organized presentation in this report. Projects classified as "Structural" involve the development of additional storage through new reservoir construction, while those classified as "Operational" involve modification of existing structures, acquisition of existing water rights, or re-activation of a project found to be economically unfeasible. Structural recharge enhancement projects analyzed include the following:

- Enlargement of the existing San Geronimo Creek Recharge Dam and/or development of additional storage upstream.
- Development of a program of small SCS/FRS in the Leon, Helotes, and Government Creek watersheds similar to that in the Salado Creek watershed.

- Cibolo Dam No. 1 on Cibolo Creek near Selma.
- One additional SCS/FRS in the Dry Comal Creek watershed.
- Lower Blanco project on the Blanco River near Kyle.

Operational recharge enhancement projects analyzed include the following:

- Acquisition of irrigation rights at Medina and Diversion Lakes for diversion and injection to the Edwards Aquifer.
- Modification or closure of SCS/FRS outlets in the Salado Creek, Dry Comal Creek, and upper San Marcos River watersheds.
- Cloptin Crossing project on the Blanco River near Wimberley.

Potential recharge enhancement with the Structural Program in place was calculated subject to two water rights and three Edwards Aquifer pumpage/springflow scenarios. The two water rights scenarios include full use of permitted water rights and reported use for 1988. Simulations under the Full Water Rights Scenario are based on the following assumptions:

- All rights and contracts divert full authorized amounts.
- Permitted annual diversions and contractual obligations from Canyon Lake total 50,000 ac-ft.
- Flow requirement of 600 cfs at Lake Dunlap for hydroelectric power generation.
- Annual consumptive use (forced evaporation) at Braunig, Calaveras, and Coleto Creek Lakes based on estimated full potential power generation.
- Return flows in each stream segment equal to those reported for 1988.

Simulations under the 1988 Water Usage Scenario are based on the following assumptions:

- All rights and contracts divert amounts reported for 1988. Diversion and storage rights associated with Applewhite Reservoir and the Leon Creek Diversion are excluded from this scenario.

- Permitted annual diversions and contractual obligations from Canyon Lake total 50,000 ac-ft.

- Flow requirement of 0 cfs at Lake Dunlap assuming full subordination of hydroelectric power generation.

- Annual consumptive use (forced evaporation) at Braunig, Calaveras, and Coleto Creek Lakes equal to that reported for 1988.

- Return flows in each stream segment equal to those reported for 1988.

The three Edwards Aquifer pumpage/springflow scenarios considered in this study assumed fixed annual use of water directly from the aquifer totalling 250,000 ac-ft, 400,000 ac-ft, or 450,000 ac-ft. With the assistance of the TWDB, monthly springflow sequences were calculated for Comal, San Marcos, San Antonio, and San Pedro Springs utilizing their model of the Edwards Aquifer. The TWDB modified the Edwards Aquifer model in order to include HDR estimates of historical recharge in both the Nueces and Guadalupe - San Antonio River Basins and to estimate aquifer discharge to the Guadalupe River near Hueco Springs.

7.3 Structural Program

The results of recharge enhancement calculations for the Structural Program are summarized in Tables 7-1 and 7-2 for long-term average and drought conditions, respectively. Long-term average (1934-89) Guadalupe - San Antonio River Basin recharge enhancement due to the listed new reservoirs totalled approximately 48,300 ac-ft/yr (an

Table 7-1
Recharge Enhancement with Structural Program for Average Conditions (1934-89)

Recharge Basin	New Reservoirs	Maximum Storage (Ac-Ft)	Historical[1] Average Annual Recharge (Ac-Ft/Yr)		Recharge Enhancement With Structural Program (Ac-Ft/Yr)[3]: Pumpage Scenario 1 250,000 Ac-Ft/Yr		Pumpage Scenario 2 400,000 Ac-Ft/Yr		Pumpage Scenario 3 450,000 Ac-Ft/Yr	
			Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage
5) Medina River			40,610	42,250						
6) Area between Medina River and Cibolo Creek			85,550	85,550						
	San Geronimo	3,500			1,715	3,550	1,715	3,550	1,715	3,550
	Leon Creek FRS[2]	25,200			5,230	6,120	5,205	6,120	5,205	6,120
7) Cibolo Creek and Dry Comal Creek			113,965	114,300						
	Cibolo Dam	10,000			8,485	8,520	8,485	8,520	8,485	8,520
	Dry Comal FRS	2,075			1,335	1,335	1,335	1,335	1,335	1,335
8) Guadalupe River			11,255	11,255						
9) Blanco River			68,135	68,295						
	Lower Blanco	35,230			31,610	31,715	31,515	31,650	31,495	31,640
Recharge Enhancement (Ac-Ft/Yr)[3]					48,375	51,240	48,255	51,175	48,235	51,165
Total Recharge (Ac-Ft/Yr)			319,515	321,650	367,890	372,890	367,770	372,825	367,750	372,815
Percent Increase in Historical[1] Recharge					15.1%	15.9%	15.1%	15.9%	15.1%	15.9%
Total Spring Flow (Ac-Ft/Yr)			340,850		382,815		264,925		226,960	

Notes:
1) Historical Recharge is adjusted for existing structures and includes Medina Lake, San Geronimo Dam, and SCS/FRS programs in place for the entire period.
2) Leon Creek FRS includes an SCS/FRS program in the Leon Creek, Helotes Creek, and Government Creek watersheds.
3) Development of these projects will likely require compromises in size, location, mitigation of wildlife habitat, and other factors which may reduce the actual recharge enhancement attainable relative to the theoretical amounts reported herein.

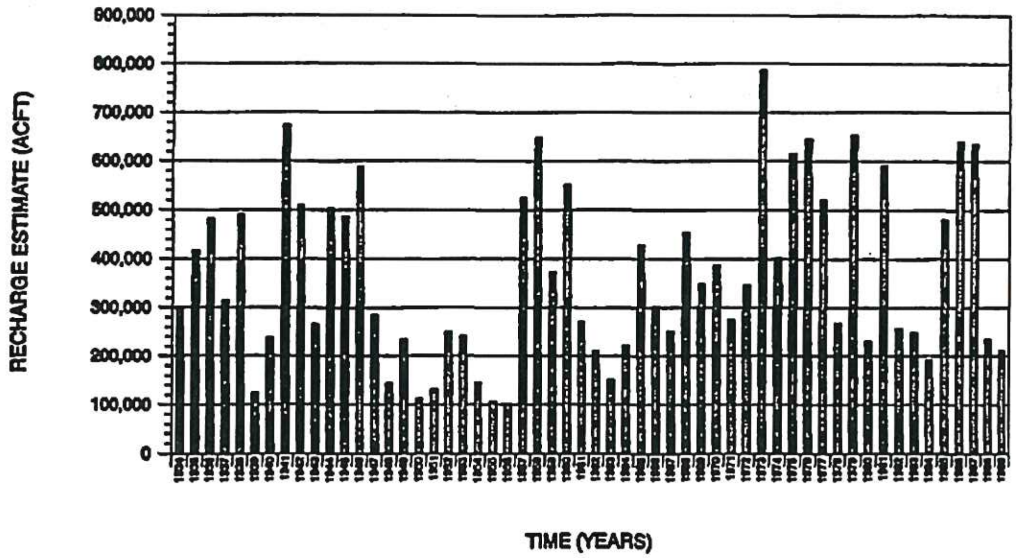
Table 7-2
Recharge Enhancement with Structural Program for Drought Conditions (1947-56)

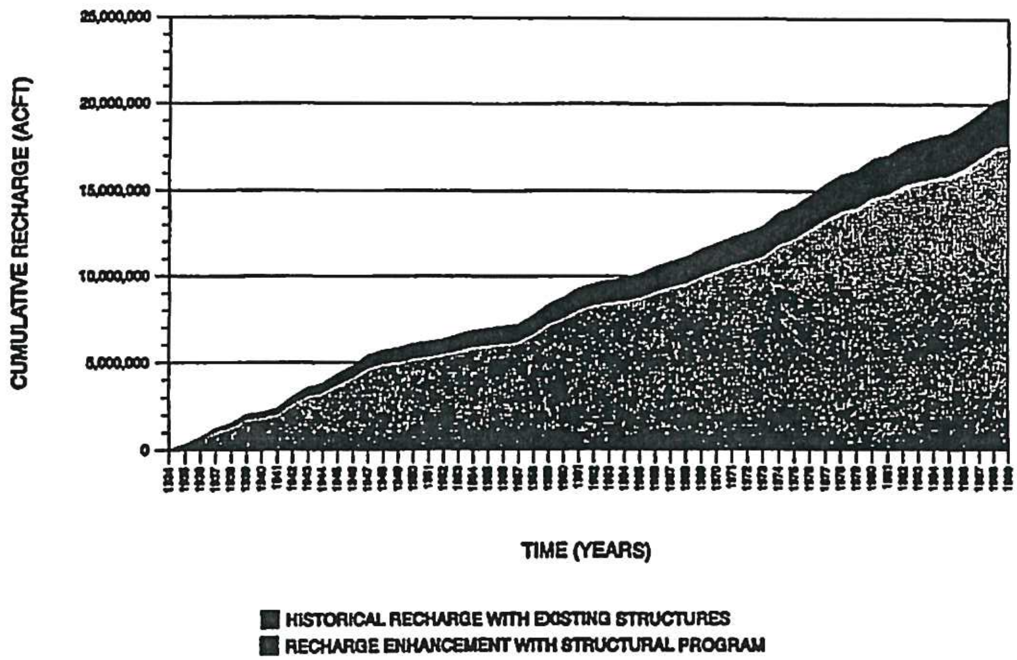
Recharge Basin	New Reservoirs	Maximum Storage (Ac-Ft)	Historical[1] Average Annual Recharge (Ac-Ft/Yr)		Recharge Enhancement With Structural Programs (Ac-Ft/Yr)[3]					
					Pumpage Scenario 1 250,000 Ac-Ft/Yr		Pumpage Scenario 2 400,000 Ac-Ft/Yr		Pumpage Scenario 3 450,000 Ac-Ft/Yr	
			Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage	Full Water Rights	1988 Water Usage
5) Medina River			11,755	12,370						
6) Area between Medina River and Cibolo Creek			33,705	33,705						
	San Geronimo	3,500			560	785	560	785	560	785
	Leon Creek FRS[2]	25,200			1,950	2,395	1,815	2,395	1,815	2,395
7) Cibolo Creek and Dry Comal Creek			52,735	52,990						
	Cibolo Dam	10,000			1,265	1,265	1,265	1,265	1,265	1,265
	Dry Comal FRS	2,075			520	525	520	525	520	525
8) Guadalupe River			17,595	17,595						
9) Blanco River	Lower Blanco	35,230	37,355	37,725	19,850	20,105	19,515	19,850	19,465	19,835
Recharge Enhancement (Ac-Ft/Yr)[3]					24,145	25,075	23,675	24,820	23,625	24,805
Total Recharge (Ac-Ft/Yr)			153,145	154,385	177,290	179,460	176,820	179,205	176,770	179,190
Percent Increase in Historical[1] Recharge					15.8%	16.2%	15.5%	16.1%	15.4%	16.1%
Total Springflow (Ac-Ft/Yr)			230,970		203,800		96,980		66,425	

Notes:
1) Historical Recharge is adjusted for existing structures and includes Medina Lake, San Geronimo Dam, and SCS/FRS programs in place for the entire period.
2) Leon Creek FRS includes an SCS/FRS program in the Leon Creek, Helotes Creek, and Government Creek watersheds.
3) Development of these projects will likely require compromises in size, location, mitigation of wildlife habitat, and other factors which may reduce the actual recharge enhancement attainable relative to the theoretical amounts reported herein.

increase of 15.1 percent over the historical recharge) under the Full Water Rights Scenario and 51,200 ac-ft/yr (an increase of 15.9 percent over the historical recharge) under the 1988 Water Usage Scenario. Drought average (1947-56) recharge enhancement due to the listed new reservoirs totalled approximately 24,000 ac-ft/yr (an increase of 15.7 percent over the historical recharge) under the Full Water Rights Scenario and 25,000 ac-ft/yr (an increase of 16.1 percent over the historical recharge) under the 1988 Water Usage Scenarios. As is apparent in Tables 7-1 and 7-2, recharge enhancement with new structures is not very sensitive to either the assumed Edwards Aquifer pumpage/springflow scenario (with minor exceptions) or to the degree of water rights utilization. Recharge enhancement is typically limited by the volumes of runoff reaching each site and the physical capability to impound and recharge that runoff. Figure 7-2 presents annual and cumulative recharge of the Edwards Aquifer in the Guadalupe - San Antonio River Basin for the 1934-89 period, illustrating the relative magnitudes of baseline historical recharge with existing structures and enhanced recharge with the Structural Program subject to the Full Water Rights Scenario. Figure 7-3 provides a similar illustration focusing on annual recharge estimates during the 1947-56 drought period. See Appendix J (Volume III) for summaries of annual recharge by control point.

It is interesting to note that about 65 percent of the potential additional recharge under average conditions and over 80 percent of the potential additional recharge under drought conditions is a result of the Lower Blanco Reservoir. This reservoir is the largest in the Structural Program with an assumed maximum storage volume of 35,230 ac-ft. Due to the limited recharge rates observed in this portion of the Blanco River, net evaporation losses were considered, and direct diversions to the upper San Marcos River watershed for injection or





NOTES:
PUMPAGE SCENARIO 3: 450,000 ACFT/YR
FULL WATER RIGHTS SCENARIO

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

STRUCTURAL PROGRAM
RECHARGE ENHANCEMENT

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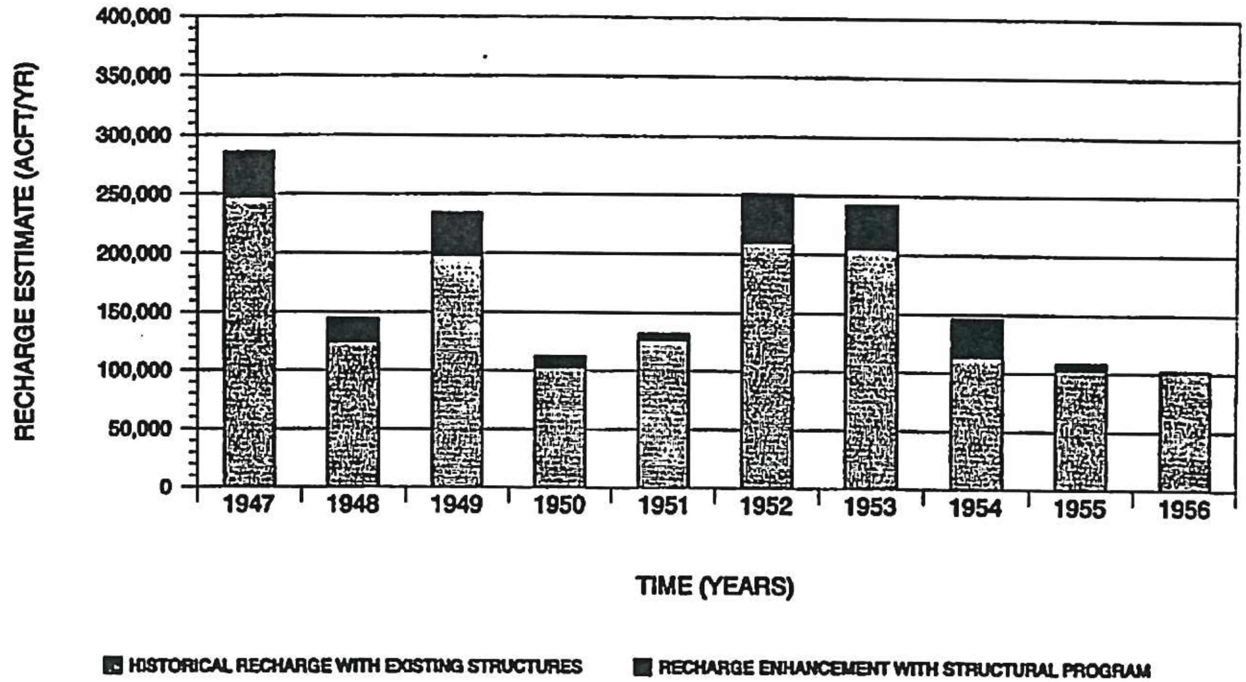
FIGURE 7-2



NOTES:
PUMPAGE SCENARIO 3: 450,000 ACFT/YR
FULL WATER RIGHTS SCENARIO

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GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

STRUCTURAL PROGRAM DROUGHT RECHARGE ENHANCEMENT

FIGURE 7-3

natural recharge were assumed, in order to obtain the full recharge enhancement potential at this site. The Lower Blanco Reservoir is also quite efficient with respect to minimization of losses to evaporation. The free water surface area exposed to evaporative losses at maximum storage for this project is one-third less than that for the same storage volume at the upstream Cloptin Crossing site.

Tables 7-1 and 7-2 also reveal the significant differences in recharge enhancement potential in the San Geronimo and Leon Creek watersheds subject to each water rights scenario. Long-term average combined recharge enhancement in these two watersheds totals about 6,920 ac-ft/yr (an increase of 8.1 percent over the historical recharge) under the Full Water Rights Scenario and 9,670 ac-ft/yr (an increase of 11.3 percent over the historical recharge) under the 1988 Water Usage Scenario. This difference of 2,730 ac-ft/yr in recharge enhancement is a result of the exclusion of Applewhite Reservoir and the Leon Creek Diversion from the 1988 Water Usage Scenario.

7.4 Operational Program

Potential recharge enhancement with the Operational Program added to the Structural Program was calculated subject to the Full Water Rights Scenario previously described and springflows resulting from a fixed annual pumpage of 450,000 ac-ft from the Edwards Aquifer. Simulations for the Operational Program include all projects from the Structural Program except the Lower Blanco Reservoir which would not likely be feasible in conjunction with the Cloptin Crossing project. Long-term average (1934-89) Guadalupe - San Antonio River Basin recharge enhancement under the Operational Program totalled approximately 123,060 ac-ft/yr (an increase of 38.5 percent over the historical recharge) and drought average (1947-56) recharge enhancement totalled approximately 66,300 ac-ft/yr (an increase of 43.3 percent over the historical recharge). Table 7-3 provides a side-by-side comparison of potential recharge enhancement in each recharge basin for the Operational Programs. Figure 7-4 presents annual and cumulative recharge of the Edwards Aquifer in the Guadalupe-San Antonio River Basin for the 1934-89 period, illustrating the relative magnitudes of baseline historical recharge with existing structures and enhanced recharge with the Operational Program subject to the Full Water Rights Scenario. Figure 7-4 provides a similar illustration, focusing on annual recharge estimates during the 1947-56 drought period.

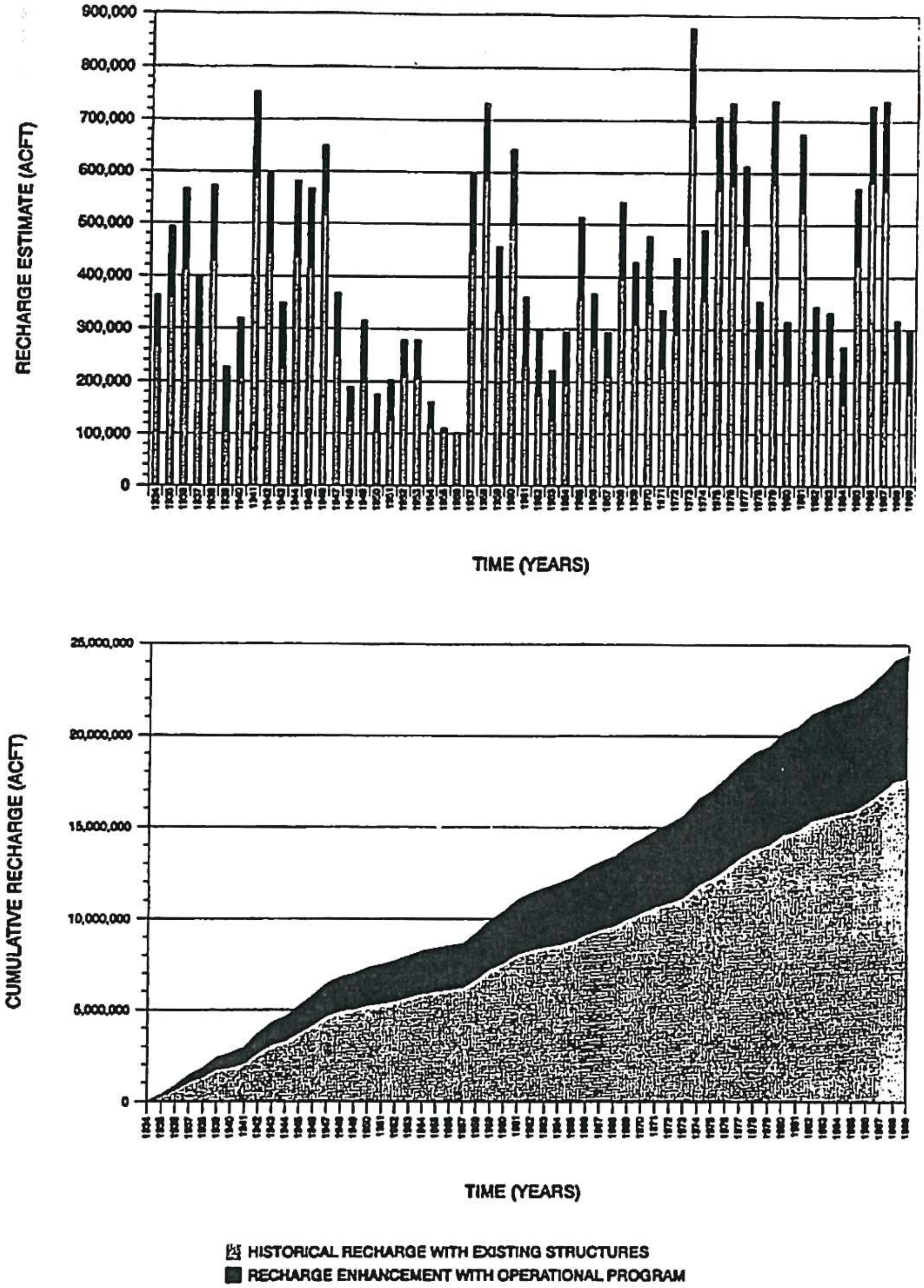
An average of approximately 55,395 ac-ft/yr (45.0 percent of the long-term average recharge enhancement under the Operational Program) could be available for diversion and injection to the Edwards Aquifer by acquisition of Medina and Diversion Lake irrigation rights totalling 67,830 ac-ft/yr. Such diversions were assumed to be accomplished on a monthly schedule similar to that for irrigation use so that historical recharge estimates for Medina and Diversion Lakes would be unaffected. Figure 7-6 summarizes annual quantities of surface water available for diversion under these rights and clearly illustrates that diversions would be severely limited during drought due to depletion of storage in Medina Lake. Although recharge enhancement averaged 20,935 ac-ft/yr during the 1947-56 drought period, water available during the 1954-56 period averaged only 3,735 ac-ft/yr.

The Cloptin Crossing Reservoir project was found to be economically unfeasible by the U.S. Army Corps of Engineers in 1979 and was placed in a deferred category (Ref 37). Simulations indicate, however, that is could provide significant recharge enhancement in both

Table 7-3
Recharge Enhancement with Structural and Operational Programs

Recharge Basin	Operational Projects	Historical[1] Recharge (Ac-Ft/Yr) Average (1934-89)	Historical[1] Recharge (Ac-Ft/Yr) Drought (1947-56)	Recharge Enhancement (Ac-Ft/Yr)[2,5] Structural Program Average (1934-89)	Recharge Enhancement Structural Program Drought (1947-56)	Recharge Enhancement Structural and Operational Programs[3] Average (1934-56)	Recharge Enhancement Structural and Operational Programs[3] Drought (1947-56)
5) Medina River		40,610	11,755				
	Irrigation Purchase					55,395	20,935
6) Area between Medina River and Cibolo Creek		85,550	33,705	6,920	2,375	6,920	2,375
	Salado Creek FRS					485	0
7) Cibolo Creek and Dry Comal Creek		113,965	52,735	9,820	1,785	9,820	1,785
	Dry Comal FRS					1,145	390
8) Guadalupe River		11,255	17,595				
9) Blanco River		68,135	37,355	31,495	19,465		
	Cloptin Crossing					48,275	40,690
	San Marcos FRS					1,020	125
Recharge Enhancement (Ac-Ft/Yr)[5]				48,235	23,625	123,060	66,300
Total Recharge (Ac-Ft/Yr)		319,515	153,145	367,750	176,770	442,575	219,445
Percent Increase in Historical[1] Recharge				15.1%	15.4%	38.5%	43.3%
Estuarine Inflow (Ac-Ft/Yr) and Percent Reduction[4]		1,548,395	514,065	-2.0%	-2.7%	-3.4%	-3.2%

Notes:
1) Historical Recharge is adjusted for existing structures and includes Medina Lake, San Geronimo Dam, and SCS/FRS programs in place for the entire period.
2) Recharge Enhancement based on Pumpage Scenario 3 (450,000 Ac-Ft/Yr) and Full Water Rights Scenario.
3) Includes all projects from the Structural Program except Lower Blanco Reservoir.
4) Estuarine inflows and percent reductions are based on flows at the Saltwater Barrier near Tivoli subject to Pumpage Scenario 3 (450,000 ac/ft-yr). Figures shown reflect no increase in return flows and/or springflows due to recharge enhancement.
5) Development of these projects will likely require compromises in size, location, mitigation of wildlife habitat, and other factors which may reduce the actual recharge enhancement attainable relative to the theoretical amounts reported herein.



NOTES:
PUMPAGE SCENARIO 3: 450,000 ACFT/YR
FULL WATER RIGHTS SCENARIO

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

HDR

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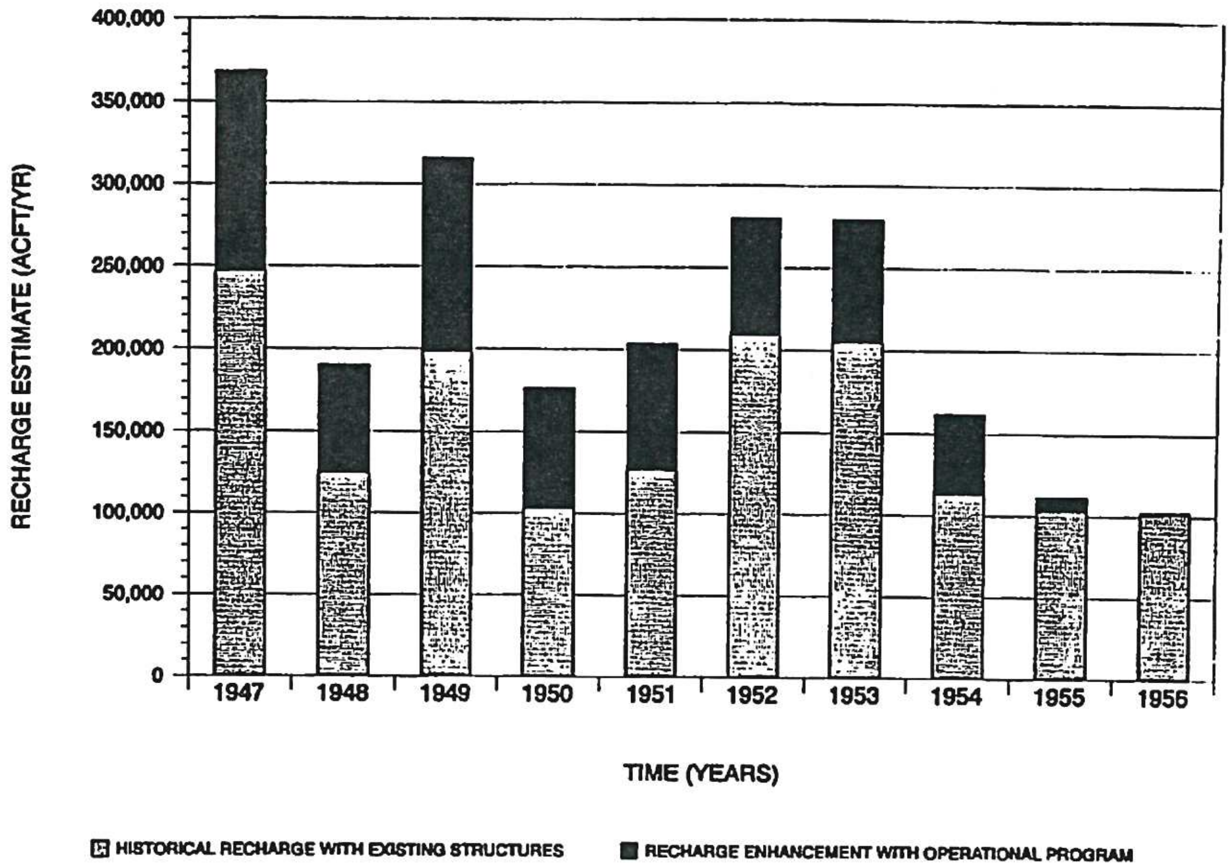
OPERATIONAL PROGRAM RECHARGE ENHANCEMENT

FIGURE 7-4



NOTES:
PUMPAGE SCENARIO 3: 450,000 ACFT/YR
FULL WATER RIGHTS SCENARIO

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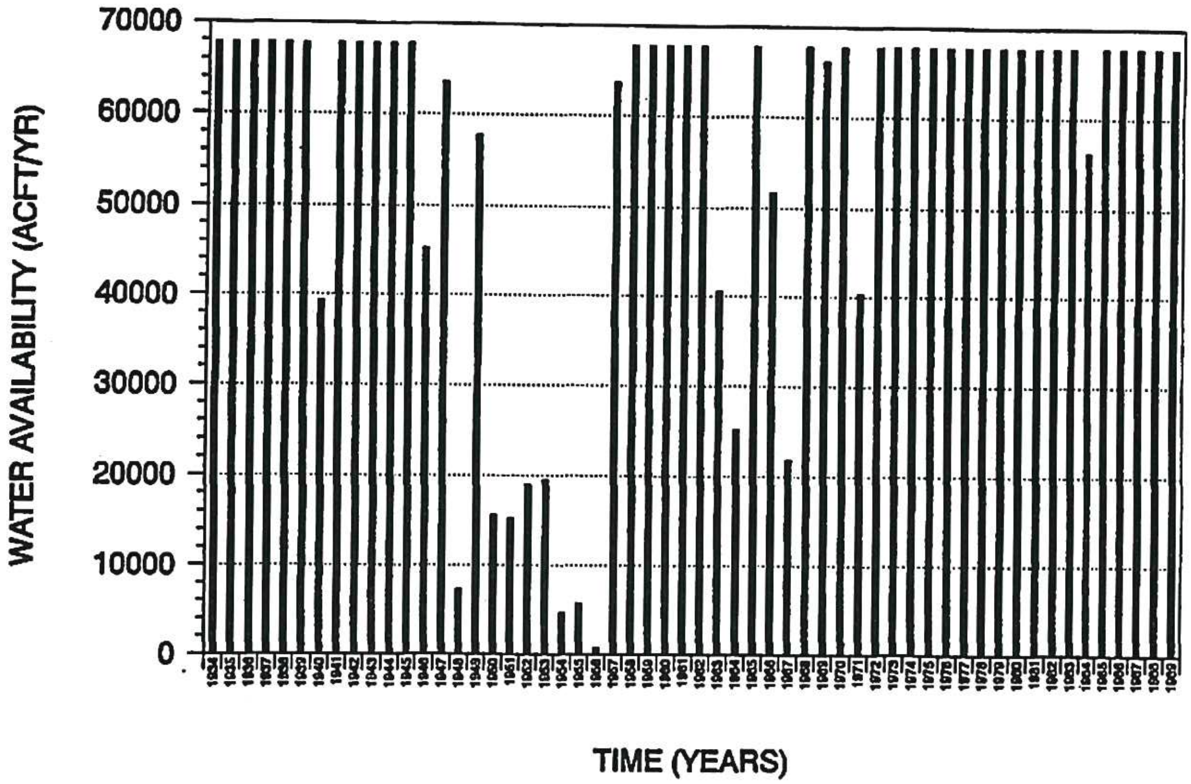
GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

OPERATIONAL PROGRAM DROUGHT RECHARGE ENHANCEMENT

FIGURE 7-5



IRRIGATION RIGHTS = 67,830 ACFT/YR

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

MEDINA AND DIVERSION LAKE WATER AVAILABILITY UNDER IRRIGATION RIGHTS

HDR Engineering, Inc.

FIGURE 7-6

average times and during severe drought periods. Comparing the Cloptin Crossing Reservoir with the previously discussed Lower Blanco Reservoir reveals that the Cloptin Crossing Reservoir could provide 53 percent and 109 percent more recharge enhancement under average and drought conditions, respectively. However, the conservation storage of Cloptin Crossing Reservoir (283,400 ac-ft) is eight times that of the Lower Blanco Reservoir and the assumed diversion rate from Cloptin Crossing for injection to the Edwards Aquifer was more than four times that assumed for the Lower Blanco Reservoir. More detailed economic and hydrologic analyses will be necessary to evaluate the relative merits of these alternative projects.

As indicated in Table 7-3, an additional measure of recharge enhancement could be obtained through closure of SCS/FRS outlets in the watersheds where SCS/FRS programs are in place. It is estimated that, on the average, the existing SCS/FRS programs increase recharge in the Guadalupe - San Antonio River Basin by 12,760 ac-ft/yr (4.0 percent) over that which would occur naturally. Closure of SCS/FRS outlets in the Salado Creek, Dry Comal Creek (including the outlet of the additional SCS/FRS included in the Structural Program), and upper San Marcos River watersheds could contribute an additional 2,650 ac-ft/yr (0.8 percent) on the average. Further investigation of design assumptions and regulatory constraints associated with closing or modifying the outlets of existing SCS/FRS projects is necessary to assess feasibility.

8.0 WATER POTENTIALLY AVAILABLE AT SELECTED LOCATIONS

The Guadalupe - San Antonio River Basin Model was used to estimate monthly quantities of water potentially available at the following locations:

- San Marcos River Below the Blanco River Confluence;
- Guadalupe River Below the Comal River Confluence; and
- Canyon Lake.

Calculations were performed subject to two general scenarios selected to present the reasonable range of water potentially available during average and drought conditions without consideration of instream flow and/or estuarine inflow requirements:

Scenario 1: Full utilization of existing water rights based on springflows resulting from a fixed Edwards Aquifer pumpage rate of 450,000 ac-ft/yr. Water potentially available under this scenario is comparable to unappropriated flow.

Scenario 2: Utilization of existing water rights to the extent reported in 1988 based on springflows resulting from a fixed Edwards Aquifer pumpage rate of 250,000 ac-ft/yr. Diversion of water potentially available under this scenario implicitly assumes that it would be necessary to purchase existing water rights which were not used in 1988.

Average quantities of water potentially available which are reported herein are theoretical maximums and may be subject to significant reductions due to economic, environmental, structural, and political limitations.

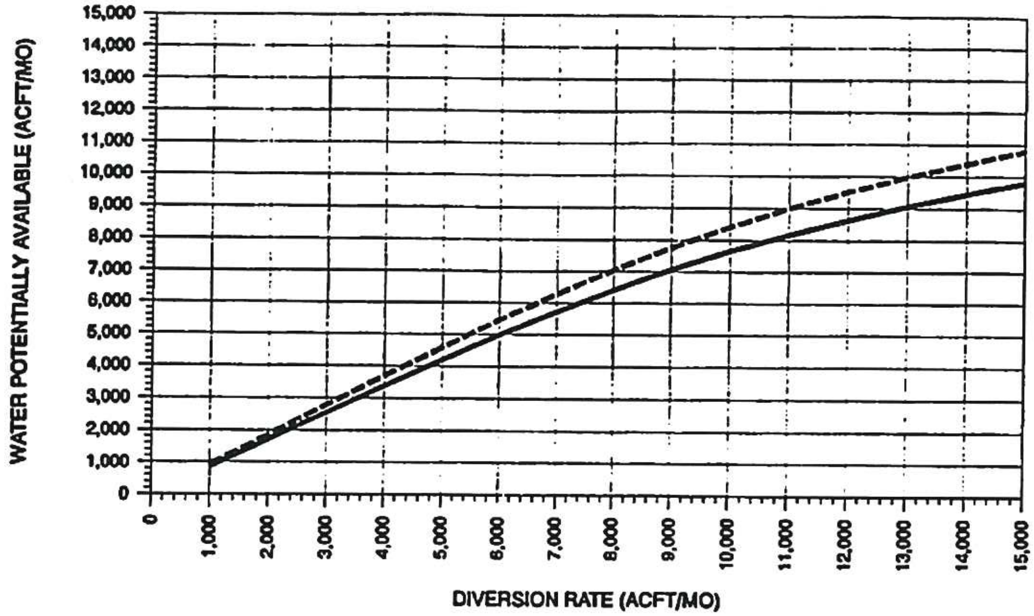
8.1 San Marcos River

Figure 8-1 presents estimates of water potentially available at the selected location on the San Marcos River based on diversion rates ranging from 1,000 ac-ft/month (17 cfs) to 15,000 ac-ft/month (250 cfs). Operating under Scenario 1 with a 6,000 ac-ft/month (100 cfs) diversion rate, for example, a long-term average of approximately 5,000 ac-ft/month (60,000 ac-ft/yr) and a drought average of approximately 2,750 ac-ft/month (33,000 ac-ft/yr) might be available. While increased quantities of water potentially available could be obtained under Scenario 2 or by increasing diversion rate, Figure 8-1 reveals that availability does not increase uniformly with diversion rate and does, in fact, begin to approach a maximum. Furthermore, it is important to note that there would be no water available at this location under either scenario approximately 13 percent and 45 percent of the time subject to average and drought conditions, respectively. Monthly summaries of theoretical maximum quantities of water potentially available under Scenarios 1 and 2 are included in Appendix K (Volume III).

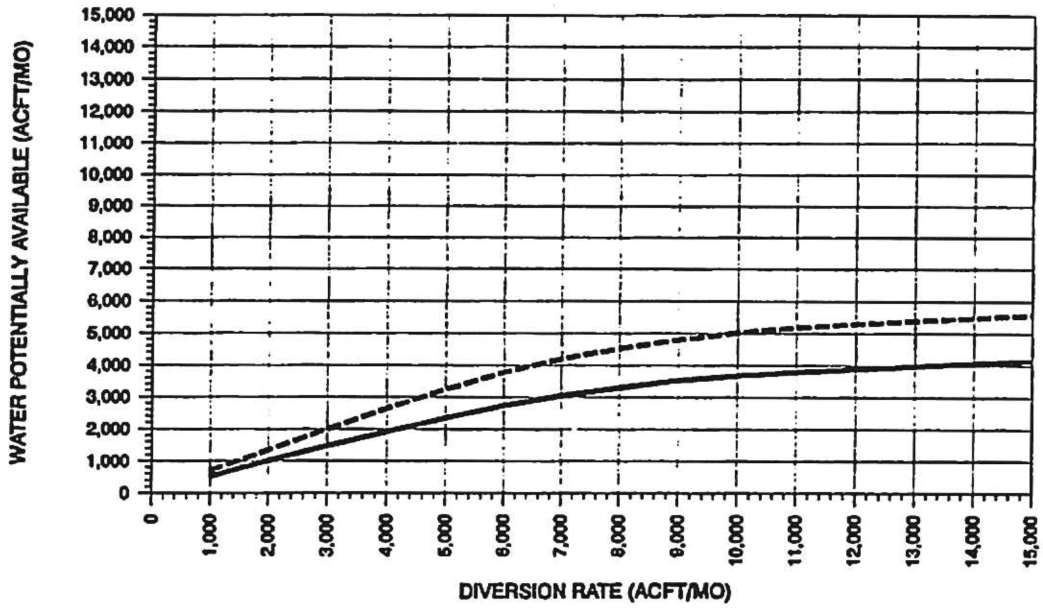
8.2 Guadalupe River

Figure 8-2 presents estimates of water potentially available on the Guadalupe River below the Comal River confluence based on diversion rates ranging from 1,000 ac-ft/month (17 cfs) to 15,000 ac-ft/month (250 cfs). Operating under Scenario 1 with a 6,000 ac-ft/month (100 cfs) diversion rate, a long-term average of only about 1,250 ac-ft/month (15,000 ac-ft/yr) and a drought average of only about 250 ac-ft/month (3,000 ac-ft/yr) might be available. Under this scenario, no water would be available at the selected location

SAN MARCOS RIVER BELOW THE BLANCO RIVER CONFLUENCE
AVERAGE CONDITIONS (1934-89)



SAN MARCOS RIVER BELOW THE BLANCO RIVER CONFLUENCE
DROUGHT CONDITIONS (1947-56)



—— SCENARIO 1: FULL WATER RIGHTS, PUMPAGE = 450,000 ACFT/YR

– – – SCENARIO 2: 1988 WATER USAGE, PUMPAGE = 250,000 ACFT/YR

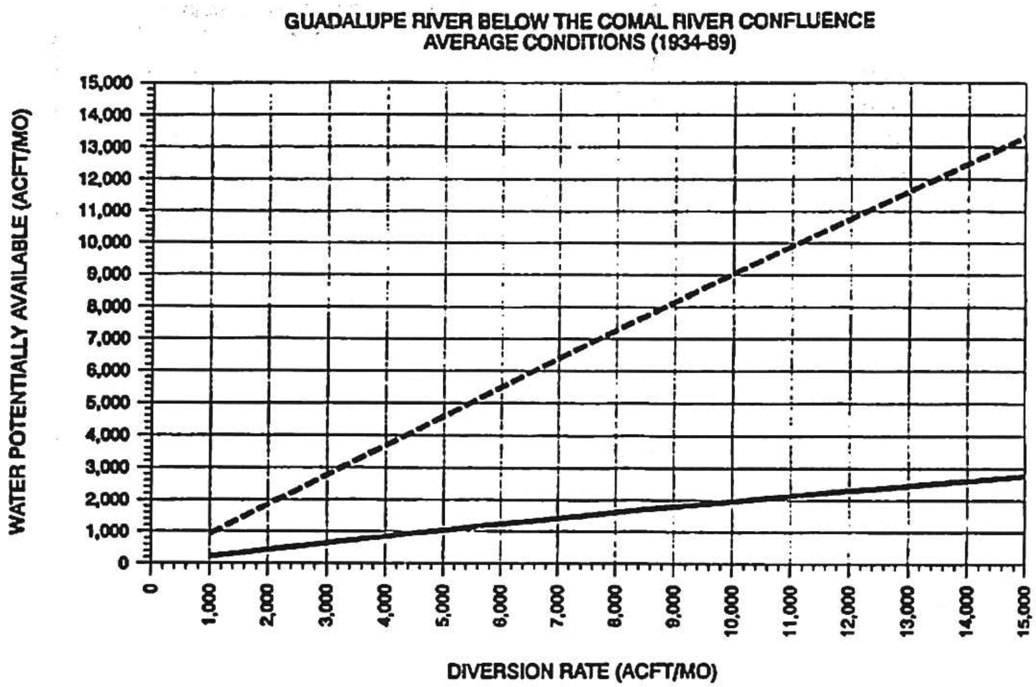
GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

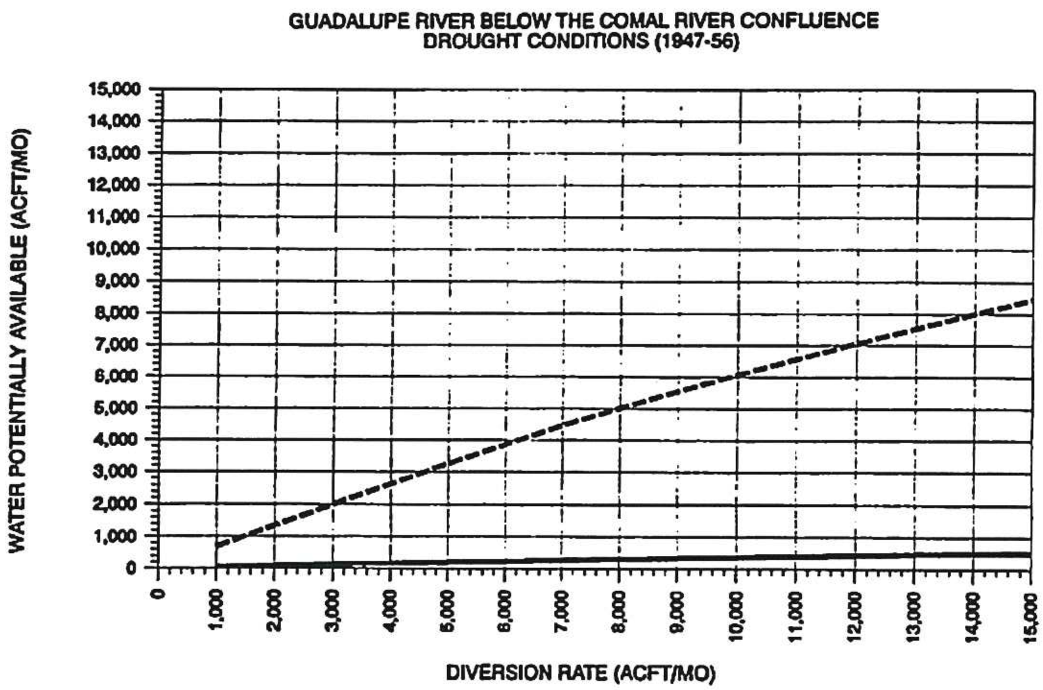
WATER POTENTAILLY AVAILABLE
SAN MARCOS RIVER

HDR

HDR Engineering, Inc.

FIGURE 8-1





——— SCENARIO 1: FULL WATER RIGHTS, PUMPAGE = 450,000 ACFT/YR
– – – SCENARIO 2: 1988 WATER USAGE, PUMPAGE = 250,000 ACFT/YR

HDR

HDR Engineering, Inc.

GUADALUPE-SAN ANTONIO RIVER BASIN
RECHARGE ENHANCEMENT STUDY

WATER POTENTAILLY AVAILABLE
GUADALUPE RIVER

FIGURE 8-2

between 78 percent and 95 percent of the time subject to average and drought conditions, respectively. For the same diversion rate under Scenario 2, however, about 5,500 ac-ft/month (66,000 ac-ft/yr) and 3,900 ac-ft/month (46,800 ac-ft/yr) might be available subject to average and drought conditions, respectively. Under Scenario 2, no water would be available at the selected location between 12 percent and 44 percent of the time subject to average and drought conditions, respectively. Estimates of water potentially available in the Guadalupe River are significantly more sensitive to assumptions regarding Edwards Aquifer pumpage/springflow and water rights utilization than are those for the San Marcos River. Monthly summaries of theoretical maximum quantities of water potentially available under Scenarios 1 and 2 are included in Appendix K (Volume III).

8.3 Canyon Lake

Development of estimates of water potentially available (unutilized firm yield) from Canyon Lake was substantially more complex than the estimation of water potentially available at selected stream locations. The added complexity is attributable to the complicated relationship between the firm yield of Canyon Lake and Edwards Aquifer pumpage and resulting springflows, subordination of hydroelectric rights, and losses in delivery of inflows passed through or storage released from Canyon Lake in fulfillment of downstream obligations. For the purposes of this study, utilization of Canyon yield is comprised of releases and direct diversions from the lake and is defined to be the difference between the volume necessary to meet senior water rights and the volume necessary to meet both senior water rights and contractual obligations. The GSA Model does not make releases from Canyon Lake storage to meet senior downstream water rights. Water potentially available or unutilized firm yield is, for purposes of this study, defined to be the annual difference between firm yield and utilization.

A previous study (Ref. 7) sponsored by the Guadalupe - Blanco River Authority (GBRA) indicates that the firm yield based on historical springflows, full water rights, and subordination of GBRA hydroelectric rights to 600 cfs is about 50,000 ac-ft/yr which is consistent with the permitted annual diversion from Canyon Lake. Operating under Scenario 1 and meeting all current contractual obligations (with the exception of make-up water for Coleto Creek Reservoir which was delivered as needed), utilization of Canyon firm yield was estimated to average approximately 30,500 ac-ft/yr with a maximum utilization of about 47,900 ac-ft in 1956 and a typical utilization of about 28,200 ac-ft/yr when no releases for Coleto Creek Reservoir were necessary. Hence, an average of approximately 19,500 ac-ft/yr is potentially available at Canyon Lake under the existing diversion right of 50,000 ac-ft/yr. Comparing contractual obligations which total about 25,000 ac-ft/yr (excluding Central Power & Light at Coleto Creek Reservoir) with the typical utilization of 28,200 ac-ft/yr indicates that, on the average, about 3,200 ac-ft/yr or 11 percent is lost in delivery. In the event of further subordination of GBRA hydroelectric rights, the firm yield of Canyon Lake would increase and additional quantities of water from Canyon Lake could become available.

9.0 CONCLUSIONS

Significant study findings and conclusions are as follows:

1) The potential for recharge enhancement estimated in this report is a theoretical maximum and, on more detailed review, will likely be subject to significant reductions due to economic, environmental, structural, and political limitations. When analyzed as a part of a total regional water resources program, there may be other types of water resource projects which provide greater benefits than some of the projects identified in this report.

2) Recharge of the Edwards Aquifer in the Guadalupe - San Antonio River Basin may be increased by an average of about 123,000 ac-ft/yr if all Structural and Operational projects identified in this report (with the exception of the Lower Blanco Reservoir) are implemented and all water rights are honored. This represents an increase of about 38.5 percent in the historical average recharge. Recharge during the 10-year drought period from 1947 through 1956 could be increased by about 66,300 ac-ft/yr or 43.3 percent of the historical average during this period.

3) If the Structural and Operational programs identified (with the exception of the Lower Blanco Reservoir) are fully implemented, inflows to the Guadalupe Estuary could be reduced by an average of about 53,200 ac-ft/yr. The construction of only the Structural Program (which includes the Lower Blanco Reservoir and excludes the Cloptin Crossing Reservoir) could reduce inflows by about 31,000 ac-ft/yr. These figures represent between 3.4 and 2.0 percent of the average annual flow of the Guadalupe and San Antonio Rivers into the Guadalupe Estuary. Note that these average estuarine inflow reductions do not reflect potential increases in return flow and/or springflow associated with recharge enhancement.

4) Estimates of recharge enhancement associated with the structural and operational programs are not very sensitive to the various aquifer pumpage/springflow scenarios or to the degree of water rights utilization. Recharge enhancement is typically limited by the volume of runoff reaching each site and the physical capability to impound and recharge that runoff.

5) Potentially significant quantities of water may be available in the San Marcos River below the Blanco River confluence, in the Guadalupe River below the Comal River confluence, and in Canyon Lake for recharge enhancement or other uses. Theoretical maximum quantities of water available have been presented in this report for a range of assumptions as to Edwards Aquifer pumpage/springflow and utilization of existing water rights. As water is not available at these locations in each and every month, storage would be required to sustain a firm supply.

6) Methods used in this study to calculate historical recharge to the Edwards Aquifer result in estimates that differ from previous estimates by the USGS. In particular, there are significant differences at Medina Lake and Diversion Lake (HDR estimates are lower), the area between the Medina River and Cibolo Creek (HDR estimates are higher), and the upper San Marcos River watershed (HDR estimates are higher). In addition, the methods used in this study show that significant recharge does occur in the Guadalupe River Basin where previous estimates by the USGS do not consider recharge in this basin.

10.0 RECOMMENDATIONS

The findings of this study indicate that recharge to the Edwards Aquifer may be substantially enhanced by the construction of additional recharge structures and/or changes in existing operational and institutional constraints. In order to determine whether these projects and/or operational changes are truly feasible and to quantify potential benefits to well yields and springflows, the following additional work is recommended:

1) Information developed in this study should be analyzed as a part of a total regional water resources program which compares the relative merits of recharge enhancement to other water supply options. After the role of recharge is determined in the regional water resources planning effort, selected recharge projects should be carried forward for additional detailed study.

2) The Texas Water Development Board model of the Edwards Aquifer should be recalibrated using the recharge values developed in this study and used to evaluate the various recharge options under consideration for the Nueces and Guadalupe - San Antonio River Basins to determine benefits to well yields and springflows.

3) Significant numbers of additional streamgages and raingages should be added to the hydrologic data collection network to more accurately calculate recharge in ungaged areas and to significantly improve the accuracy of recharge estimates in areas directly over the recharge zone. A state-of-the-art recharge calculation methodology for the Edwards Aquifer should be developed which utilizes the additional streamgages and raingages and incorporates appropriate elements of the USGS and HDR procedures. It is expected that consideration of these state-of-the-art recharge estimates will result in significant improvement in aquifer model calibration.

4) The TWDB Edwards Aquifer model and the surface water/recharge models of the Nueces and Guadalupe - San Antonio River Basins should be combined into one model to fully evaluate recharge enhancement options and to aid in the evaluation of various aquifer and surface water management alternatives.

5) Benefit/cost analyses of recharge projects (and/or operational changes) should be performed in detailed studies considering economic, environmental, geological, institutional, and structural feasibility of individual projects as well as combinations of projects.

6) Special hydrologic studies addressing the following specific items should be undertaken in support of improved recharge estimates:

- Field studies of Medina Lake and Diversion Lake to better understand and define relationships between reservoir levels and recharge and leakage rates;

- Field studies of water exchange rates between the Edwards Aquifer and the Guadalupe River downstream of Canyon Lake over a range of aquifer water levels;

- Refinement of firm yield estimates for Canyon Lake to include consideration of water delivery losses in conjunction with Edwards Aquifer pumpage/springflow scenarios and potential subordination of hydroelectric rights;

- Consideration of new geologic mapping of Bexar, Comal, and Hays Counties nearing completion by the USGS which should result in improved recharge zone definition and more accurate recharge basin drainage areas; and

- Investigation of the possibility of calculating historical total daily flow estimates (including flows which are not springflows) for the USGS San Marcos River springflow gage to provide more accurate historical recharge estimates for the upper San Marcos River watershed. This is similar to the procedure used at the USGS Comal River gage.

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APPENDIX "E"

Intensive Survey of Martinez Creek – Report IS-23 (Texas Department of Water Resources, June 1981)

INTENSIVE SURVEY OF MARTINEZ CREEK

IS-23

Prepared by the Texas Department of Water Resources
P. O. Box 13087, Capitol Station, Austin, Texas 78711

INTENSIVE SURVEY OF MARTINEZ CREEK

* Hydrology
* Field Measurements
* Water Chemistry

Prepared By

Donald D. Ottmers
Water Quality Assessment Unit

Texas Department of Water Resources

IS-23

June 1981

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INTENSIVE SURVEY
OF
MARTINEZ CREEK

INTRODUCTION

DIRECTIVE

This intensive survey was accomplished in accordance with the Texas Water Quality Act, Section 21.257, as amended in 1973. The report is to be used in developing and maintaining the State Water Quality Strategy required by regulations published in 40 CFR 35.1511-2 pursuant to Section 303(e) of the Federal Clean Water Act of 1977.

PURPOSE

The purpose of this intensive survey was to provide the Texas Department of Water Resources with a valid information source:

1. to determine quantitative cause and effect relationships of water quality;

2. to obtain data for updating water quality management plans, setting effluent limits, and, where appropriate, verifying the classifications of segments;

3. to set priorities for establishing or improving pollution controls; and

4. to determine any additional water quality management actions required.

LIST OF FIGURES

SUMMARY

Martinez Creek originates in North-Central Bexar County and flows eastward to discharge into Cibolo Creek at the Bexar-Guadalupe County line. Stream flow is low and intermittent in the upper reaches and is in fact contained by a Soil Conservation Service flood control dam across the stream about 15 stream miles upstream of the Cibolo Creek confluence. Only a trickle of water passes through the dam so flow in the lower reaches essentially originates with the discharge from the San Antonio River Authority Martinez Creek Sewage Treatment Plant located immediately downstream of the dam. Martinez Creek is quite deep at the point of discharge and stream velocity is very low. A manmade pond approximately one surface acre in size located a short distance downstream of the plant, further impedes stream flow. Downstream of this pond the creek is narrow and shallow and velocity is much higher. Two main tributaries, Salatrillo Creek and Woman Hollow Creek merge with Martinez Creek before it discharges into Cibolo Creek.

Two water quality surveys were conducted on Martinez Creek in 1979. The first was conducted on November 27 and the second on December 17. Both surveys included diurnal field measurements of dissolved oxygen, pH, temperature and conductivity and chemical analysis of water samples collected at the sewage treatment plant discharge (Station 1), upstream of the discharge (Station A), seven locations downstream of the discharge (Stations B-H) and at the two tributary streams (Stations I and J). Twelve-hour composite samples were collected at all stations except Stations I and J where a single grab sample was collected at each. Grab samples were also collected at 3-hour intervals at Stations 1, B and E in addition to the 12-hour composite. A time-of-travel study from the treatment plant outfall to a point approximately 4 miles downstream was conducted during the November survey.

Field data did not indicate any significant water quality problems in Martinez Creek. Dissolved oxygen levels immediately downstream of the treatment plant discharge (Station B) were somewhat lower than other stations but all measurements were greater than 5.0 mg/l. The greatest range of dissolved oxygen levels over a diurnal period was found at Station E on both surveys 6.4 mg/l to 11.3 mg/l on the first survey and 9.7 mg/l to 14.8 mg/l on the second. The diurnal range of dissolved oxygen levels at the other stations was generally less than 3.0 mg/l. Dissolved oxygen levels in the treatment plant effluent ranged from 2.6 mg/l to 3.6 mg/l except for one measurement of 4.5 mg/l occurring at 0600 hours on November 27.

Laboratory analyses indicated ammonia nitrogen levels in the discharge exceeded detectable levels of 0.02 mg/l on three occasions when levels of 0.18 mg/l, 0.63 mg/l and 0.13 mg/l were observed. Nitrate nitrogen

levels in the effluent averaged 4.4 mg/l on the first survey and 10.9 mg/l on the second. Nitrite nitrogen was almost undetectable with no measurements exceeding 0.01 mg/l. Ortho-phosphorus levels on both surveys ranged from 8.99 mg/l to 10.06 mg/l and total phosphorus ranged from 9.22 mg/l to 10.14 mg/l. Five day BOD levels in the effluent were generally less than 5 mg/l; total suspended solids were less than 10 mg/l on the first survey, and ranged between 11 and 12 mg/l on the second.

Ammonia nitrogen levels downstream of the treatment plant averaged slightly higher than levels found in the effluent, 0.19 mg/l on the first survey and 0.34 mg/l on the second. Nitrate nitrogen levels remained relatively constant at downstream stations, averaging about 3.0 mg/l with the exception of high readings, 7.25 to 8.43 mg/l, found at Station B on the December survey. Ortho-phosphorus and total phosphorus showed little change from station-to-station on either survey.

Stream flow was constant on both surveys. Essentially flow originated with the treatment plant discharge of 1.5 cfs. Tributary inflow was somewhat less during the December survey, 3.08 cfs in December vs. 4.56 cfs in November but total discharge at the most downstream station was virtually the same, 5.88 cfs in November and 5.90 cfs in December.

CONCLUSIONS

No water quality problems were identified as a result of the two surveys. The Martinez Creek sewage treatment plant is currently producing a good quality effluent which does not appear to downgrade Martinez Creek. All parameters tested were well within the limit suggested in the General Criteria for surface waters described in the Texas Surface Water Quality Standards. Since Martinez Creek flows through rangeland utilized for grazing, the occasional higher than average levels of suspended solids and ammonia nitrogen observed are undoubtedly the result of livestock activities. The general appearance of the creek is good with clean water, no excessive algae growth or objectional odors. Local residents indicated that fishing was excellent in the deeper pools of the creek . These fine water quality conditions are likely to persist providing the treatment levels at the Martinez Creek Sewage Treatment Plan are maintained.

The data collected on this survey will be utilized by the TDWR, through mathematical modeling processes, to specifically evaluate treatment levels for the San Antonio River Authority's Martinez Creek STP.

METHODS

Field and laboratory procedures used during this survey are described in Appendix A. The data were collected November 27 and December 17, 1979 by the Texas Department of Water Resources Water Quality Assessment Unit personnel. Laboratory analyses of water samples were conducted by the Texas Department of Health water chemistry laboratory in Austin, Texas. Parametric coverages, sampling frequencies and spatial relationships of sampling stations are consistent with the objective of the survey and with known or suspected forms and variability of pollutants entering the stream.

PRESENTATION OF DATA

Table 1
Station Descriptions

Station No.	Description
1	SARA Martinez Creek STP discharge
A	Martinez Creek at private road crossing just upstream of discharge
B	Martinez Creek at Benz-Engleman Road
C	Martinez Creek at private road downstream of small pond
D	Martinez Creek at I-10
E	Martinez Creek at FM 1516
F	Martinez Creek at Shuwirth Road
G	Martinez Creek at FM 1518
H	Martinez Creek at Gable Road
I	Salatrillo Creek at FM 1518
J	Woman Hollow Creek at Gable Road

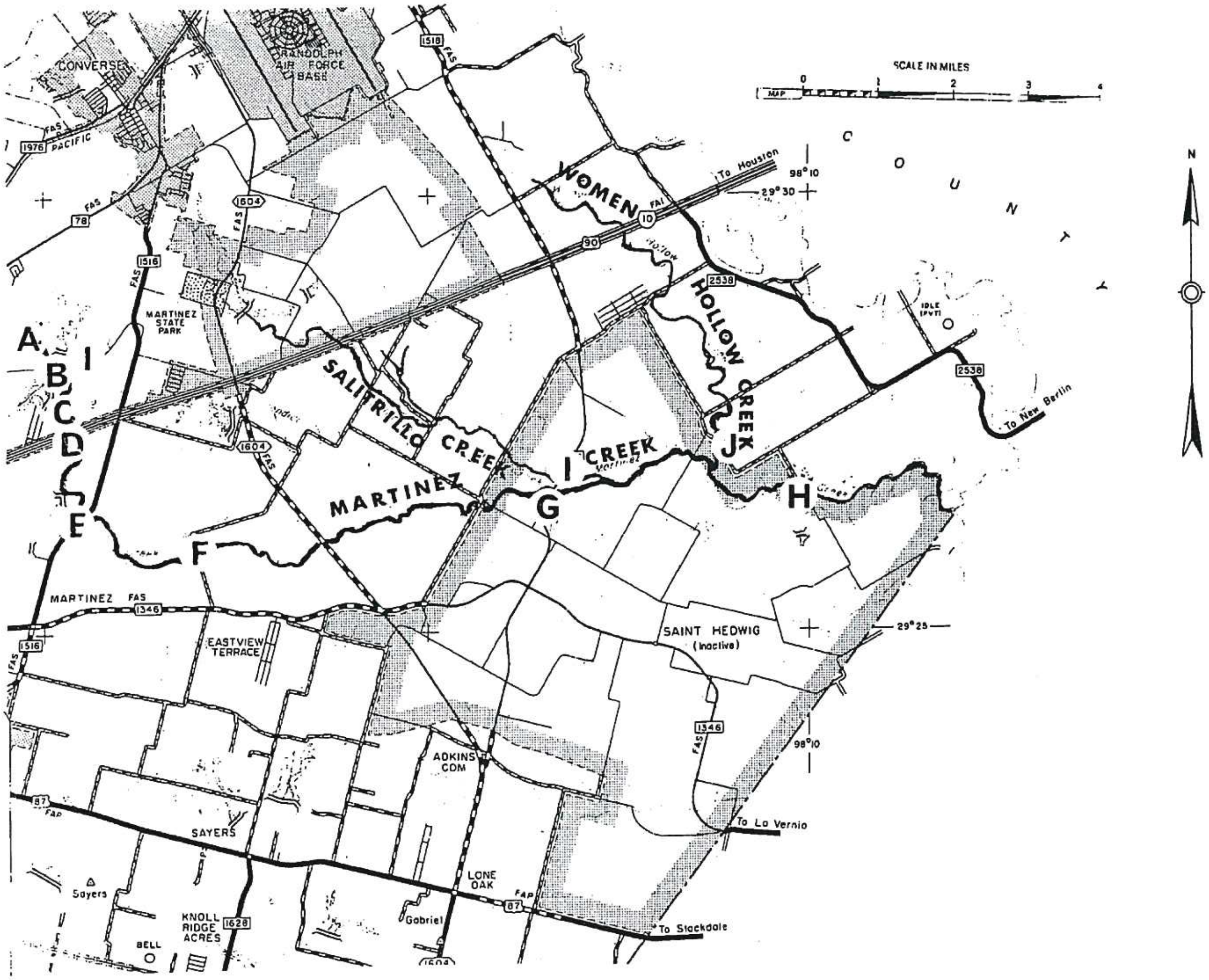

Figure 1
Map of Study Area

Table 2
Hydrological Data

Flow Measurements
11/26 & 27/79

Station	Date	Time	Method	Flow (cfs)
1	11/26/79	24 hr. ave.	Recording Flow Meter	1.546
C	11/26/79	1330	Electronic Flow Meter	2.126
D	11/27/79	1230	Electronic Flow Meter	1.551
E	11/27/79	1700	Electronic Flow Meter	1.517
F	11/26/79	1655	PM	2.538
G	11/26/79	1525	PM	2.612
H	11/26/79	1410	PM	5.881
I	11/26/79	1551	PM	3.325
J	11/27/79	1610	Electronic Flow Meter	1.232

Flow Measurements
12/16 & 17/79

Station	Date	Time	Method	Flow (cfs)
1	12/16/79	24 hr. ave.	Recording Flow Meter	1.52
C	12/17/79	1318	Electronic Flow Meter	2.430
D	12/17/79	1340	Electronic Flow Meter	2.133
E	12/17/79	1430	Electronic Flow Meter	1.999
F	12/17/79	1450	Electronic Flow Meter	2.694
G	12/17/79	1335	PM	1.807
H	12/17/79	1235	PM	5.902
I	12/17/79	1400	PM	2.185
J	12/18/79	1220	Electronic Flow Meter	0.895

Table 2 (Cont.)
Hydrological Data

Cross-section Data

Station	Location	x-width (ft.)	x-depth (ft.)
A	Upstream of discharge	26.6	--
B	Between discharge and Station B	22.6	--
	Between B and small pond	19.0	--
	Small pond	107.3	--
C	Upstream of Station C	13.4	5.2
	Downstream of Station C	6.9	1.5
D	Upstream of Station D		
	Downstream of Station D	10.7	1.2
E	Upstream of Station E	4.9	--
	Downstream of Station E	26.2	3.2

Time-of-Travel

From	To	Distance (ft.)	Time (min.)	Velocity (ft./sec.)
STP Discharge	Station B	1100	288	0.07
Station B	Outlet of Small Pond	1000	295	0.06
Outlet	Station C	750	48	0.26
Station C	Station D	4000	260	0.26
Station C	Between Station E and F	16000	1245	0.22

Table 3-A

Field Measurements

11/27/79

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity	
							P-Alk	T-Alk
1	0600	4.5	7.9	20.0	6.85	1000	0	205
	0900	3.4	5.0	19.5	7.0	1100	--	--
	1200	3.4	5.2	19.0	6.75	1090	--	--
	1450	3.0	3.0	20.0	6.9	1100	--	--
	1740	2.6	3.7	20.5	7.0	1000	--	--
A	1135	9.5	--	15.0	7.7	590	--	--
B	0705	5.7	0.6	18.0	7.25	1000	--	--
	0915	5.7	0.6	18.5	7.0	1100	--	--
	1210	7.3	1.0	19.2	6.5	1000	0	183
	1505	9.1	0.5	20.0	6.7	1000	--	--
	1755	8.8	0.5	20.0	6.4	1020	--	--
C	0645	6.8	0.4	16.0	7.4	1000	--	--
	0930	8.1	0.25	16.5	7.4	1050	--	--
	1230	9.3	0.3	18.5	7.3	1000	0	206
	1520	8.8	0.25	19.5	7.5	1000	--	--
	1810	7.4	0.3	20.0	7.5	1000	--	--
D	0720	6.2	0.15	15.0	7.6	1020	--	--
	0950	6.6	0.15	15.5	7.4	1020	--	--
	1250	8.4	0.15	18.0	7.7	1000	0	210
	1545	8.0	0.15	20.5	7.7	1000	--	--
	1820	8.6	0.20	19.5	7.7	1050	--	--
E	0735	6.4	0.15	13.5	8.0	1100	--	--
	1005	7.0	0.10	14.0	7.4	1050	0	210
	1300	8.5	0.05	15.8	7.6	1000	--	--
	1600	9.8	--	18.0	7.8	1000	--	--
	1830	11.3	--	18.0	8.0	1050	--	--
F	0700	9.7	--	12.1	8.1	770	--	--
	1030	10.0	--	13.2	8.2	763	--	--
	1255	10.5	--	16.0	8.2	810	--	--
	1600	10.2	--	17.5	8.05	815	--	--
	1830	9.9	--	15.5	8.15	795	--	--
G	0635	8.9	--	12.0	8.1	800	--	--
	0946	11.2	--	12.6	8.0	779	--	--
	1225	11.5	--	13.9	8.0	788	0	196
	1545	11.4	--	16.0	8.1	810	--	--
H	0605	9.1	--	11.8	8.1	940	--	--
	0926	9.4	--	11.8	8.1	870	--	--
	1200	9.3	--	12.5	8.0	910	0	200
	1526	9.6	--	13.2	7.95	929	--	--
	1755	9.9	--	13.9	8.0	908	--	--

Table 3-A (Cont.)
Field Measurements
11/27/79

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
I	1000	8.4	--	13.0	8.3	990	5.0	214
J	1435	10.2	--	15.0	7.95	610	0	188

Table 3-B
Field Measurements
12/17/79

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
1	0610	2.6	4.5	15.0	6.8	1200	--	--
	0900	3.6	9.2	14.5	6.7	1050	0	166
	1200	3.65	2.8	15.0	7.0	1120	--	--
	1450	3.2	1.8	15.5	7.1	----	0	164
	1750	3.1	8.4	15.5	6.7	1150	--	--
A	1145	15.4	--	7.0	7.6	--	0	132
B	0625	7.3	2.4	11.7	7.2	1050	--	--
	0907	7.4	2.0	11.5	7.3	1000	0	184
	1210	8.0	0.8	13.2	7.0	1100	--	--
	1505	8.7	0.8	14.5	6.8	----	0	188
	1740	8.7	1.3	14.0	6.0	1000	--	--
C	0640	8.85	0	8.0	7.65	1000	--	--
	0920	10.0	0	9.5	7.4	940	0	192
	1220	10.7	0	12.0	7.5	1000	--	--
	1515	10.1	0	13.5	7.5	--	0	194
	1730	9.2	0	11.5	7.45	1000	--	--
D	0655	9.85	0	7.5	7.8	920	--	--
	0940	10.8	0	7.0	7.2	900	0	188
	1235	12.2	0	10.8	7.55	1050	--	--
	1535	11.4	0	13.5	7.9	--	0	196
	1800	10.2	0	12.0	7.6	1000	--	--
E	0705	9.7	0	6.0	7.65	910	--	--
	0950	10.7	0	6.0	7.3	880	0	200
	1245	12.8	0	8.0	7.6	1000	--	--
	1550	14.8	0	10.0	7.8	950	0	208
	1815	14.8	0	10.0	8.1	950	--	--
F	0700	11.0	--	5.7	8.0	725	--	--
	0930	11.3	--	5.8	7.85	715	0	198
	1320	11.9	--	8.3	8.0	730	--	--
	1540	12.1	--	10.0	8.2	745	0	186
	1806	11.6	--	8.6	8.15	720	--	--
G	0645	10.6	--	5.9	8.0	755	--	--
	0915	10.9	--	5.5	7.9	750	0	206
	1250	12.5	--	7.3	8.1	770	--	--
	1225	13.4	--	8.6	8.3	775	0	196
	1750	12.6	--	9.0	8.3	758	--	--

Table 3-B (Cont.)
Field Measurements
12/17/79

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
H	0615	10.7	--	6.1	7.8	855	--	--
	0853	10.4	--	6.2	7.7	850	0	208
	1200	10.7	--	6.5	7.8	870	--	--
	1500	11.1	--	7.2	7.8	880	0	210
	1735	11.4	--	7.5	7.8	885	--	--
I	1300	12.3	--	7.0	7.8	940	0	226
J	1235	10.9	--	6.9	7.9	595	0	202

Table 4-A
Laboratory Water Analyses
11/27/79

Parameter / Station No. / Time	1 Comp.	1 0600 Grab	1 0900 Grab	1 1200 Grab	1 1450 Grab	1 1740 Grab
pH	7.3	7.2	7.4	7.3	7.3	7.4
Conductivity	1043	1014	1022	1038	1057	1026
Residue, Total Filterable	570	540	560	580	570	570
Total Suspended Solids	< 10	< 10	< 10	< 10	< 10	< 10
Volatile Suspended Solids	< 10	< 10	< 10	< 10	< 10	< 10
Ammonia Nitrogen	0.07	< 0.02	0.02	< 0.02	0.18	0.63
Nitrite Nitrogen	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.01
Nitrate Nitrogen	4.45	0.15	4.67	6.98	5.35	4.85
Kjeldahl Nitrogen	1.74	1.43	2.27	1.81	1.81	2.15
Total Phosphorus	9.62	10.14	9.85	9.47	9.35	9.22
Orthophosphorus	9.46	10.06	9.79	9.46	9.31	8.99
Chloride	104	104	95	10.5	106	104
Sulfate	95	96	95	94	96	95
Total Organic Carbon (filtered)	5.0	8	9	5	7	6
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	4.0	3.0	4.5	2.5	3.5	2.5
BOD_{20}, (N-Supp.)	8.5	8.0	9.0	6.0	6.5	6.5
BOD_{20}, (N-Supp., filtered)	7.5	7.0	6.0	4.5	6.5	5.5
BOD_1, (N-Supp.)	1.5	--	--	--	--	--
BOD_2, (N-Supp.)	3.0	--	--	--	--	--
BOD_3, (N-Supp.)	4.5	--	--	--	--	--
BOD_4, (N-Supp.)	5.0	--	--	--	--	--
BOD_5, (N-Supp.)	5.0	4.0	5.5	3.0	3.5	3.5
BOD_6, (N-Supp.)	5.5	--	--	--	--	--
BOD_7, (N-Supp.)	5.5	--	--	--	--	--
Chlorophyll a	< 0.02	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pehophytin a	< 0.02	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002

Table 4-A (Cont.)
Laboratory Water Analyses
11/29/79

Station No. / Time / Parameter	A 1135 Grab	B Comp	B 0705 Grab	B 0915 Grab	B 1210 Grab	B 1505 Grab
pH	8.0	7.6	7.6	7.6	7.4	7.5
Conductivity	540	9.66	978	978	960	972
Residue, Total Filterable	326	5.20	550	540	500	530
Total Suspended Solids	31	< 10	< 10	< 10	< 10	< 10
Volatile Suspended Solids	1.0	< 10	< 10	< 10	< 10	< 10
Ammonia Nitrogen	0.19	0.10	0.16	0.20	0.18	0.17
Nitrite Nitrogen	0.02	0.01	0.01	0.01	< 0.01	< 0.01
Nitrate Nitrogen	0.12	1.64	0.37	0.31	0198	2.87
Kjeldahl Nitrogen	0.84	3.42	3.55	3.20	3.07	2.62
Total Phosphorus	0.11	8.94	9.28	9.34	8.82	8.72
Orthophosphorus	0.04	8.59	8.77	8.96	8.46	8.57
Chloride	25	90	90	89	89	89
Sulfate	26	94	95	95	93	93
Total Organic Carbon (filtered)	7	6	7	7	6	5
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	1.0	4.0	3.0	3.0	3.0	3.0
BOD_{20}, (N-Supp.)	4.0	7.0	9.5	7.0	8.0	6.5
BOD_{20}, (N-Supp., filtered)	2.0	6.5	6.5	6.0	6.5	6.5
BOD_1, (N-Supp.)	< 0.5	1.0		--	--	--
BOD_2, (N-Supp.)	0.5	1.5	--	--	--	--
BOD_3, (N-Supp.)	1.0	2.5	--	--	--	--
BOD_4, (N-Supp.)	1.5	3.5	--	--	--	--
BOD_5, (N-Supp.)	1.5	3.5	4.5	3.0	3.5	3.0
BOD_6, (N-Supp.)	2.0	4.0		--	--	--
BOD_7, (N-Supp.)	2.0	4.5	--	--	--	--
Chlorophyll a	< 0.002	0.003	0.003	0.003	< 0.002	< 0.002
Pehophytin a	< 0.002	< 0.002	< 0.002	< 0.002	0.013	< 0.002

Table 4-A (Cont.)
Laboratory Water Analyses
11/29/79

Station No. / Parameter — Time	B 1755 Grab	C Comp	D Comp	E Comp	E 0735 Grab	E 1005 Grab
pH	7.6	7.7	7.9	7.9	7.9	7.9
Conductivity	984	984	990	996	1014	1002
Residue, Total Filterable	540	550	550	570	560	560
Total Suspended Solids	< 10	< 10	32	27	37	37
Volatile Suspended Solids	< 10	< 10	7	4	11	7
Ammonia Nitrogen	0.07	0.52	0.38	0.25	0.23	0.27
Nitrite Nitrogen	0.01	0.15	0.24	0.15	0.15	0.16
Nitrate Nitrogen	3.87	1.33	1.62	2.33	2.60	2.56
Kjeldahl Nitrogen	3.42	3.74	2.56	1.58	1.93	1.43
Total Phosphorus	8.42	9.20	9.20	9.16	9.45	9.49
Orthophosphorus	8.29	8.88	8.73	9.10	9.22	9.30
Chloride	91	92	94	98	98	98
Sulfate	92	92	92	92	91	91
Total Organic Carbon (filtered)	6	6	6	5	7	7
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	3.0	1.5	1.0	1.0	1.0	1.0
BOD_{20}, (N-Supp.)	6.5	5.0	6.0	5.5	5.0	5.5
BOD_{20}, (N-Supp., filtered)	6.0	3.5	4.0	2.5	3.5	3.5
BOD_1, (N-Supp.)	--	< 0.5	< 0.5	< 0.5	--	--
BOD_2, (N-Supp.)	--	0.5	1.0	1.0	--	--
BOD_3, (N-Supp.)	--	1.0	1.5	1.5	--	--
BOD_4, (N-Supp.)	--	1.5	2.0	1.5	--	--
BOD_5, (N-Supp.)	3.0	2.0	2.5	2.0	2.0	2.0
BOD_6, (N-Supp.)	--	2.0	3.0	2.0	--	--
BOD_7, (N-Supp.)	--	2.5	3.0	2.5	--	--
Chlorophyll a	0.002	0.003	0.004	0.004	0.007	0.006
Pehophytin a	< 0.002	0.002	< 0.002	< 0.002	0.004	0.005

Table 4-A (Cont.)
Laboratory Water Analyses
11/29/79

Parameter / Station No. / Time	E 1300 Grab	E 1600 Grab	E 1830 Grab	F -- Comp	G -- Comp	H -- Comp
pH	7.9	8.0	8.1	8.1	8.0	7.8
Conductivity	1002	1002	1002	996	1002	1155
Residue, Total Filterable	550	550	560	540	560	620
Total Suspended Solids	35	22	29	106	18	14
Volatile Suspended Solids	6	6	7	73	2	9
Ammonia Nitrogen	0.27	0.26	0.26	0.03	< 0.02	0.04
Nitrite Nitrogen	0.15	0.14	0.12	0.02	0.02	0.04
Nitrate Nitrogen	2.20	2.16	2.06	2.65	4.72	2.65
Kjeldahl Nitrogen	1.66	1.47	3.17	1.89	1.41	1.64
Total Phosphorus	9.43	9.07	8.78	8.86	8.25	3.10
Orthophosphorus	9.26	8.99	8.70	8.64	8.05	3.07
Chloride	97	96	98	101	104	137
Sulfate	92	93	93	89	91	110
Total Organic Carbon (filtered)	7	6	6	5	6	6
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	1.0	1.0	1.0	1.0	1.0	1.0
BOD_{20}, (N-Supp.)	5.5	6.0	5.0	3.5	4.5	4.0
BOD_{20}, (N-Supp., filtered)	3.5	4.0	3.5	2.0	3.0	3.0
BOD_1, (N-Supp.)	--	--	--	< 0.5	< 0.5	< 0.5
BOD_2, (N-Supp.)	--	--	--	< 0.5	0.5	1.0
BOD_3, (N-Supp.)	--	--	--	0.5	1.0	1.0
BOD_4, (N-Supp.)	--	--	--	1.0	1.5	1.5
BOD_5, (N-Supp.)	2.0	2.5	2.0	1.0	1.5	1.5
BOD_6, (N-Supp.)	--	--	--	1.0	1.5	2.0
BOD_7, (N-Supp.)	--	--	--	1.0	2.0	2.0
Chlorophyll _a_	0.006	0.005	0.004	0.009	0.006	0.008
Pehophytin _a_	0.002	< 0.002	0.005	< 0.002	< 0.002	0.004

Table 4-A (Cont.)
Laboratory Water Analyses
11/29/79

Station No. / Parameter / Time	I	J				
	1000 Grab	1435 Grab				
pH	8.3	8.1				
Conductivity	1350	710				
Residue, Total Filterable	740	388				
Total Suspended Solids	90	10				
Volatile Suspended Solids	19	10				
Ammonia Nitrogen	< 0.002	0.04				
Nitrite Nitrogen	0.12	< 0.01				
Nitrate Nitrogen	6.04	0.09				
Kjeldahl Nitrogen	1.70	0.30				
Total Phosphorus	1.73	0.04				
Orthophosphorus	1.42	0.02				
Chloride	167	55				
Sulfate	123	55				
Total Organic Carbon (filtered)	8	3				
BOD_5	--	--	--			
BOD_5, (N-Supp., filtered)	2.0	2.5				
BOD_{20}, (N-Supp.)	11.0	2.5				
BOD_{20}, (N-Supp., filtered)	4.5	1.5				
BOD_1, (N-Supp.)	1.0	< 0.5				
BOD_2, (N-Supp.)	2.0	< 0.5				
BOD_3, (N-Supp.)	3.0	< 0.5				
BOD_4, (N-Supp.)	3.5	0.5				
BOD_5, (N-Supp.)	4.0	0.5				
BOD_6, (N-Supp.)	4.5	0.5				
BOD_7, (N-Supp.)	6.0	1.0				
Chlorophyll *a*	0.032	0.002				
Pehophytin *a*	0.008	< 0.002				

Table 4-B
Laboratory Water Analyses
12/18/79

Station No. / Parameter Time	1 Comp	1 0610 Gfab	1 0900 Grab	1 1200 Grab	1 1450 Grab	1 1750 Grab
pH	7.2	7.1	7.0	7.8	7.2	7.1
Conductivity	1078	1071	1065	1078	1085	1092
Residue, Total Filterable	580	620	590	600	610	610
Total Suspended Solids	12	12	10	11	11	12
Volatile Suspended Solids	6	7	10	7	5	4
Ammonia Nitrogen	< 0.02	< 0.02	< 0.02	0.13	< 0.02	< 0.02
Nitrite Nitrogen	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Nitrate Nitrogen	10.92	9.91	10.75	10.02	11.31	12.38
Kjeldahl Nitrogen	1.0	0.9	1.0	1.1	1.0	0.9
Total Phosphorus	9.83	9.95	10.04	9.91	9.72	9.72
Orthophosphorus	9.41	9.46	9.52	9.41	9.41	9.41
Chloride	111	110	114	105	109	118
Sulfate	94	113	95	97	95	95
Total Organic Carbon (filtered)	5	7	7	--	6	6
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	3.0	3.0	3.0	3.0	3.0	2.5
BOD_{20}, (N-Supp.)	10.0	6.0	7.0	7.5	6.5	6.0
BOD_{20}, (N-Supp., filtered)	5.0	5.0	6.5	5.5	5.0	5.0
BOD_1, (N-Supp.)	< 0.5	--	--	--	--	--
BOD_2, (N-Supp.)	1.0	--	--	--	--	--
BOD_3, (N-Supp.)	2.0	--	--	--	--	--
BOD_4, (N-Supp.)	3.0	--	--	--	--	--
BOD_5, (N-Supp.)	3.0	3.0	3.5	3.0	3.0	2.5
BOD_6, (N-Supp.)	3.5	--	--	--	--	--
BOD_7, (N-Supp.)	4.0	--	--	--	--	--
Chlorophyll a	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Pehophytin a	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002

Table 4-B (Cont.)
Laboratory Water Analyses
12/18/79

Parameter / Station No. / Time	A 1145 Grab	B Comp	B 0625 Grab	B 0907 Grab	B 1210 Grab	B 1505 Grab
pH	8.0	7.5	7.5	7.5	7.3	7.5
Conductivity	556	984	984	990	972	966
Residue, Total Filterable	322	550	570	550	530	550
Total Suspended Solids	23	02	21	18	11	11
Volatile Suspended Solids	8	8	10	9	5	6
Ammonia Nitrogen	0.19	0.24	0.43	0.40	0.08	0.16
Nitrite Nitrogen	0.02	0.02	0.02	0.02	< 0.02	0.02
Nitrate Nitrogen	0.18	7.82	7.25	7.36	8.43	7.85
Kjeldahl Nitrogen	1.1	1.2	1.5	1.4	1.1	1.1
Total Phosphorus	0.09	8.46	8.95	8.61	8.62	8.36
Orthophosphorus	0.04	7.84	8.40	8.34	8.29	8.06
Chloride	25	91	91	90	94	89
Sulfate	81	94	96	94	92	92
Total Organic Carbon (filtered)	7	5	7	6	6	6
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	1.0	3.0	3.0	3.0	3.0	5.0
BOD_{20}, (N-Supp.)	4.0	12.0	14.5	7.5	5.5	5.0
BOD_{20}, (N-Supp., filtered)	2.5	6.0	12.5	5.0	5.5	4.5
BOD_1, (N-Supp.)	--	0.5	--	--	--	--
BOD_2, (N-Supp.)	--	1.5	--	--	--	--
BOD_3, (N-Supp.)	--	2.0	--	--	--	--
BOD_4, (N-Supp.)	--	3.0	--	--	--	--
BOD_5, (N-Supp.)	2.0	3.0	3.5	3.5	3.0	2.5
BOD_6, (N-Supp.)	--	3.5	--	--	--	--
BOD_7, (N-Supp.)	--	4.0	--	--	--	--
Chlorophyll a	0.012	< 0.002	< 0.002	0.004	< 0.002	< 0.002
Pehophytin a	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002

Table 4-B (Cont.)
Laboratory Water Analyses
12/18/79

Station No. / Parameter (Time)	B 1740 Grab	C Comp	D Comp	E Comp	E 0705 Grab	E 0950 Grab
pH	7.5	7.7	8.0	8.0	8.0	8.0
Conductivity	984	952	942	948	936	948
Residue, Total Filterable	560	530	540	510	520	530
Total Suspended Solids	12	21	43	26	32	27
Volatile Suspended Solids	6	6	10	8	10	9
Ammonia Nitrogen	0.21	0.77	0.77	0.63	0.65	0.65
Nitrite Nitrogen	0.02	0.12	0.15	0.10	0.10	0.11
Nitrate Nitrogen	8.43	3.61	3.27	2.86	2.93	2.84
Kjeldahl Nitrogen	1.3	2.0	1.9	1.6	1.5	1.6
Total Phosphorus	8.21	7.67	7.48	7.18	7.56	7.60
Orthophosphorus	7.95	7.06	6.78	6.78	7.28	7.34
Chloride	92	81	80	79	79	80
Sulfate	92	95	96	97	95	96
Total Organic Carbon (filtered)	6	6	6	6	6	6
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	2.5	1.0	1.5	1.0	2.0	1.0
BOD_{20}, (N-Supp.)	6.5	4.5	9.5	4.5	4.0	5.0
BOD_{20}, (N-Supp., filtered)	5.5	3.5	3.5	3.5	3.5	3.0
BOD_1, (N-Supp.)	--	0.5	0.5	0.5	--	--
BOD_2, (N-Supp.)	--	0.5	1.5	0.5	--	--
BOD_3, (N-Supp.)	--	1.0	--	1.0	--	--
BOD_4, (N-Supp.)	--	1.5	2.5	1.5	--	--
BOD_5, (N-Supp.)	3.0	2.0	2.5	2.0	2.0	2.0
BOD_6, (N-Supp.)	--	2.0	3.5	2.0	--	--
BOD_7, (N-Supp.)	--	2.0	3.5	2.5	--	--
Chlorophyll a	< 0.002	< 0.002	0.005	0.003	< 0.002	0.003
Pehophytin a	< 0.002	< 0.002	< 0.002	< 0.002	0.003	< 0.002

Table 4-B (Cont.)
Laboratory Water Analyses
12/18/79

Station No. / Parameter Time	E	E	E	F	G	H
	1245 Grab	1550 Grab	1815 Grab	Comp	Comp	Comp
pH	8.2	8.2	8.3	7.9	8.2	7.9
Conductivity	936	936	936	948	990	1192
Residue, Total Filterable	530	520	530	530	560	680
Total Suspended Solids	27	25	27	28	23	18
Volatile Suspended Solids	9	7	7	6	6	6
Ammonia Nitrogen	0.64	0.61	0.61	0.03	< 0.02	0.02
Nitrite Nitrogen	0.11	0.10	0.10	0.02	0.02	0.05
Nitrate Nitrogen	2.88	2.84	2.90	5.85	4.70	5.93
Kjeldahl Nitrogen	1.6	1.7	1.6	0.9	0.8	0.8
Total Phosphorus	7.56	7.25	7.14	7.16	7.64	4.64
Orthophosphorus	7.20	6.91	6.76	6.33	6.89	4.43
Chloride	79	79	78	86	98	133
Sulfate	95	95	95	94	91	111
Total Organic Carbon (filtered)	6	6	6	6	5	6
BOD_5	--	--	--	--	--	--
BOD_5, (N-Supp., filtered)	1.5	1.0	1.5	1.0	1.0	1.0
BOD_{20}, (N-Supp.)	5.0	7.0	5.5	3.0	3.5	3.5
BOD_{20}, (N-Supp., filtered)	3.5	3.5	3.5	2.5	2.5	2.5
BOD_1, (N-Supp.)	--	--	--	< 0.5	0.5	0.5
BOD_2, (N-Supp.)	--	--	--	0.5	1.0	1.0
BOD_3, (N-Supp.)	--	--	--	0.5	1.0	1.0
BOD_4, (N-Supp.)	--	--	--	1.0	1.0	1.0
BOD_5, (N-Supp.)	2.0	3.0	2.0	1.0	1.5	1.5
BOD_6, (N-Supp.)	--	--	--	1.0	1.5	1.5
BOD_7, (N-Supp.)	--	--	--	1.5	2.0	2.0
Chlorophyll a	0.003	0.004	0.005	< 0.002	< 0.002	< 0.002
Pehophytin a	< 0.002	< 0.002	< 0.002	0.003	0.003	< 0.002

Table 4-B (Cont.)
Laboratory Water Analyses
12/18/79

Station No. / Parameter Time	I	J				
	1300 Grab	1235 Grab				
pH	8.2	8.2				
Conductivity	1350	700				
Residue, Total Filterable	740	376				
Total Suspended Solids	36	< 10				
Volatile Suspended Solids	11	< 10				
Ammonia Nitrogen	0.10	< 0.02				
Nitrite Nitrogen	0.18	< 0.02				
Nitrate Nitrogen	7.65	0.17				
Kjeldahl Nitrogen	1.5	1.3				
Total Phosphorus	3.65	0.03				
Orthophosphorus	3.19	0.03				
Chloride	159	56				
Sulfate	118	55				
Total Organic Carbon (filtered)	7	3				
BOD_5	--	--				
BOD_5, (N-Supp., filtered)	1.0	0.5				
BOD_{20}, (N-Supp.)	7.0	3.0				
BOD_{20}, (N-Supp., filtered)	3.5	2.0				
BOD_1, (N-Supp.)	--	--				
BOD_2, (N-Supp.)	--	--				
BOD_3, (N-Supp.)	--	--				
BOD_4, (N-Supp.)	--	--				
BOD_5, (N-Supp.)	3.0	0.5				
BOD_6, (N-Supp.)	--	--				
BOD_7, (N-Supp.)	--	--				
Chlorophyll a	0.018	< 0.002				
Pehophytin a	< 0.002	< 0.002				

APPENDIX A

FIELD AND LABORATORY PROCEDURES

The following methods are utilized for field and laboratory determinations of specified physical and chemical parameters. Unless otherwise indicated composite water samples are collected at each sampling station and stored in polyethylene containers on ice until delivery to the laboratory. Sediment samples are collected with a dredge or coring device, decanted, mixed, placed in appropriate containers (glass for pesticides analyses and plastic for metals analyses), and stored on ice until delivery to the laboratory. Laboratory chemical analyses are conducted by the Water Chemistry Laboratory of the Texas Department of Health unless otherwise noted.

WATER ANALYSES

Field Measurements

Parameter	Method
Temperature	Hand mercury thermometer, temperature probe of Hydrolab Model 60 Surveyor, or Hydrolab 4041.
Dissolved Oxygen	Azide modification of Winkler titration method, oxygen probe attachment of Hydrolab Model 60 Surveyor, or Hydrolab 4041
pH	Hydrolab Model 60 Surveyor, Hydrolab 4041 or Sargent-Welch portable pH meter.
Conductivity	Hydrolab Model 60 Surveyor, Hydrolab 4041, or Hydrolab TC-2 conductivity meter
Alkalinity	Titration as described in "Standard Methods for the Examination of Water and Wastewater" 13th Ed., using phenolphthalein and methyl red/bromcresol green indicators.

Laboratory Analyses

Parameter	Method
BOD_5, Nitrogen-Suppressed	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
BOD_{1-7}, Nitrogen-Suppressed	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
BOD_{20}, Nitrogen-Suppressed	Membrane electrode method(1) Nitrogen Suppression using TCMP method(2).
TSS	Gooch crucibles and glass fiber discs(1).
VSS	Gooch crucibles and glass fiber discs(1).
Kjel-N	Micro-Kjeldahl digestion and automated colorimetric phenate method(3).
NH_3-N	Distillation and automated colorimetric phenate method(3).
NO_2-N	Colorimetric method(1).
NO_3-N	Automated cadmium reduction method(3).
T-PO_4	Persulfate digestion followed by ascorbic acid method(1).
O-PO_4	Ascorbic acid method(1).
Sulfates	Turbidimetric method(1).
Chlorides	Automated thiocyanate method(3).
TDS	Evaporation at 180°C(3).
TOC	Beckman TOC analyzer.
Conductivity	Wheatstone bridge utilizing 0.01 cell constant(1).

Parameter	Method
Chlorophyll *a*	Trichromatic method(1).
Pheophytin *a*	Pheophytin correction method(1).

SEDIMENT ANALYSES

Field Measurements

Immediate Dissolved Oxygen Demand (IDOD)

$$\text{mg/l IDOD} = \frac{D_0 p - D_1}{P}$$

where D_0 = D.O. to original dilution water

$p = \frac{\text{dilution water used (ml)}}{\text{volume of BOD bottle (ml)}}$

$P = \frac{\text{amount of sample used (ml)}}{\text{volume of BOD bottle (ml)}}$

D_1 = D.O. of diluted sample 15 min. after preparation using membrane electrode method

Laboratory Analyses

Parameter	Method
Arsenic	Colorimetric
Mercury	Potassium permanganate digestion followed by atomic absorption(4).
All other metals	Atomic absorption(4).
Volatile Solids	Ignition in a muffle furnace.
COD	Dichromate reflux method.
Kjel-N	Micro-Kjeldahl digestion and automated colorimetric method(3).
T-PO_4	Ammonium molybdate(4).
Pesticides	Gas chromatographic method(5).

BACTERIOLOGICAL

Bacteriological samples are collected in sterilized glass bottles provided by the Texas Department of Health and stored on ice until delivery to the laboratory or until cultures are set up by survey personnel (within 6 hours of collection). Bacteriological analyses are conducted by survey personnel or a suitable laboratory in the survey area.

Parameter	Method
Total Coliform	Membrane filter method(1)
Fecal Coliform	Membrane filter method(1)
Fecal Streptococci	Membrane filter method(1)

BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates are collected with a Surber sampler (1.0 ft.^{2}) in riffles and an Ekman dredge (0.25 ft.^{2}) in pools. Samples are preserved in 5% formalin, stained with Rose Bengal, and sorted, identified, and enumerated in the laboratory.

Diversity is calculated according to Wilhm's(6) equation:

$$\bar{d} = - \sum_{1}^{s} (n_i/n) \log_2 (n_i/n)$$

where n is the total number of individuals in the sample, n_i is the number of individuals per taxon, and s is the number of taxa in the sample.

Redundancy is calculated according to the equations derived by Young et al.(7)

$$(1) \quad \bar{d} \max = \log_2 s$$

$$(2) \quad \bar{d} \min = - \frac{s-1}{n} \log_2 \frac{1}{n} - \frac{n-(s-1)}{n} \log_2 \frac{n-(s-1)}{n}$$

$$(3) \quad \bar{r} = \frac{\bar{d} \max - \bar{d}}{\bar{d} \max - \bar{d} \min}$$

where s is the number of taxa in the sample and n is the total number of individuals in the sample.

The number of individuals per square meter is determined by dividing the total number of individuals by the area sampled.

PLANKTON

Phytoplankton

Stream phytoplankton are collected beneath the water surface. Sampling stations are located both upstream and downstream from pollution sources and care is taken to preclude confusing interferences such as contributions of plankton from reservoirs, from backwater areas, scouring of periphyton from the streambed, etc. Reservoir phytoplankton samples are collected with a tube device in which sample collection is vertically integrated throughout the depth of the euphotic zone (3 times Secchi disc measurement). In cases where the euphotic zone depth exceeds the tube length, samples are collected with an appropriate water sampler at depths evenly spaced throughout the euphotic zone.

Samples are stored in quart cubitainers on ice and transferred to the laboratory where representative small portions of each sample are analyzed live to aid in taxonomic identification. Samples (950 ml) are then preserved with 50 ml of 95% buffered formalin or 9.5 ml of Lugols solution and stored in the dark until examination is completed. Identification and enumeration of phytoplankton is conducted with an inverted microscope utilizing standard techniques. The diversity index ($\bar{d}$) is calculated as described previously.

Zooplankton

Zooplankton are concentrated at the site by either filtering a known volume of water through a No. 20 mesh standard Wisconsin plankton net or vertically towing the net a known distance. Concentrated samples are preserved with Lugols solution or in a final concentration of 5% buffered formalin. The organisms are identified to the lowest taxonomic level possible and counts are made utilizing a Sedgwick-Rafter cell. Diversity is calculated as described previously.

NEKTON

Nekton samples are collected by the following methods(1):

Common-sense minnow seine	- 20' x 6' with 1/4" mesh
Otter trawl	- 12' with 1 3/16" outer mesh and 1/2" mesh liner
Chemical fishing	- rotenone

Experimental gill nets - 125' x 8' (five 25' sections ranging in mesh size of 3/4" to 2 1/2")

Electrofishing - backpack and boat units (both equipped with AC or DC selection). Boat unit is equipped with variable voltage pulsator.

These organisms are collected to determine: (1) species present, (2) relative and absolute abundance of each species, (3) size distribution, (4) condition, (5) success of reproduction, (6) incidence of disease and/or parasitism, (7) palatability, and/or (8) presence or accumulations of toxins.

Nekton collected for palatability are iced or frozen immediately. Samples collected for heavy metals analyses are placed in leak-proof plastic bags and placed on ice. Samples collected for pesticides analyses are wrapped in aluminum foil, placed in a water proof plastic bag and placed on ice.

As special instances dictate, specimens necessary for positive identification, parasite examination, etc., are preserved in 10% formalin containing 3 grams borax and 50 ml glycerin per liter. Specimens over 7.5 cm in length are slit at least one-third of the length of the body to enhance preservation of the internal organs. Other specimens are weighed and measured before being returned to the reservoir or stream.

ALGAL ASSAYS

The "*Selenastrum capricornutum* Printz Algal Assay Bottle Test" procedure(8) is utilized in assaying nutrient limitation in freshwater situations whereas the "Marine Algal Assay Procedure Bottle Test"(9) is utilized in marine and estuarine situations. Samples are collected according to the phytoplankton collection methodology. *Selenastrum capricornutum* is the freshwater assay organism and *Dunaliella tertiolecta* is the marine assay alga.

PRODUCTIVITY/RESPIRATION

Two methods are utilized to estimate productivity and respiration in the study area. In areas where restricted flow produces natural or artificial ponding of sufficient depth, standard light bottle-dark bottle techniques are used. In flowing water the diurnal curve analysis is utilized.

Light Bottle-Dark Bottle Analyses

The light and dark bottle technique is used to measure net production and respiration in the euphotic zone of a lentic environment. The depth of the euphotic zone is considered to be three times the Secchi disc transparency ($3 \times Z_{SD}$). This region is subdivided into three sections. Duplicate light bottles (300 ml BOD bottles) and dark bottles (300 ml BOD bottles covered with electrical tape, wrapped in aluminum foil and enclosed in a plastic bag) are filled with water collected from the mid-point of each of the three vertical sections, placed on a horizontal metal rack and suspended from a flotation platform to the mid-point of each vertical section. The platform is oriented in a north-south direction to minimize shading of the bottles. An additional BOD bottle is filled at each depth for determining initial dissolved oxygen concentrations (modified Winkler method). The bottles are allowed to incubate for a varying time interval, depending on the expected productivity of the waters. A minimum of four hours incubation is considered necessary.

The following equations are used to calculate respiration and photosynthesis:

(1) For plankton community respiration (r), expressed as mg/l O_2/hour

$$R = \frac{DO_I - DO_{DB}}{\text{Hours incubated}}$$

where DO_I = initial dissolved oxygen concentration.

and DO_{DB} = average dissolved oxygen concentration of the duplicate dark bottles.

(2) For plankton net photosynthesis (P_N), expressed as mg/l O_2/hour

$$P_N = \frac{DO_{LB} - DO_I}{\text{Hours incubated}}$$

where DO_{LB} = average dissolved oxygen concentration of the duplicate light bottles.

(3) For plankton gross photosynthesis (P_G), expressed as mg/l O_2/hour

$$P_G = P_N + R$$

Conversion of respiration and photosynthesis may be accomplished by multiplying the depth of each of the three vertical zones (expressed in meters) by the measured dissolved oxygen levels expressed in grams/m^3. These products are added and the result is expressed as grams O_2/m^2/day by multiplying by the photoperiod. Conversions from oxygen to carbon may be accomplished by multiplying grams O_2 by 12/32.

Diurnal Curve Analysis

In situations where the stream is flowing, relatively shallow, and/or contains appreciable growths of macrophytes or filamentous algae, the diurnal curve analysis is utilized to determine productivity and respiration. The procedure is adopted from the U. S. Geological Survey (10).

Both the dual station and single station analyses are utilized, depending upon the various controlling circumstances.

Dissolved oxygen and temperature data are collected utilizing the Hydrolab surface units, sondes, data scanners, and strip chart recorders. Calibration of the instruments are conducted utilizing the azide modification of the Winkler dissolved oxygen method and hand mercury thermometers. Recalibration is conducted as often as necessary. Diffusion rate constants are directly measured in those instances where atmospheric reaeration rate studies have been conducted. In situations where direct measurements are not made, either the diffusion dome method is utilized, or an appropriate alternative. These alternatives are: (1) calculations from raw data, (2) substitution into various published formulas for determination of K_2, and (3) arbitrary selection of a value from tables of measured diffusion rates for similar streams.

Presently, the productivity and respiration rates are hand-calculated The capability exists for computer analyses in this program which may be utilized in the future.

BENTHAL OXYGEN DEMAND MEASUREMENTS

A benthic respirometer, constructed of clear plexiglass, is utilized on intensive surveys to measure benthal oxygen demand(11). Brass or stainless steel hardward is used to inhibit water-induced corrosion. A D.O. probe, paddle, solenoid valve and air diffuser are mounted inside the test chamber. The paddle which is magnetically driven by an electric motor is used to simulate stream velocity (and/or scour) and produce circulation over the probe. The solenoid valve allows air to escape from the test chamber during aeration. The air diffuser is connected by plastic tubing to a 12-volt air compressor which is used to pump air into the test chamber if required.

The paddle, solenoid valve, and air compressor are actuated by switches on a control panel which is housed in an aluminum box. The control box also contains two 12-volt batteries, the air compressor, a strip-chart recorder (for automatic recordings of D.O. meter readings), a battery charger, and a batter test meter.

Selection of a specific test site must be made in the field by the investigator with the depth, velocity, and benthic substrate taken into consideration. At the test site the D.O. meter, and strip-chart recorder are calibrated, the respirometer is dry tested by opening and closing switches, testing batteries, etc., a stream velocity measurement is taken (for paddle calibration and a water sample is collected just above the stream bottom near the sampling site. Portions of this water sample are poured into separate BOD bottles, one of which is opaque. The opaque bottle is placed on the respirometer and left for the remainder of the test. The initial D.O. value in the other bottle is measured when the test begins, while the D.O. in the opaque bottle is measured at the end of the benthic uptake test. The difference in the two D.O. values represents the oxygen demand of the water column.

The respirometer can be lowered from a boat or bridge, or can be placed by hand in shallow streams. Care is taken to insure that the sediment at the test location is not disturbed and that a good seal between the base of the instrument and bottom of the stream is made. After teh respirometer has been placed in the stream, the D.O. is recorded. If it is 5 mg/l or less the air compressor is actuated until a level in excess of 5 mg/l is attained in the test chamber. The test chamber is then closed and the paddle frequency adjusted. Recordings of D.O. are made until it drops to 0.5 mg/l or 6 hours has elapsed, whichever comes first.

Paddle Frequency

$$f = 36\ v$$

where: f = Paddle frequency in RPM

v = Velocity to be simulated in ft./sec. (measured with current meter)

Benthic Oxygen Uptake

$$B^{T}DO_1 - DO_2 = 196\ \frac{(DO_1 - DO_2) - BOD_t}{\Delta t}$$

where: $B^{T}DO_1\text{-}DO_2$ = Oxygen uptake rate in gm/m^2/day corresponding to the sample temperature, T

DO_1 = Initial DO reading in mg/l

DO_2 = Final DO reading in mg/l

Δt = Time interval between DO_1 and DO_2 readings in minutes

T = Temperature of sample in °C

BOD_t = Measured difference in DO between the two BOD bottles

HYDROLOGICAL

Parameter	Method
Flow Measurement	(1) Pygmy current meter (Weather Measure Corporation Model F583), (2) Marsh-McBirney Model 201 electronic flow meter, (3) Price Current Meter (Weather Measure Corporation Model F582)(4), or gage height readings at USGS gaging stations.
Time-of-Travel	Tracing of Rhodamine WT dye using a Turner Model 110 or 111 fluorometer(12).
Stream Cross-sections	Measure average width and average depth at each mainstream station. At least 4 cross-section measurements are made in the vicinity of each mainstream station.

STREAM REAERATION MEASUREMENTS

The stream reaeration technique, requiring the use of radioactive krypton-85 and hydrogen-3 (tritiated water molecules), is utilized to measure the physical reaeration capacity of a desired stream segment(13).

The method depends on the simultaneous release of three tracers in a single aqueous solution: a dispersion/dilution tracer (Tritiated water molecules), a dissolved gaseous tracer for oxygen (krypton-85) and Rhodamine WT dye to indicate when to sample for the radiotracers in the field. The tracer release location is chosen to meet two requirements: (1) must be upstream of the segment for which physical reaeration data is desired, (2) must be at least 2 ft. deep and where the most complete mixing takes place. Before the release, samples are collected at the release site and designated sampling stations to determine background levels of radiation. The first samples are collected 50-200 ft. downstream from the release site in order to establish the initial krypton-85/tritium ratio. Sampling sites are located downstream to monitor the dye cloud every 4-6 hours for 35-40 hours. The Rhodamine WT dye is detected with Turner 111 flow-through fluorometers. Samples are collected in glass bottles (1 oz.) equipped with polyseal caps which are sealed with black electrical tape. Samples are collected every 2-5 min. during the passage of the dye cloud peak. The three samples collected nearest the peak are designated for analysis in the lab (three alternates are also designated). Extreme caution is exercised throughout the field and laboratory handling of samples to prevent entrainment of air.

Samples are transferred within 24 hours of the collection time. Triplicate counting vials are prepared from each primary sample. All counting vials are counted in a Tracor Analytic 6892 LSC Liquid Scintillation Counter which has been calibrated. Each vial is counted a minimum of three, 10 min. cycles. The data obtained is analyzed to determine the changes in the krypton-85/tritium ratio as the tracers flow downstream.

The calculations utilized in determining the physical reaeration capacity of a stream segment from the liquid scintillation counter data are included here. Krypton-85 transfer in a well-mixed water system is described by the expression:

$$\frac{dC_{kr}}{dt} = -K_{kr}(C_{kr},t) \qquad (1)$$

where: C_{kr},t = concentration of krypton-85 in the water at time(t)

K_{kr} = gas transfer rate coefficient for krypton-85

The gas transfer rate coefficient for oxygen (K_{ox}) is related to K_{kr} by the equation;

$$\frac{K_{kr}}{K_{ox}} = 0.83 \pm 0.04 \quad (2)$$

The krypton-85 coefficient (K_{kr}) is derived from the krypton-85 (C_{kr})/tritium (C_h) concentration ratio (R) in the samples collected at the time of peak concentrations;

$$R = \frac{C_{kr}}{C_h} \quad (3)$$

Applying Eq. 3 to Eq. 1 gives;

$$\frac{dR}{dt} = -K_{kr}R \quad (4)$$

Equation 4 can be transformed to;

$$K_{kr} = \frac{In(R_d/R_u)}{-t} \quad (5)$$

where: R_u and R_d = peak krypton-85/tritium concentration ratios at an upstream and downstream station

t_f = peak-to-peak dye time of flow between the upstream and downstream station

Finally K_{ox} is determined by;

$$K_{ox} = \frac{K_{kr}}{0.83} \quad (6)$$

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APPENDIX "F"

Intensive Survey of Cibolo Creek Segment 1902 – Report IS-39
(Texas Department of Water Resources, June 1982)

INTENSIVE SURVEY
OF
CIBOLO CREEK
SEGMENT 1902

*Hydrology
*Water Chemistry
*Biology
*Reaeration Rates

Prepared by

David Buzan
Water Quality Assessment Unit

Texas Department of Water Resources

IS-39

June 1982

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INTENSIVE SURVEY
OF
CIBOLO CREEK
SEGMENT 1902

INTRODUCTION

DIRECTIVE

This intensive survey was accomplished in accordance with the Texas Water Quality Act, Section 21.257, as amended in 1973. The report is to be used in developing and maintaining the State Water Quality Strategy required by regulations published in 40 CFR 35.1511-2 pursuant to Section 303(e) of the Federal Clean Water Act of 1977.

PURPOSE

The purpose of this intensive survey was to provide the Texas Department of Water Resources with a valid information source:

1. to determine quantitative cause and effect relationships of water quality;

2. to obtain data for updating water quality management plans, setting effluent limits, and where appropriate, verifying the classifications of segments;

3. to set priorities for establishing or improving pollution controls; and

4. to determine any additional water quality management actions required.

SUMMARY

Cibolo Creek, TDWR Segment 1902, was subjected to an intensive water quality survey (April 16-17, 1980) followed by benthic macroinvertebrate and periphyton sampling (May 8, 1980) and a reaeration study (June 10-12, 1980). Normal low flow conditions, partly cloudy skies and mild temperatures (range = 15°C - 29°C) persisted during the water quality and reaeration surveys. Biological sampling took place during a minor rainfall event which affected only the upstream half of the segment.

Cibolo Creek, Segment 1902, extends upstream from its confluence with the San Antonio River in Karnes County to the Missouri-Pacific Railroad bridge west of Bracken in Comal County, a distance of 146 river km. The upper 14 river km traverse the Edwards Aquifer recharge zone and therefore are normally dry. Headwater flow originates southwest of the City of Schertz in an area which is partially urbanized and partially cropland. The creek flows from the Edwards Plateau southeastward to the West Gulf Coastal Plain and drops in elevation from 229 m to 67 m above msl. Land in the downstream drainage area consists of dry cropland and forest land (TDWR, 1977). Mean annual precipitation is 79 cm (TWDB, 1969).

The study area consisted of Cibolo Creek from the City of Schertz (river km 130) downstream past the town of Panna Maria (river km 4.0) (Figure 1) (Table 1). Water quality and hydrological measurements were made at 22 mainstream stations, five tributaries and two sewage treatment plants.

Cibolo Creek averaged 12 m in width and 0.62 m in depth over the study area (Table 2). Headwater flow was 0.03 m^3/sec. while the flow leaving the study area was 0.86 m^3/sec. (Table 3). Sampled tributaries and sewage treatment plants contributed 9% (0.076 m^3/sec.) and 10% (0.088 m^3/sec.) of the total flow respectively. Estimated time-of-travel over the length of the segment was 60-90 days at an average velocity of 0.02 m/sec. (Table 4). Low physical reaeration rate coefficients [K_2 (20°C) from 0.37 - 1.40] reflected the abundance of wide, deep pools in the upper half of the segment (Table 5).

Several physicochemical parameters measured in the field displayed longitudinal trends. A dissolved oxygen sag zone extended 6.3 river km downstream from the O. J. Riedal STP where the mean concentration equalled 3.6 mg/l (range = 1.2 - 6.8 mg/l) (15% - 78% saturation) (Tables 6 and 9). Outside the sag zone, dissolved oxygen levels averaged 7.8 mg/l (range = 4.1 - 10.7 mg/l) (45% - 118% saturation) (Table 6). Conductivity increased in a downstream direction from 788 μmhos/cm (Station A) to 1685 μmhos/cm (Station X).

Total alkalinity levels decreased in a downstream direction from 306 mg/l (Station A) to 261 mg/l (Station X). Water temperature and pH varied little, ranging from 17.5°C - 22.8°C and 6.8 - 8.1 respectively. Dischargers and tributaries displayed similar values for all field parameters except conductivity which ranged from 910 μmhos/cm (Station 1) to 6040 μmhos/cm (Station 0) (Tables 10 and 11).

The O. J. Riedal STP significantly impacted the water quality of Cibolo Creek by raising nutrient and BOD levels. Ammonia nitrogen increased 120 times (0.04 to 4.74 mg/l from Station A to Station BB); NO_2-N increased by a factor of 34; and NO_3-N rose by 36%. Kjeldahl nitrogen rose by a factor of 15, total and orthophosphorus increased 45 times and BOD_5 doubled (Table 12). All nutrient concentrations and BOD levels decreased downstream reaching levels at Station X similar to those at Station A. BOD_5 (N-suppressed) ranged from a low of 0.5 mg/l at several stations in the lower end of the segment to 6.5 mg/l at Station BB.

Concentrations of chlorides, sulfates and total dissolved solids increased in a downstream direction; 37, 44 and 472 mg/l respectively at Station A to 185,286 and 990 mg/l respectively at Station X. Elm Creek exhibited high concentrations of chlorides (1330 mg/l) and sulfates (840 mg/l) while Alum Creek had high sulfate (1430 mg/l) levels (Table 13). The high sulfate concentration and low pH (2.1) of Alum Creek suggested the presence of sulfuric acid.

Observations on the benthic macroinvertebrate and periphytic communities reflected the significant impact of the O. J. Riedal STP discharge on Cibolo Creek and indicated adverse biological effects as far downstream as Station G (Table 18).

Diversity at the first station below the discharge (Station E; 1.45) was anomalously low compared with all other stations, falling into the range considered indicative of moderate organic pollution (1.0 - 2.6; Wilhm, 1967). The high nutrient levels at Station E supported dense growths of aquatic macrophytes and filamentous algae, and herbivores (limpets, snails, amphipods) dominated the benthic community.

Some deree of water quality recovery was evident by the diversity observed at Station G (3.08). However, clean water indicative organisms (mayflies, stoneflies) were absent. Detritivores (planaria, oligochaetes, clams) were predominant at Station G due to an abundance of decaying plant material from upstream vegetation beds.

Diversities at the four downstream stations were very high (3.87 - 4.11) compared to values observed in other Central Texas stream, indicating an advanced degree of recovery from the effects of the

STP discharge and identifying lower Cibolo Creek as a stream with high biological integrity. Clean water organisms such as stonefly and mayfly nymphs were important components of the benthic community in the lower reach.

The periphytic diatom community at Station E downstream from the O. J. Riedal STP exhibited the lowest diversity ($\bar{d}$ = 2.30) of the seven Cibolo Creek communities sampled (Table 19). Species diversity at the remainder of the stations ranged from 2.71 to 4.42. Only 22 taxa were identified from Station E, whereas 42 or more taxa were found at each of the other stations.

CONCLUSIONS

Oxygen depletion is a water quality problem in Segment 1902, particularly for at least 6.3 river km downstream from the O. J. Riedal STP. The dissolved oxygen standard (minimum - 5.0 mg/l) was violated at Stations BB, C, D, E and EE on April 17, 1980. Violations of the dissolved oxygen standard resulted from the addition of nutrients and biochemical oxygen demanding materials by the O. J. Riedal STP discharge to Cibolo Creek in a stream reach exhibiting low physical reaeration rates. Low species diversity in both the benthic macroinvertebrate and periphytic diatom communities at Station E reflected the adverse affects of the O. J. Riedal STP discharge on the stream biota.

The data collected on this survey will be utilized by the Texas Department of Water Resources to update the waste load evaluation for Segment 1902 of Cibolo Creek.

METHODS

Field and laboratory procedures used are described in Appendix A. Data were collected April 16-17, May 8 and June 10-12, 1980 by Texas Department of Water Resources Water Quality Assessment Unit personnel assisted by TDWR District 8 personnel. Laboratory analyses of water samples were conducted by the Texas Department of Health Environmental Chemistry Lab. Parametric coverages, sampling frequencies and spatial relationships of sampling stations were consistent with the objectives of the survey and with known or suspected forms and variability of pollutants entering the stream.

Periphyton samples were collected by scraping a representative area from each type of substrate available at each station into a glass bottle. Diatoms were acid-cleaned and mounted in Hyrax. A total analysis time of 10 hr/station was spent during which all frustules encountered under 1500 magnification were counted and identified.

Personnel collecting water quality data on April 16-17 were David Buzan, Charles Ezell, Lynn Coles, David Petrick, Jeff Kirkpatrick, Steve Twidwell, Don Ottmers, Jack Davis, Richard Respess, Augustine De La Cruz and Henry Karnei. The reaeration survey was conducted by Don Ottmers, Steve Twidwell, Charles Ezell, Jack Davis and David Buzan. Jack Davis collected and analyzed the benthic macroinvertebrate data and David Buzan collected and analyzed the periphytic diatom data.

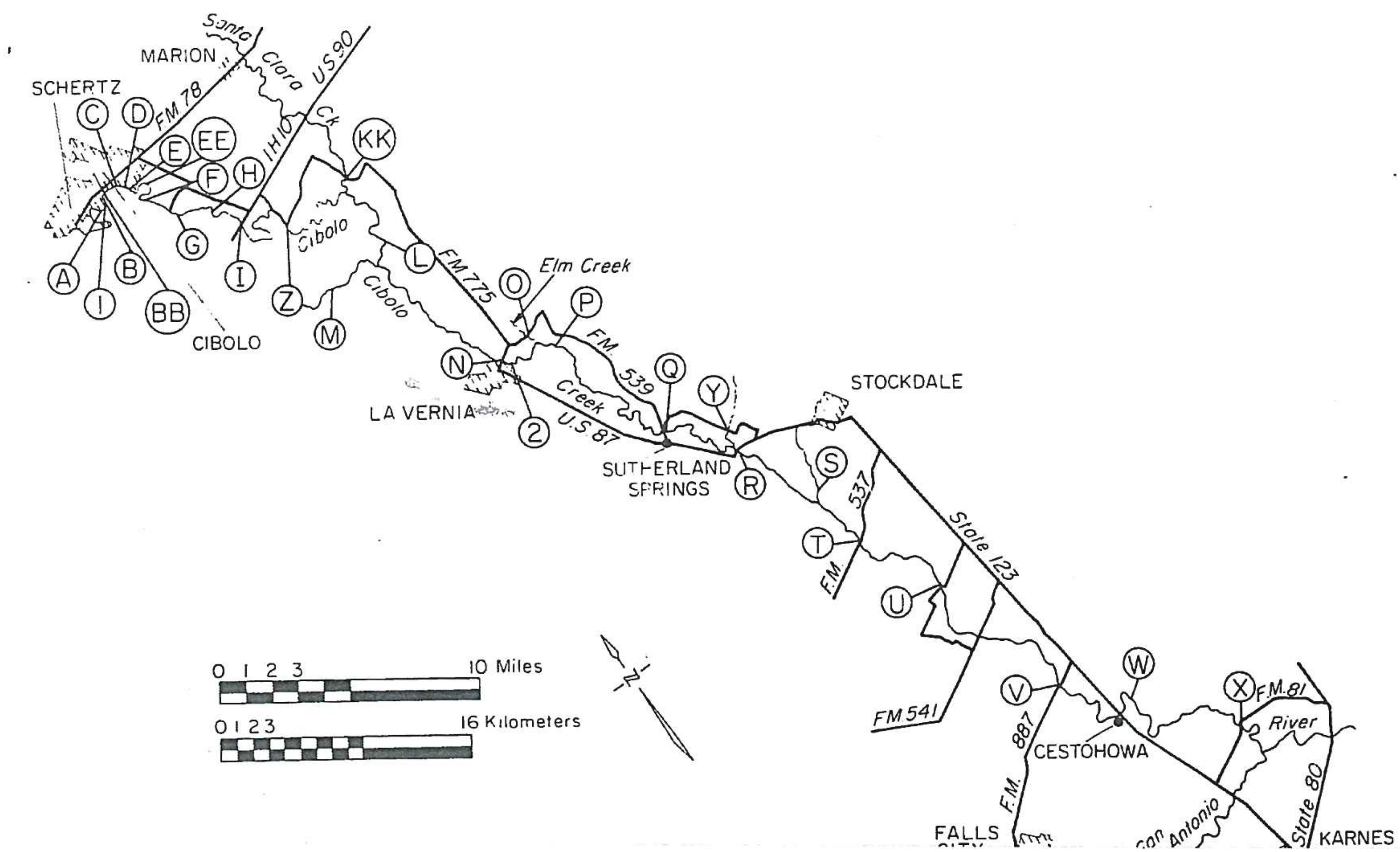
PRESENTATION OF DATA

Table 1
Cibolo Creek, Segment 1902, Waste Load Evaluation Survey Stations
4/16-17/80 and 6/10-12/80

Station	Station Description (Stream Monitoring Network Stations)	River Kilometer Upstream From Confluence With San Antonio River
	Cibolo Creek Stations	
A	South end of River Road in Schertz, immediately downstream from old Schertz STP	129.5
B	Middle of pool into which the Odo J. Riedal STP discharges	128.9
BB	Downstream end of pool into which the O. J. Riedal STP discharges	128.6
C	Upstream side of Cibolo City Park	127.6
D	Downstream end of pool on Don Brown's property	127.1
E	Schaefer Road (1902.0250)	126.8
EE	Upstream side of gravel operation	125.0
F	Furthest downstream crossing in gravel operation	123.2
G	Weir Road	120.8
H	Upstream side of Kenney's property	117.9
I	IH 10 (1902.0200)	115.2
Z	Trainer-Hale Road in Zuehl	107.0
J	Ulhrich Road, SE of Zuehl	103.5
L	FM 2538, W of New Berlin (1902.0180)	94.1
N	FM 775, N side of La Vernia (1902.0160)	79.2
P	County road SE of La Vernia	74.5
Q	FM 539, E of Sutherland Springs	60.0
R	US 87, W of Stockdale (1902.0150)	52.5

Table 1 (Cont.)
Cibolo Creek, Segment 1902, Waste Load Evaluation Survey Stations
4/16-17/80 and 6/10-12/80

Station	Station Description (Stream Monitoring Network Stations)	River Kilometer Upstream From Confluence With San Antonio River
T	FM 537, SW of Stockdale	41.8
U	Plummer Crossing N of Kosciusko	34.6
V	FM 887, W of Pawelekville	22.7
W	County Road E of Cestohowa	14.5
X	FM 81, E of Panna Maria (1902.0050)	4.0
	Tributary Stations	
K	Santa Clara Creek, County Road NW of New Berlin	99.1
M	Martinez Creek, Grable Road W of New Berlin	91.4
O	Elm Creek, FM 2772 NE of La Vernia	75.9
Y	Alum Creek, County Road NW of Stockdale	53.6
S	Clifton Branch, on Dale Valley Ranch SW of Stockdale	46.0
	Sewage Treatment Plants	
1	Odo J. Riedal STP, off Schaefer Road SE of Schertz	129.0
2	La Vernia STP, NE side of La Vernia	78.8



MARION
SCHERTZ
Santa
Clara
Ck
US 90
IH 10
FM 78
Cibolo
Cibolo
CIBOLO
FM 775
Elm Creek
FM 539
Creek
U.S. 87
LA VERNIA
SUTHERLAND
SPRINGS
STOCKDALE
537
F.M.
State 123
FM 541
F.M. 887
CESTOHOWA
FALLS
F.M. 81
River
State 80
KARNES
A
B
BB
C
D
E
EE
F
G
H
I
KK
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
2
0 1 2 3
10 Miles
0 1 2 3
16 Kilometers

Table 2
Cibolo Creek Cross-sections
(4/16/80)

Station	Width(m)	Depth(m)		
		Minimum	Maximum	Mean
A	9.9	0.76	1.24	1.06
B	23.1	0.38	1.07	0.83
	37.5	0.30	1.28	0.95
	28.9	0.94	1.95	1.51
BB	7.7	0.21	0.69	0.51
	12.9	0.21	0.73	0.59
C	7.3	0.43	0.75	0.57
	9.0	0.43	0.94	0.77
E	7.3 6.7	0.15	0.41	0.33
	6.1	0.17	0.32	0.27
F	26.5	0.94	1.58	1.32
	15.7	0.34	2.01	1.50
	6.0 19.55	0.06	0.34	0.21
	30.0	--	est. >2.45	--
G	6.3	0.12	0.42	0.30
	10.6	0.46	1.92	1.35
I	9.0	0.13	0.86	0.54
	9.0	0.23	0.48	0.38
J	22.7	0.30	1.25	0.80
	6.0	0.25	0.47	0.42
L	8.5	0.36	0.91	0.68
	9.8	0.86	1.22	1.01
N	15.8	0.30	1.17	0.88
	6.7	0.36	0.84	0.63
P	6.4	0.13	0.33	0.18
	8.8	0.10	0.74	0.57
	5.5	0.18	1.07	0.69
	10.4	0.13	0.51	0.35
Q	7.6	0.18	0.90	0.63
	12.8	0.44	1.09	0.92
R	8.5	0.18	0.28	0.22
	8.2	0.06	0.51	0.27
T	17.7 14.95	0.06	0.38	0.21
	12.2	0.13	0.59	0.45 ,33
U	9.1	0.21	0.79	0.51
	10.7 9.43	0.12	0.64	0.40 ,51
	8.5	0.27	0.79	0.62

Table 2 (Cont.)
Cibolo Creek Cross-sections
(4/16/80)

Station	Width(m)	Depth(m)		
		Minimum	Maximum	Mean
V	8.5	0.21	0.82	0.62
	12.8	0.15	0.30	0.24
	13.4	0.67	1.22	1.08
W	12.2	0.18	0.46	0.35
	11.0	0.15	0.64	0.45
	11.6	0.38	0.82	0.65
X	10.7	0.15	0.73	0.43
	10.1	0.09	0.43	0.32
	10.1	0.18	0.64	0.44

Table 3
Flow Data

Station	Date	Time	Discharge (m^3/sec)
	Cibolo Creek Stations		
A	4/16/80	1115	0.030
BB	4/16/80	1228	0.119
C	4/16/80	1445	0.100
E	4/16/80	1335	0.100
F	4/16/80	1535	0.096
G	4/16/80	1632	0.105
H	4/16/80	1732	0.175
I	4/17/80	0817	0.113
J	4/17/80	0608	0.198
L	4/17/80	0914	0.224
N	4/17/80	1042	0.358
P	4/17/80	1223	0.385
R	4/17/80	1350	0.664
T	4/17/80	1600	0.805
V	4/17/80	1838	0.787
USGS 08186000	4/16/80	1510	0.847*
USGS 08186000	4/17/80	1830	0.878*
X	4/17/80	1737	0.855
	Tributary Stations		
M	4/17/80	0712	0.069
O	4/17/80	1145	0.006
S	4/17/80	1516	0.001

Table 3 (Cont.)
Flow Data

Station	Date	Time	Discharge (m^3/sec)
	Sewage Treatment Plants		
1	4/15/80	(daily average)	0.087**
	4/16/80	(daily average)	0.087**
2	4/17/80	0620	0.00068***
		0955	0.00140***
		1245	0.00178***
		1600	0.00178***
		1850	0.00178***

* - Flow measurements taken from USGS gage at SH 123 between Stations V and W. All other instream flow measurements were made with a Marsh-McBirney Model 201 Electric Flow Meter.

** - Daily average computed from STP totalizer.

*** - Determined by measuring head over a 90°V-notch weir. (Table 6-1E, p. 96, in ISCO Open Channel Flow Measurement Handbook by D. M. Grant).

Table 4
Cibolo Creek Time-of-Travel
(6/10-12/80)

Station	Time-of-travel (hr.)	to Station	Discharge (m^3/sec)*	Distance (km)**	Velocity(m/sec)*** calculated
1	5.0	B	--	0.3	0.016
B	8.7	BB	0.052	0.3	0.010
BB	12.1	C	0.104	1.0	0.023
C	6.2	D	0.114	0.6	0.027
D	8.2	E	0.113	0.4	0.014

* - Measured at time of peak dye passage at downstream station with a Marsh-McBirney Model 201 Electronic Flow Meter.

** - Measured from 7.5 minute topographic map (Marion Quadrangle, Texas)

*** - Calculated by dividing distance (km) by time-of-travel between stations.

Table 5
Cibolo Creek Reaeration Data
(6/10-12/80)

Station	to	Station	Temp. (°C)	K_2 at Temp. (°C)	K_2 at 20°C
1		B	27.1 27.0	0.7423 1.0672	0.6494 .9555
B		BB	26.6 27.0	0.5332 .2454	0.4709 .2191
BB		C	26.2 26.5	1.5720 1.6407	1.3989 1.4518
C		D	26.9 27.2	0.4220 .4303	0.3706 .3758
D		E	26.7 26.6	0.9716 .9518	0.8565 .8406

Table 6
Cibolo Creek Stations
Field Measurements
4/17/80

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
A	0512	5.2	--	17.5	6.8	788	--	--
	0827	5.8	--	17.8	6.9	795	0	306
	1323	8.4	--	20.0	7.1	791	--	--
	1534	8.3	--	20.4	7.1	798	0	294
	1930	6.0	--	19.3	7.1	807	--	--
BB	0612	2.0	0.0	18.6	7.1	988	--	--
	0929	2.4	0.0	18.8	7.0	982	0	300
	1228	5.5	0.1	20.8	7.3	972	--	--
	1632	6.8	0.1	22.0	7.4	970	--	--
	1838	3.8	--	21.2	7.2	969	0	296
C	0537	1.6	--	18.6	7.1	980	--	--
	0845	2.1	--	18.8	7.1	978	--	286
	1305	4.6	--	20.3	7.3	972	--	--
	1551	5.2	--	21.2	7.4	966	--	308
	1917	3.1	--	21.1	7.3	971	--	--
E	0544	4.2	--	18.7	7.2	951	--	--
	0901	3.8	--	19.0	7.2	959	0	296
	1254	5.6	--	21.7	7.3	951	--	--
	1606	5.6	--	22.3	7.5	963	0	277
	1907	4.6	--	21.6	7.4	961	--	--
F	0559	6.6	--	18.8	7.3	937	--	--
	0915	6.8	--	18.9	7.3	934	0	296
	1245	8.4	--	21.2	7.4	932	--	--
	1618	9.3	--	22.8	7.6	928	0	288
	1857	8.2	--	22.3	7.5	924	--	--
G	0525	5.3	--	18.8	7.3	897	--	--
	0900	5.3	--	18.6	7.3	898	0	294
	1200	6.1	--	18.9	7.4	901	--	--
	1500	7.1	--	20.3	7.6	904	0	296
	1830	7.4	--	20.5	7.7	900	--	--
H	0545	7.6	--	18.3	7.6	880	--	--
	0915	7.7	--	18.3	7.6	888	0	288
	1215	8.4	--	18.8	7.8	891	--	--
	1520	10.3	--	21.5	8.0	888	0	288
	1845	10.7	--	20.1	8.1	888	--	--
I	0600	4.1	--	19.3	7.4	846	--	--
	0935	4.3	--	19.2	7.5	852	0	288
	1225	8.1	--	20.5	7.9	847	--	--
	1530	9.1	--	22.4	8.0	845	0	294
	1900	6.2	--	21.9	7.8	852	--	--

Table 6 (Cont.)
Field Measurements
4/17/80

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
J	0630	7.5	--	17.6	7.6	839	--	--
	1010	7.5	--	18.0	7.6	853	0	298
	1300	8.2	--	19.2	7.8	849	--	--
	1610	8.1	--	19.6	7.8	850	0	296
	1940	8.4	--	19.6	7.8	852	--	--
L	0500	7.7	--	18.2	7.6	900	--	--
	0845	7.7	--	18.1	7.7	903	0	310
	1145	7.9	--	18.8	7.8	903	--	--
	1500	8.7	--	20.3	8.0	906	0	300
	1750	8.5	--	20.3	8.1	901	--	--
N	0538	8.3	--	19.0	7.7	1100	0	292
	0920	8.5	--	19.2	7.7	1110	--	--
	1215	9.4	--	20.1	7.8	1113	--	--
	1520	9.9	--	21.6	7.9	1115	0	282
	1820	9.0	--	21.1	8.0	1115	--	--
P	0600	7.8	--	18.6	7.7	1150	--	--
	0940	8.0	--	19.0	7.8	1150	0	282
	1230	8.9	T*	20.4	7.9	1143	--	--
	1545	9.5	--	22.4	8.0	1145	0	286
	1830	8.7	--	21.6	8.0	1152	--	--
Q	0540	6.6	--	18.7	7.2	1017	--	--
	0840	6.6	T*	19.1	7.3	1016	0	245
	1200	6.7	--	20.3	7.3	1010	--	--
	1455	7.2	--	21.8	7.3	1008	0	240
	1805	7.2	--	21.6	7.3	1012	--	--
R	0615	7.4	--	18.5	7.4	1062	--	--
	0930	8.0	T*	19.3	7.5	1066	0	244
	1215	8.9	--	20.5	7.6	1069	--	--
	1510	9.2	--	21.7	7.7	1070	0	228
	1815	7.9	--	20.7	7.6	1074	--	--
T	0640	7.9	--	19.5	7.7	1189	--	--
	1050	7.3	--	19.1	7.6	1184	0	244
	1315	7.7	--	20.1	7.7	1179	--	--
	1700	8.5	--	21.0	7.7	1181	0	236
	1900	8.5	--	20.5	7.7	1187	--	--
U	0600	7.7	--	18.8	7.8	1402	--	--
	0905	8.0	--	19.3	7.8	1304	0	246
	1205	9.7	--	20.9	8.0	1298	--	--
	1530	10.0	--	22.0	8.0	1436	0	254
	1845	8.4	--	20.7	7.9	1355	--	--
V	0620	8.0	--	17.7	7.8	1657	--	--
	0930	8.0	--	18.1	7.8	1525	0	252
	1330	9.0	--	20.0	7.9	1509	--	--
	1600	8.7	--	20.9	7.9	1600	0	249
	1915	8.3	--	20.5	7.8	1620	--	--

Table 6 (Cont.)
Cibolo Creek Stations
Field Measurements
4/17/80

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
W	0640	7.7	--	17.9	7.9	1646	--	--
	1000	7.9	--	18.4	8.0	1440	0	258
	1415	9.3	--	20.1	8.0	1505	--	--
	1630	8.3	--	20.0	7.9	1569	0	260
	1930	8.7	--	20.0	7.9	1647	--	--
X	0655	7.7	--	17.8	8.0	1556	--	--
	1045	8.0	--	19.0	7.9	1515	0	262
	1455	9.2	--	21.0	8.1	1584	--	--
	1740	8.9	--	20.4	8.0	1626	0	261
	2010	8.6	--	20.1	8.0	1685	--	--

Table 7
Station D Continuous Monitoring
Field Measurements
4/16-17/80

Station No.	Time	Dissolved Oxygen mg/l	Temp. °C	pH	Conductivity µmhos/cm
	4/16/80				
D	1316	4.2	18.0	7.4	1000
	1327	4.4	18.4	7.4	1000
	1337	4.5	18.2	7.5	1000
	1348	4.6	18.5	7.5	1000
	1358	4.8	18.7	7.5	1000
	1409	4.7	18.8	7.5	1000
	1419	4.8	18.9	7.5	1000
	1430	5.2	18.9	7.5	1000
	1440	5.1	19.0	7.5	1000
	1451	5.2	19.1	7.5	1000
	1501	5.5	19.0	7.5	1000
	1512	5.6	19.1	7.6	1000
	1522	5.6	19.2	7.6	1000
	1533	5.8	19.3	7.6	1000
	1543	5.8	19.4	7.6	950
	1554	6.0	19.3	7.6	950
	1604	6.1	19.3	7.6	950
	1615	6.0	19.4	7.6	950
	1625	6.0	19.4	7.6	950
	1636	6.1	19.3	7.6	950
	1646	6.2	19.2	7.6	950
	1657	6.3	19.2	7.6	950
	1707	6.3	19.2	7.6	950
	1718	6.3	19.2	7.6	950
	1728	6.4	19.2	7.6	950
	*1739	6.6	20.2	7.8	1000
	1750	6.4	19.1	7.6	950
	1801	6.4	19.0	7.6	950
	1811	6.4	19.0	7.6	950
	1822	6.5	19.0	7.7	950
	1832	6.6	18.9	7.7	950
	1843	6.7	18.9	7.7	950
	1853	6.8	18.8	7.7	950
	1904	6.8	18.8	7.7	950
	1914	6.8	18.8	7.7	950
	1925	6.8	18.8	7.7	950

* - Indicates readings taken from Hydrolab surface unit instead of strip-chart recorder.

Table 7(cont.)
Station D Continuous Monitoring
Field Measurements
4/16-17/80

Station No.	Time	Dissolved Oxygen mg/l	Temp. °C	pH	Conductivity µmhos/cm
	4/16/80				
D	1935	6.9	18.9	7.7	950
	1946	7.0	18.9	7.7	950
	1956	7.0	18.9	7.7	950
	2007	7.0	18.9	7.7	950
	2017	7.0	18.9	7.7	950
	2028	7.0	19.0	7.7	950
	2038	7.0	18.9	7.7	950
	2049	7.0	19.0	7.7	950
	2059	7.0	18.9	7.7	950
	2110	6.9	19.0	7.7	950
	2120	6.9	18.9	7.7	950
	2131	6.9	18.9	7.7	950
	2141	6.9	18.9	7.7	950
	2152	6.9	18.8	7.7	950
	2202	6.8	18.8	7.7	950
	2213	6.8	18.8	7.7	900
	2223	6.8	18.8	7.7	950
	2234	6.7	18.8	7.7	950
	2244	6.7	18.9	7.7	950
	*2317	6.8	20.0	7.9	1000
	2328	6.6	18.8	7.7	950
	2339	6.5	18.8	7.7	950
	2350	6.4	18.8	7.7	950
	4/17/80				
	0001	6.4	18.8	7.6	950
	0012	6.4	18.7	7.7	950
	0023	6.3	18.7	7.7	950
	0034	6.3	18.7	7.7	950
	0045	6.2	18.7	7.7	950
	0056	6.2	18.7	7.7	950
	0107	6.2	18.7	7.7	950
	0118	6.1	18.7	7.6	950
	0129	6.0	18.7	7.6	950
	0140	6.0	18.7	7.7	950
	0151	6.0	18.7	7.7	950
	0202	5.9	18.6	7.6	950
	0213	5.9	18.6	7.6	950
	0224	5.8	18.6	7.6	950

* - Indicates readings taken from Hydrolab surface unit instead of strip-chart recorder.

Table 7(cont.)
Station D Continuous Monitoring
Field Measurements
4/16-17/80

Station No.	Time	Dissolved Oxygen mg/l	Temp. °C	pH	Conductivity μmhos/cm
	4/17/80				
D	0235	5.7	18.6	7.6	950
	0246	5.6	18.6	7.6	950
	0257	5.5	18.6	7.6	950
	0308	5.4	18.6	7.6	950
	0319	5.3	18.6	7.6	950
	0330	5.2	18.6	7.6	950
	0341	5.1	18.5	7.6	950
	0352	5.0	18.5	7.6	950
	0403	4.9	18.5	7.6	900
	0414	4.7	18.4	7.6	950
	0425	4.5	18.5	7.6	950
	0436	4.3	18.5	7.6	950
	0447	4.2	18.5	7.6	950
	0458	4.1	18.5	7.6	950
	0509	4.0	18.4	7.6	950
	0610	3.8	18.4	7.6	950
	0621	3.6	18.5	7.6	950
	0632	3.5	18.5	7.6	950
	0643	3.3	18.5	7.6	950
	0654	3.2	18.5	7.5	950
	0705	3.1	18.5	7.5	950
	0716	3.0	18.5	7.5	950
	0727	2.9	18.5	7.5	950
	0738	2.8	18.5	7.5	950
	0749	2.7	18.5	7.5	1000
	0800	2.6	18.6	7.5	1000
	0811	2.5	18.6	7.5	1000
	0822	2.5	18.6	7.5	1000
	0833	2.4	18.6	7.5	---

Table 8
Station EE Continuous Monitoring
Field Measurements
4/16-17/80

Station No.	Time	Dissolved Oxygen mg/l	Temp. °C	pH	Conductivity µmhos/cm
	4/16/80				
EE	*1323	4.4	17.0	8.3	800
	1335	4.5	17.0	8.4	800
	1347	4.6	17.0	8.5	780
	1359	4.5	17.0	8.5	770
	1411	4.6	17.2	8.6	740
	1423	4.6	17.2	8.6	720
	1435	4.7	17.4	8.7	710
	1447	4.8	17.5	8.7	700
	1459	4.9	17.2	8.7	690
	1511	4.9	17.5	8.7	670
	1523	4.9	17.4	8.8	660
	1535	4.9	17.5	8.8	640
	1547	4.9	17.5	8.8	640
	1559	4.9	17.5	8.8	640
	1611	4.9	17.4	8.8	640
	1623	5.0	17.4	8.8	630
	1635	5.0	17.4	8.8	620
	1647	5.0	17.2	8.8	600
	1659	5.1	17.2	8.8	600
	1711	5.1	17.1	8.9	600
	*1730	5.1	17.0	8.85	790
	1742	5.1	17.0	8.9	590
	1754	5.0	17.0	8.9	580
	1806	5.0	17.0	8.9	570
	1818	4.9	17.0	8.9	570
	1830	4.9	16.8	8.9	560
	1842	4.9	16.8	8.9	560
	1854	5.0	16.7	9.0	560
	1906	5.0	16.7	9.0	560
	1918	5.0	16.7	9.0	550
	1930	5.0	16.7	9.0	550
	1942	5.1	16.6	9.0	530
	1954	5.5	16.6	9.0	540
	2006	5.6	16.5	9.0	530
	2018	5.7	16.5	9.1	520
	2030	5.7	16.5	9.1	520
	2042	5.6	16.5	9.1	520
	2054	5.6	16.4	9.2	520

* - Indicates readings taken from Hydrolab surface unit instead of strip-chart recorder.

Table 8 (Cont.)
Station EE Continuous Monitoring
Field Measurements
4/16-17/80

Station No.	Time	Dissolved Oxygen mg/l	Temp. °C	pH	Conductivity µmhos/cm
	4/16/80				
EE	2106	5.6	16.4	9.2	520
	2118	5.7	16.4	9.2	520
	2130	5.6	16.4	9.2	510
	2142	5.8	16.4	9.3	520
	2154	5.7	16.4	9.2	510
	2206	5.6	16.3	9.3	510
	2218	5.7	16.3	9.3	510
	2230	5.6	16.3	9.3	500
	2242	5.5	16.3	9.4	500
	*2303	5.4	16.2	7.4	750
	2315	5.3	16.2	9.4	490
	2327	5.4	16.2	9.4	500
	2339	5.3	16.2	9.4	490
	2351	5.4	16.1	9.5	490
	2403	5.3	16.1	9.5	490
	2415	5.3	16.1	9.5	480
	2427	5.3	16.0	9.5	480
	2439	5.2	16.0	9.5	490
	4/17/80				
EE	2451	5.2	16.0	9.5	480
	0003	5.1	16.0	9.6	480
	0015	5.0	15.9	9.6	470
	0027	5.0	15.7	9.6	480
	0039	4.9	15.8	9.6	470
	0051	5.0	15.8	9.6	480
	0103	4.9	15.7	9.7	480
	0115	4.8	15.7	9.7	480
	0127	4.8	15.6	9.7	480
	0139	4.6	15.6	9.7	470
	0151	4.6	15.6	9.8	480
	0203	4.5	15.6	9.8	490
	0215	4.3	15.6	9.8	490
	0227	4.3	15.5	9.8	490
	0239	4.2	15.4	9.8	480
	0251	4.1	15.5	9.8	480
	0303	4.0	15.4	9.8	480
	0315	3.9	15.6	9.8	470
	0327	4.0	15.5	9.8	470
	0339	3.8	15.6	9.8	470

* - Indicates readings taken from Hydrolab surface unit instead of strip chart recorder.

Table 8 (Cont.)
Station EE Continuous Monitoring

Field Measurements
4/16-17/80

Station No.	Time	Dissolved Oxygen mg/1	Temp. °C	pH	Conduc-tivity µmhos/cm
	4/17/80				
EE	0351	3.8	15.4	9.8	470
	0403	3.8	15.4	9.8	470
	0415	3.7	15.3	9.8	470
	0427	3.7	15.4	9.9	470
	0439	3.6	15.4	9.9	470
	0451	3.5	15.4	9.8	470
	0503	3.5	15.4	9.8	470
	0515	3.5	15.3	9.8	470
	0527	3.4	15.2	9.8	480
	0539	3.3	15.3	9.8	470
	0551	3.3	15.2	9.8	470
	0603	3.2	15.2	9.7	470
	0615	3.2	15.2	9.8	470
	0627	3.1	15.2	9.8	470
	0639	3.1	15.2	9.8	470
	0651	3.1	15.3	9.8	470
	0703	3.1	15.2	9.8	480
	0715	3.0	15.2	9.9	470
	0727	3.0	15.2	9.9	480
	0739	2.9	15.3	9.9	470
	0751	3.0	15.4	9.9	460
	0803	3.0	15.4	9.9	460
	0815	2.9	15.4	9.9	460
	0827	2.9	15.3	9.9	470
	0839	2.8	15.4	9.9	470
	0851	2.8	15.4	9.9	470
	0903	3.0	15.4	10.0	480
	0915	2.8	15.5	10.0	480
	0927	2.7	15.4	9.9	480
	0939	2.8	15.4	9.9	480
	0951	2.8	15.4	9.9	480
	1003	2.7	15.4	9.9	470
	1015	2.6	15.5	9.8	460
	1027	2.6	15.5	9.8	470
	1039	2.4	15.5	9.8	460
	1051	2.6	15.6	9.8	460
	1103	2.6	15.7	9.7	470
	1115	2.7	15.8	9.6	470
	1127	2.6	15.8	9.6	470
	1139	2.7	15.8	9.6	470

Table 8 (Cont.)
Station EE Continuous Monitoring

Field Measurements
4/16-17/80

Station No.	Time	Dissolved Oxygen mg/l	Temp. °C	pH	Conductivity µmhos/cm
	4/17/80				
EE	1151	2.7	15.9	9.6	460
	1203	2.7	16.0	9.6	460
	1215	2.6	16.3	9.5	450
	1227	2.8	16.3	9.5	450
	1239	3.0	16.4	9.5	440
	1251	3.0	16.4	9.5	450
	1303	3.5	16.5	9.5	450
	1315	3.5	16.7	9.4	450
	1327	3.8	16.8	9.4	450
	1339	3.9	16.8	9.4	440
	1351	4.1	17.0	9.4	440
	1403	3.6	17.0	9.4	440
	1415	4.4	17.3	9.4	440
	1427	4.9	17.2	9.4	450
	1439	4.8	17.2	9.4	450
	1451	4.9	17.3	9.4	440
	1503	5.0	17.4	9.4	430
	1515	4.6	17.3	9.4	440
	1527	5.6	17.5	9.4	440
	1539	5.7	17.5	9.4	440
	1551	5.6	17.5	9.5	420
	1603	5.4	17.5	9.5	420
	1615	5.0	17.4	9.5	420
	**1720	4.7	17.5	9.5	790

** pH - recalibrated, read 7.7 in 7.0 buffer
Conductivity - recalibrated, read 800 in 1460 standard

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Table 9
Cibolo Creek Reaeration Survey
Field Measurements
6/10-12/80

Station No.	Time	Dissolved Oxygen mg/l	Temp. °C	pH	Conductivity µmhos/cm
	6/10/80				
B	1428	3.6	27.5	7.0	898
	2031	5.7	27.3	7.1	917
	2212	3.5	26.4	7.0	891
	6/11/80				
	0004	3.4	26.3	7.1	894
BB	*0159	2.9	26.1	6.9	903
	0231	2.6	26.0	6.8	900
C	0733	2.2	25.3	6.9	910
	0910	2.1	25.7	6.9	924
	0950	2.3	25.8	7.0	924
	1109	2.4	26.2	7.0	904
	1310	2.9	26.9	7.1	899
	*1400	3.1	26.9	7.1	899
	1505	3.4	27.1	7.1	900
	6/11/80				
D	1800	6.7	28.2	7.3	896
	1900	6.1	27.7	7.3	900
	2000	5.1	27.5	7.2	903
	*2040	4.7	27.4	7.2	905
	2155	5.2	27.2	7.3	909
	6/12/80				
E	0110	2.0	26.3	7.1	910
	0310	1.4	26.0	7.1	913
	*0410	1.3	25.7	7.1	915
	*0505	1.3	25.5	7.0	917
	0600	1.2	25.4	7.0	918

* - Indicates time of dye peak passage

Table 10
Tributary Stations
Field Measurements
4/17/80

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
K	1630	18.1	--	24.7	8.7	1354	1.2	110
M	0615	7.6	--	16.8	7.7	1150	--	--
	0955	7.4	--	17.2	7.7	1158	0	208
	1245	7.1	--	17.7	7.9	1168	--	--
	1555	7.2	--	18.2	7.9	1166	0	200
	1925	7.5	--	18.6	7.8	1179	--	--
O	1300	8.7	--	21.9	7.4	6040	0	380
S	0700	6.7	--	17.6	7.4	2370	--	--
	1005	7.6	--	19.1	7.5	2370	0	286
	1250	9.1	--	23.0	7.6	2360	--	--
	1615	9.5	--	24.8	7.8	2360	0	278
	1835	9.5	--	22.4	7.7	2360	--	--
Alum Cr.	1730	7.1	--	27	2.1	3820	0	0

Table 11
Sewage Treatment Plant Stations
Field Measurements
4/17/80

Station No.	Time	Dissolved Oxygen mg/l	Chlorine Residual mg/l	Temp. °C	pH	Conductivity umhos/cm	Alkalinity P-Alk	Alkalinity T-Alk
1	0639	6.4	0.5	18.1	7.2	910	--	--
	0946	7.5	1.0	20.0	7.4	933	0	256
	1212	7.9	1.5	22.1	7.5	944	--	--
	1652	7.7	1.6	23.5	7.6	1022	--	262
	1955	7.8	--	21.9	7.5	1028	--	--
2	0620	4.8	--	20.6	6.9	2430	--	--
	0955	4.2	1.2	20.3	7.0	2470	--	--
	1245	4.3	1.2	20.7	7.2	2500	--	--
	1600	4.1	0.8	21.2	7.5	2500	0	262
	1850	4.4	--	21.3	7.3	2510	--	--

Table 12
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	A	BB(Comp)	BB(0612)	BB(0929)	BB(1228)
pH	7.6	7.7	7.6	7.6	7.8
Conductivity	852	1036	1043	--	--
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	< 10	< 10	16	< 10	< 10
Volatile Suspended Solids	< 10	< 10	4	< 10	< 10
Ammonia Nitrogen	0.04	4.74	4.94	4.73	4.83
Nitrite Nitrogen	0.03	1.03	1.02	0.97	1.04
Nitrate Nitrogen	2.81	4.39	4.25	4.70	4.44
Kjeldahl Nitrogen	0.4	6.0	6.0	6.6	5.6
Total Phosphorus	0.12	5.31	5.39	5.34	5.52
Ortho Phosphorus	0.11	5.14	5.20	5.04	5.23
Chloride	37	88	--	--	--
Sulfate	44	53	--	--	--
Total Dissolved Solids	472	560	570	570	560
Total Organic Carbon (filtered)	3	6	7	7	7
BOD_5 (Nitrogen Suppressed)	2	5	4.5	4.5	4
BOD_5 (Filtered, Nitrogen Suppressed)	1	3	3.5	3	3
BOD_{20} (Nitrogen Suppressed)	4	12	14	13	13
BOD_{20} (Filtered, Nitrogen Suppressed)	2.5	11	13	11	11
Chlorophyll a	0.005	0.005	--	--	--
Pheophytin a	0.002	< 0.002	--	--	--

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	BB(1632)	BB(1838)	C	E(Comp)	E(0544)
pH	7.8	7.7	7.6	7.8	7.7
Conductivity	--	--	1015	994	--
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	< 10	< 10	< 10	< 10	< 10
Volatile Suspended Solids	< 10	< 10	< 10	< 10	< 10
Ammonia Nitrogen	4.64	4.99	4.41	3.75	3.77
Nitrite Nitrogen	1.06	1.09	1.04	1.02	0.99
Nitrate Nitrogen	4.61	4.62	4.48	4.63	4.58
Kjeldahl Nitrogen	6.0	6.2	5.4	4.5	4.3
Total Phosphorus	5.31	5.41	5.31	5.06	5.04
Ortho Phosphorus	5.09	5.17	5.06	4.92	4.85
Chloride	--	--	85	82	--
Sulfate	--	--	53	53	--
Total Dissolved Solids	560	560	570	540	530
Total Organic Carbon (filtered)	5	7	6	5	7
BOD_5 (Nitrogen Suppressed)	4.5	4.5	4	4.5	4.5
BOD_5 (Filtered, Nitrogen Suppressed)	2.5	3.5	2.5	2.5	3
BOD_{20} (Nitrogen Suppressed)	14	14	11	11	11
BOD_{20} (Filtered, Nitrogen Suppressed)	10	11	11	9	9
Chlorophyll a	--	--	0.004	0.002	--
Pheophytin a	--	--	< 0.002	0.002	--

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	E(0901)	E(1254)	E(1606)	E(1907)	F(Comp)
pH	7.8	7.9	7.8	7.9	7.9
Conductivity	--	--	--	--	984
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	< 10	< 10	< 10	< 10	< 10
Volatile Suspended Solids	< 10	< 10	< 10	< 10	< 10
Ammonia Nitrogen	3.74	3.65	3.67	3.80	1.13
Nitrite Nitrogen	1.05	1.05	1.05	1.01	0.51
Nitrate Nitrogen	4.64	4.79	4.70	4.56	4.30
Kjeldahl Nitrogen	5.1	5.0	5.5	5.1	2.4
Total Phosphorus	5.19	5.23	5.69	5.03	3.85
Ortho Phosphorus	4.95	4.95	4.86	4.95	3.73
Chloride	--	--	--	--	83
Sulfate	--	--	--	--	54
Total Dissolved Solids	560	550	550	550	520
Total Organic Carbon (filtered)	6	5	6	7	5
BOD_5 (Nitrogen suppressed)	3.5	3.5	4	3.5	4
BOD_5 (Filtered, Nitrogen Suppressed)	2.5	2	3	1	1.5
BOD_{20} (Nitrogen Suppressed)	11	11	12	10.5	9
BOD_{20} (Filtered, Nitrogen Suppressed)	9	8	9	4	4
Chlorophyll a	--	--	--	--	0.020
Pheophytin a	--	--	--	--	< 0.002

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	F(0559)	F(0915)	F(1245)	F(1618)	F(1857)
pH	7.9	8.0	7.9	8.0	7.9
Conductivity	--	--	--	--	--
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	15	10	< 10	10	13
Volatile Suspended Solids	5	1	< 10	1	2
Ammonia Nitrogen	1.19	1.22	1.11	1.06	1.11
Nitrite Nitrogen	0.48	0.49	0.50	0.50	0.51
Nitrate Nitrogen	4.16	4.30	4.25	4.33	4.51
Kjeldahl Nitrogen	1.3	1.6	2.0	1.8	2.7
Total Phosphorus	3.87	3.87	3.81	3.80	3.83
Ortho Phosphorus	3.81	3.80	3.72	3.66	3.70
Chloride	--	--	--	--	--
Sulfate	--	--	--	--	--
Total Dissolved Solids	550	530	520	540	560
Total Organic Carbon (filtered)	6	4	5	6	6
BOD_5 (Nitrogen Suppressed)	2.5	3	3	4.5	5.5
BOD_5 (Filtered, Nitrogen Suppressed)	2	1.5	2	2	2.5
BOD_{20} (Nitrogen Suppressed)	6	6.5	7	8.5	11
BOD_{20} (Filtered, Nitrogen Suppressed)	5	4.5	4.5	4.5	5.5
Chlorophyll a	--	--	--	--	--
Pheophytin a	--	--	--	--	--

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	G	H	I(Comp)	I(0600)	I(0925)
pH	7.6	7.7	7.7	8.0	8.0
Conductivity	966	954	900	912	--
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	21	15	19	36	19
Volatile Suspended Solids	5	7	5	7	4
Ammonia Nitrogen	0.08	< 0.02	0.15	0.20	0.20
Nitrite Nitrogen	0.16	0.05	0.05	0.05	0.05
Nitrate Nitrogen	4.19	3.71	2.03	2.06	2.08
Kjeldahl Nitrogen	0.9	0.8	0.8	0.7	0.7
Total Phosphorus	3.34	3.05	2.14	2.16	2.21
Ortho Phosphorus	3.25	2.95	2.06	2.08	2.11
Chloride	76	75	70	--	--
Sulfate	51	51	49	--	--
Total Dissolved Solids	540	520	500	510	510
Total Organic Carbon (filtered)	3	4	4	3	2
BOD_5 (Nitrogen suppressed)	1.5	2	1	1	1
BOD_5 (Filtered, Nitrogen Suppressed)	1	1	1	1	0.5
BOD_{20} (Nitrogen Suppressed)	4.5	5	3	3.5	3
BOD_{20} (Filtered, Nitrogen Suppressed)	3	2.5	2.5	2.5	2
Chlorophyll a	0.017	0.025	0.003	--	--
Pheophytin a	< 0.002	0.006	0.003	--	--

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	I(1225)	I(1530)	I(1900)	J	L
pH	8.5	8.3	8.0	7.9	7.9
Conductivity	--	--	--	906	954
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	22	11	32	18	18
Volatile Suspended Solids	5	3	6	5	2
Ammonia Nitrogen	0.08	0.11	0.17	0.03	0.04
Nitrite Nitrogen	0.05	0.05	0.04	0.02	0.03
Nitrate Nitrogen	1.98	2.06	3.97	3.00	3.29
Kjeldahl Nitrogen	0.7	0.7	0.9	0.4	0.4
Total Phosphorus	2.04	2.04	2.13	0.98	0.67
Ortho Phosphorus	2.00	2.00	2.08	0.95	0.64
Chloride	--	--	--	61	64
Sulfate	--	--	--	50	60
Total Dissolved Solids	478	500	510	496	500
Total Organic Carbon (filtered)	3	3	3	2	2
BOD_5 (Nitrogen Suppressed)	1.5	1	1	0.5	1
BOD_5 (Filtered, Nitrogen Suppressed)	1	0.5	1	< 0.5	0.5
BOD_{20} (Nitrogen Suppressed)	3.5	3	3	1.5	2
BOD_{20} (Filtered, Nitrogen Suppressed)	2.5	2.5	2.5	1	2
Chlorophyll a	--	--	--	0.003	0.002
Pheophytin a	--	--	--	< 0.002	< 0.002

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	N	P(Comp)	P(0600)	P(0940)	P(1230)
pH	7.9	7.9	8.1	8.1	--
Conductivity	1200	1232	--	--	--
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	22	16	27	18	17
Volatile Suspended Solids	2	1	1	1	1
Ammonia Nitrogen	< 0.02	0.03	0.04	0.04	0.05
Nitrite Nitrogen	0.02	0.02	0.02	0.02	0.02
Nitrate Nitrogen	2.71	2.82	2.82	2.79	1.68
Kjeldahl Nitrogen	0.8	0.6	0.7	0.7	0.6
Total Phosphorus	1.04	0.95	0.98	0.95	0.95
Ortho Phosphorus	1.03	0.91	0.92	0.89	0.89
Chloride	107	114	--	--	--
Sulfate	106	113	--	--	--
Total Dissolved Solids	670	680	680	690	690
Total Organic Carbon (filtered)	4	3	4	3	3
BOD_5 (Nitrogen Suppressed)	1	1	0.5	1	0.5
BOD_5 (Filtered, Nitrogen Suppressed)	0.5	0.5	0.5	0.5	< 0.5
BOD_{20} (Nitrogen Suppressed)	3	2	2	2	2
BOD_{20} (Filtered, Nitrogen Suppressed)	1.5	1.5	1.5	1.5	1
Chlorophyll a	0.003	0.003	--	--	--
Pheophytin a	< 0.002	< 0.002	--	--	--

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	P(1545)	P(1830)	Q	R	T
pH	8.3	8.3	7.9	7.9	8.0
Conductivity	--	--	1078	1148	1296
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	20	19	29	18	19
Volatile Suspended Solids	4	3	2	2	4
Ammonia Nitrogen	0.02	0.04	0.06	0.05	0.05
Nitrite Nitrogen	0.03	0.02	0.02	0.01	0.01
Nitrate Nitrogen	1.67	2.71	2.07	1.86	1.40
Kjeldahl Nitrogen	1.0	0.6	0.5	0.5	0.5
Total Phosphorus	0.95	0.95	0.57	0.44	0.24
Ortho Phosphorus	0.87	0.88	0.47	0.36	0.17
Chloride	--	--	103	106	114
Sulfate	--	--	116	142	186
Total Dissolved Solids	690	690	580	640	730
Total Organic Carbon (filtered)	4	4	3	3	3
BOD_5 (Nitrogen Suppressed)	1.5	1	1	1.5	1
BOD_5 (Filtered, Nitrogen Suppressed)	1.5	< 0.5	0.5	0.5	1
BOD_{20} (Nitrogen Suppressed)	3.5	2	2.5	3	2.5
BOD_{20} (Filtered, Nitrogen Suppressed)	2.5	1.5	1.5	1.5	1.5
Chlorophyll a	--	--	0.002	0.005	0.004
Pheophytin a	--	--	< 0.002	< 0.002	< 0.002

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	U	V	W	X(Comp)	X(0655)
pH	7.7	7.7	7.8	7.9	8.1
Conductivity	1431	1720	1720	1804	--
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	20	34	32	34	66
Volatile Suspended Solids	2	5	4	4	7
Ammonia Nitrogen	0.04	0.03	0.02	0.02	0.03
Nitrite Nitrogen	0.01	0.01	0.01	0.01	0.01
Nitrate Nitrogen	1.32	1.26	1.32	1.32	1.34
Kjeldahl Nitrogen	0.5	0.6	0.5	0.5	0.5
Total Phosphorus	0.20	0.18	0.19	0.21	0.21
Ortho Phosphorus	0.16	0.12	0.15	0.16	0.16
Chloride	133	174	174	185	--
Sulfate	215	281	275	286	--
Total Dissolved Solids	790	910	920	990	1030
Total Organic Carbon (filtered)	3	3	3	4	4
BOD_5 (Nitrogen Suppressed)	1	1	1	1	1
BOD_5 (Filtered, Nitrogen Suppressed)	< 0.5	< 0.5	0.5	1	1
BOD_{20} (Nitrogen Suppressed)	2	3	2.5	2	2.5
BOD_{20} (Filtered, Nitrogen Suppressed)	1.5	1.5	1.5	2	2.5
Chlorophyll a	0.005	0.005	0.006	0.002	--
Pheophytin a	< 0.002	< 0.002	< 0.002	< 0.002	--

Table 12 (Cont.)
Cibolo Creek Stations
Laboratory Measurements
4/17/80

Parameter	Station Number			
	X(1045)	X(1455)	X(1740)	X(2010)
pH	8.2	8.2	8.2	8.2
Conductivity	--	--	--	--
Total Alkalinity	--	--	--	--
Total Suspended Solids	46	44	42	47
Volatile Suspended Solids	4	4	5	7
Ammonia Nitrogen	0.02	0.02	< 0.02	< 0.02
Nitrite Nitrogen	0.01	0.01	0.01	0.01
Nitrate Nitrogen	1.34	1.33	1.36	1.33
Kjeldahl Nitrogen	0.5	0.5	0.6	0.7
Total Phosphorus	0.21	0.21	0.21	0.21
Ortho Phosphorus	0.16	0.15	0.16	0.16
Chloride	--	--	--	--
Sulfate	--	--	--	--
Total Dissolved Solids	1010	1000	1000	1020
Total Organic Carbon (filtered)	3	3	3	3
BOD_5 (Nitrogen Suppressed)	1	1.5	1	1
BOD_5 (Filtered, Nitrogen Suppressed)	0.5	1	0.5	0.5
BOD_{20} (Nitrogen Suppressed)	2.5	3	2.5	2
BOD_{20} (Filtered, Nitrogen Suppressed)	2	2	2	1.5
Chlorophyll a	--	--	--	--
Pheophytin a	--	--	--	--

Table 13
Tributary Stations
Laboratory Measurements
4/17/80

Parameter	Station Number				
	K	M	O	S	Alum Creek
pH	8.7	7.7	7.8	8.1	3.0
Conductivity	1476	1264	1330	2720	5208
Total Alkalinity	--	--	--	--	--
Total Suspended Solids	15	45	10	< 10	< 10
Volatile Suspended Solids	5	4	1	< 10	< 10
Ammonia Nitrogen	0.02	0.06	0.15	< 0.02	0.09
Nitrite Nitrogen	< 0.01	0.03	0.06	< 0.01	< 0.01
Nitrate Nitrogen	< 0.01	2.17	0.39	< 0.01	< 0.01
Kjeldahl Nitrogen	0.8	1.2	0.9	1.0	0.9
Total Phosphorus	0.03	1.93	0.08	0.11	0.07
Ortho Phosphorus	< 0.01	1.83	0.05	0.04	< 0.01
Chloride	218	160	1330	334	392
Sulfate	218	139	840	453	1430
Total Dissolved Solids	800	682	3780	1470	2940
Total Organic Carbon (filtered)	6	6	4	7	4
BOD_5 (Nitrogen Suppressed)	2.5	2.5	1.5	3.5	2
BOD_5 (Filtered, Nitrogen Suppressed)	2	1	1	1.5	2
BOD_{20} (Nitrogen Suppressed)	6.5	5.5	4	6	3.5
BOD_{20} (Filtered, Nitrogen Suppressed)	5	3.5	2.5	3	3
Chlorophyll *a*	0.002	0.005	0.002	0.012	< 0.002
Pheophytin *a*	< 0.002	0.006	0.004	< 0.002	< 0.002

Table 14
Sewage Treatment Plant Stations
Laboratory Measurements
4/17/80

Parameter	Station Number			
	1(14 Hr Comp)	1(24 Hr Comp)	2(14 Hr Comp)	2(24 Hr Comp)
pH	8.0	8.0	7.5	7.9
Conductivity	1029	972	2730	2751
Total Alkalinity	--	--	--	--
Total Suspended Solids	14	< 10	< 10	< 10
Volatile Suspended Solids	6	< 10	< 10	< 10
Ammonia Nitrogen	5.43	4.07	0.13	0.09
Nitrite Nitrogen	1.55	1.22	0.03	0.03
Nitrate Nitrogen	8.40	6.82	17.68	17.83
Kjeldahl Nitrogen	5.5	4.9	1.5	1.7
Total Phosphorus	7.51	5.81	9.87	10.08
Ortho Phosphorus	7.05	5.42	9.62	9.91
Chloride	98	82	300	307
Sulfate	52	52	435	436
Total Dissolved Solids	560	520	1510	1540
Total Organic Carbon (filtered)	15	11	5	6
BOD_5 (Nitrogen Suppressed)	8	6.5	1	2
BOD_5 (Filtered, Nitrogen Suppressed)	3	4	0.5	2.5
BOD_{20} (Nitrogen Suppressed)	55	21	3	5.5
BOD_{20} (Filtered, Nitrogen Suppressed)	16	14	2	5
Chlorophyll _a_	--	--	--	--
Pheophytin _a_	--	--	--	--

Table 15
Cibolo Creek Stations
BOD Reaction Rate Series
4/17/80

Station	BOD Reaction Rate Series						
	BOD_1	BOD_2	BOD_3	BOD_4	BOD_5	BOD_6	BOD_7
A	0.5	1.5	1.5	2	2	2.5	2.5
BB(comp.)	1	2	3	4	5	6.5	7.5
BB(0612)	1	2.5	3.5	4.5	4.5	5.5	5.5
BB(0929)	1	2	3	3.5	4.5	5.5	5.5
BB(1228)	1	2	2.5	3.5	4	5	5.5
BB(1632)	1	2	3	3.5	4.5	5	6
BB(1838)	1	2.5	3	3.5	4.5	5.5	6
C	1	1.5	2	2.5	4	4.5	5.5
E(comp.)	1	2	3.5	3.5	4.5	5	6
E(0544)	1	2.5	3.5	4	4.5	5.5	6
E(0901)	1	2	2	3.5	3.5	4	4.5
E(1254)	0.5	2	2	3.5	3.5	4.5	4.0?
E(1606)	1	2	2	3.5	4	4.5	5.5
E(1907)	0.5	1.5	2	3	3.5	4	4.5
F(comp.)	1	2.5	3.5	3.5	4	5	5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.5	2.5	3

Table 15 (Cont.)
Cibolo Creek Stations
BOD Reaction Rate Series
4/17/80

Station	BOD Reaction Rate Series						
	BOD_1	BOD_2	BOD_3	BOD_4	BOD_5	BOD_6	BOD_7
F(0915)	1	2	2	2.5	3	3.5	3.5
F(1245)	0.5	2	2.5	2.5	3	3.5	4
F(1618)	1	2.5	3.5	3.5	4.5	5	5
F(1857)	1.5	3.5	4.5	5	5.5	6	6
G	< 0.5	1	1	1.5	1.5	2	2
H	0.5	1	1.5	1.5	2	2.5	2.5
I(comp.)	< 0.5	< 0.5	0.5	1	1	1.5	1.5
I(0600)	< 0.5	< 0.5	0.5	1	1	1.5	1.5
I(0925)	< 0.5	< 0.5	0.5	0.5	1	1	1.5
I(1225)	< 0.5	0.5	1	1	1.5	1.5	2
I(1530)	< 0.5	< 0.5	0.5	1	1	1.5	1.5
I(1900)	< 0.5	< 0.5	0.5	1	1	1.5	1.5
J	< 0.5	< 0.5	< 0.5	< 0.5	0.5	0.5	0.5
L	< 0.5	0.5	0.5	1	1	1.5	1.5
N	< 0.5	0.5	0.5	1	1	1.5	1.5
P(comp.)	< 0.5	< 0.5	< 0.5	0.5	1	1	1

Table 15 (Cont.)
Cibolo Creek Stations
BOD Reaction Rate Series
4/17/80

Station	BOD Reaction Rate Series						
	BOD_1	BOD_2	BOD_3	BOD_4	BOD_5	BOD_6	BOD_7
P(0600)	< 0.5	< 0.5	< 0.5	0.5	0.5	1	1
P(0940)	< 0.5	< 0.5	< 0.5	0.5	1	1	1
P(1230)	< 0.5	< 0.5	< 0.5	0.5	0.5	1	1
P(1545)	0.5	1	1	1.5	1.5	2	2
P(1830)	< 0.5	0.5	0.5	0.5	1	1	1
Q	< 0.5	0.5	0.5	0.5	1	1	1.5
R	< 0.5	1	1	1	1.5	1.5	1.6
T	< 0.5	0.5	1	1	1	1.5	1.5
U	< 0.5	< 0.5	0.5	0.5	1	1	1
V	< 0.5	0.5	1	1	1	1.5	1.5
W	< 0.5	0.5	0.5	0.5	1	1	1
X(comp.)	< 0.5	0.5	0.5	0.5	1	1	1
X(0655)	< 0.5	0.5	0.5	1	1	1	1.5
X(1045)	< 0.5	0.5	0.5	0.5	1	1	1
X(1455)	< 0.5	1.	1	1	1.5	1.5	1.5
X(1740)	< 0.5	0.5	0.5	1	1	1	1
X(2010)	< 0.5	< 0.5	0.5	0.5	1	1	1

Table 16
Tributary Stations
BOD Reaction Rate Series
4/17/80

Station	BOD Reaction Rate Series						
	BOD_1	BOD_2	BOD_3	BOD_4	BOD_5	BOD_6	BOD_7
K(1630)	0.5	1	1.5	2	2.5	3	3.5
M(comp.)	1	1	1.5	2	2.5	2.5	3
O(1300)	< 0.5	1	1	1.5	1.5	2	2
Alum Creek (1730)	< 0.5	1	1.5	2	2	2	2.5
S(comp.)	1	2	2.5	3	3.5	3.5	3.5

Table 17
Sewage Treatment Plant Stations
BOD Reaction Rate Series
4/16-17/80

Station	BOD Reaction Rate Series						
	BOD_1	BOD_2	BOD_3	BOD_4	BOD_5	BOD_6	BOD_7
1(14 hr. Comp.)*	0.5	3.5	4.5	6	8	11	12.5
1(24 hr. Comp.)	0.5	2	3	4	6.5	9	9
2(14 hr. Comp.)	< 0.5	0.5	0.5	0.5	1	1	1.5
2(24 hr. Comp.)*	0.5	1	1.5	1.5	2	2.5	3

* Flow-weight composited.

Table 18
Cibolo Creek Benthic Macroinvertebrates* (5/8/80)

Station	A	E	G	Z	N	T	X
Total Number of Organisms per m^2	4,852	7,444	6,116	6,944	6,619	2,679	1,799
Total Number of Taxa	31	17	31	55	46	37	36
Diversity	2.79	1.45	3.08	4.11	4.08	3.95	3.87
Redundancy	0.46	0.66	0.39	0.31	0.28	0.27	0.29
Equitability	0.56	0.35	0.62	0.71	0.71	0.74	0.75
Taxon	Number of Individuals per m^2						
COELENTERATA							
Hydra sp.				11		4	
TURBELLARIA							
Dugesia tigrina	273		2,110	144	334		
NEMERTEA	11		7	25			
NEMATODA				22			
HIRUDINEA							
Dina anoculata						4	
Helobdella fusca				7			
Mooreobdella microstoma		14		4			
OLIGOCHAETA							
Aeolosoma sp.	90		29				
Branchiura sowerbyi						4	
Dero nivea				4			
Limnodrilus sp.						7	
Limnodrilus hoffmeisteri		4	169	158	14		11
Limnodrilus udekemianus						4	
Nais communis			4				
Nais elinguis			47	29	11	25	14
Nais variabilis			4				
Pristina leidyi		7					
Pristina osborni							4
Pristina sima		4					
Pristina synclites					4		
Stylaria lacustris				7			
GASTROPODA							
Biomphalaria obstructus			136	36			
Fossaria dalli			7				
Gundlachia radiata	201	502	771	83	7		18

Table 18 (Cont.)
Cibolo Creek Benthic Macroinvertebrates* (5/8/80)

Station	A	E	G	Z	N	T	X
Taxon	Number of Individuals per m^2						
GASTROPODA (CONT.)							
Gyraulus parvus	122	22					
Helisoma anceps		420	4				
Lyrodes sp.				4			
Physa virgata	14	5,253	11	4	4	129	
Pyrgophorus coronatus			32	7			
PELECYPODA							
Corbicula fluminea			43	334	1,353	463	194
Eupera cubensis			7				
Pisidium casertanum	32	7	32				
Sphaerium transversum	409	111	1,152				
AMPHIPODA							
Hyallela azteca	39	1,073	43	14			
OSTRACODA							
Cypricercus nr *dentifera*		4					
Cypridopsis vidua	11						
HYDRACARINA							
Hydracarina sp. A				14			
Hydracarina sp. B				11			
Sperchon sp.				7	14		4
COLEOPTERA							
Berosus sp.		4		4			
Dubiraphia quadrinotata	4						
Dubiraphia vittata				22	39		
Helichus suturalis				11	47	7	
Heterelmis sp.			7				4
Heterelmis vulnerata	11			11	208	4	
Hexacylloepus ferrugineus	7			194	194		11
Microcylloepus pusillus	283	4	312	25	90	4	7
Neoelmis caesa	61			11	90		
Psephenus texanus	7			140	22		
Stenelmis bicarinata	936	7	574	359	1,058	136	25
DIPTERA							
Ablabesmyia sp.							4
Ablabesmyia mallochi					7		
Ablabesmyia parajanta				4			

Table 18 (Cont.)
Cibolo Creek Benthic Macroinvertebrates* (5/8/80)

Station Taxon	A	E	G	Z	N	T	X
	Number of Individuals per m^2						
DIPTERA (CONT.)							
Cladotanytarsus sp.	7		61	111		7	14
Cricotopus sp.	11	4	147				
Cricotopus sp. A				183	29	115	18
Cricotopus sp. B					14		
Dicrotendipes neomodestus				7		11	
Empididae	4		11	4			39
Orthocladius sp.	4						
Pentaneurini sp. A					4		
Polypedilum sp.			54				
Polypedilum halterale							4
Polypedilum illinoense				50	4	7	4
Pseudochironomus sp. A						43	
Pseudochironomus sp. B				549	122	161	104
Rheocricotopus sp.			4	68	11	14	25
Scirtes sp.			18				
Simulium nr *bivittatum*			273				
Tabanus sp.	4						
Tanytarsus sp.				7		7	7
Thienemanniella sp.				104		14	
EPHEMEROPTERA							
Baetis sp.	32						39
Baetis sp. A				25	7		
Baetis sp. B				29	7		
Caenis sp.						14	
Dactylobaetis mexicanus				39	169		
Isonychia sicca manca				176	18	4	
Leptohyphes packeri	14			79	158	36	
Pseudocloeon sp.				11			
Stenonema sp.					39	72	4
Thraulodes gonzalesi				29	65	25	11
Traverella presidiana				68	29		7
Tricorythodes albilineatus gr	11			294	50	334	208
LEPIDOPTERA							
Parargyractis sp.				499	136	115	18
MEGALOPTERA							
Corydalus cornutus			4	4			
ODONATA							
Argia sp.	4			57	4		
Brechmorhoga mendax					4		14
Erpetogomphus sp.					11	11	7
Hetaerina sp.							4

Table 18 (Cont.)
Cibolo Creek Benthic Macroinvertebrates (5/8/80)

Station	A	E	G	Z	N	T	X
	Number of Individuals per m^2						
Taxon							
PLECOPTERA							
Neoperla clymene					255	18	29
TRICHOPTERA							
Cheumatopsyche sp.	2,146	4	29	2,045	416	474	25
Chimarra sp.	25						
Helicopsyche sp.					22	72	
Hydropsyche sp.					337	22	18
Hydroptila sp.	68			520	161	151	190
Mayatrichia sp.					4		
Nectopsyche gracilis					18	14	
Ochrotrichia sp.	11		14	126	398	111	161
Oecetis sp.	7					36	4
Protoptila sp.					14		222
Smicridea sp.				154	560		327

* 3 Surber samples collected at each station

Table 19
Cibolo Creek Periphytic Diatoms (5/8/80)

Station	A	E	G	Z	N	T	X
Total number of individuals counted	1850	2650	851	1070	2190	592	609
Total number of taxa	45	22	50	45	42	44	51
Diversity	3.51	2.30	4.42	3.48	2.71	4.10	3.52
Equitability	0.63	0.52	0.78	0.63	0.49	0.75	0.62
Taxon	Percentage Composition						
Achnanthes exigua var. exigua		+			+	1	
A. exigua var. constricta	+						
A. hauckiana var. hauckiana					1		+
A. hauckiana var. rostrata							1
A. hungarica(?) var. hungarica	+	+					
A. lanceolata var. lanceolata			+	+			+
A. lanceolata var. dubia	8			+			+
A. lanceolata var. omissa						+	
A. lapponica var. ninckei	+						
A. linearis var. linearis					1		
A. linearis f. curta			1	3		1	
A. microcephala var. microcephala						+	
A.(?) minutissima var. minutissima	11						
Achnanthes (girdle view)	+		+			1	
Amphora acutiuscula var. acutiuscula							+
A. coffeiformis var. coffeiformis					+		+
A. perpusilla var. perpusilla	28		3	7	+	3	5
A. ovalis var. affinis			1				+
A. ovalis var. pediculus	+					+	+
A. veneta var. veneta			1	+	+		1
Bacillaria paradoxa			+		+	1	+
Biddulphia laevis(?)		+	1		+		+
Caloneis ventricosa(?) var. minuta				+			
Cocconeis pediculus var. pediculus			1				+
C. placentula var. placentula	4	8	3	1	1	3	
C. placentula var. euglypta							1

Table 19 (Cont.)
Cibolo Creek Periphytic Diatoms (5/8/80)

Station	A	E	G	Z	N	T	X
	Percentage Composition						
Taxon							
Cyclotella meneghiniana		28	2	+			
C. stelligera	+						
C. sp. a	1						+
Cymbella prostrata var. prostrata					+		
C. sinuata var. sinuata	+		+	+			
Denticula rainierensis(?) var. rainierensis							+
Diploneis puella var. puella	+					+	1
Entomoneis alata var. alata							+
E. paludosa var. paludosa						+	+
Eunotia sp. a	+						
E. sp. b	+						
Frustulia rhomboides var. saxonica	+		+				
Gomphonema abbreviatum var. abbreviatum	+	+	7	+			
G. angustatum var. citera						+	
G. grunowii var. grunowii			+				
G. parvulum var. parvulum	1	45	5	2	1	+	1
G. subclavatum var. mexicanum(?)	+		+				
G. tenellum var. tenellum			+				
G. tergestinum var. tergestinum						1	+
Gomphonema (girdle view)				+	+		
Gyrosigma nodiferum var. nodiferum			+				
Melosira varians	3		3	1	7	10	15
Navicula accomoda var. accomoda			+		+		
N. arenaria var. arenaria	+						+
N. arvensis var. arvensis	1		+	1			+
N. auriculata var. auriculata						+	
N. capitata var. hungarica						14	
N. cincta var. cincta	4	+	4	5	2	+	3
N. confervacea var. confervacea	4	1	4	+	1		+

Table 19 (Cont.)
Cibolo Creek Periphytic Diatoms (5/8/80)

Station / Taxon	A	E	G	Z	N	T	X
	Percentage Composition						
N. confervacea var. peregrina					+		
N. cryptocephala var. veneta	1	+	6		1	1	6
N. cuspidata var. cuspidata				+	+		
N. exigua(?) var. exigua	+						
N. exigua var. capitata						+	+
N. gastrum var. gastrum			+				
N. globulifera var. globulifera				+			
N. graciloides(?) var. graciloides				2			
N. grimmei var. grimmei	+	+	+		+		
N. halophila(?) var. halophila			+			7	
N. ingenua	+	+	1				
N. lanceolata var. lanceolata	+		+			1	
N. luzonensis var. luzonensis	1	5	9	8	3	16	1
N. minima var. minima		+	+	+		1	+
N. notha(?) var. notha				+		2	
N. paucivisitata(?) var. paucivisitata				+			
N. pelliculosa var. pelliculosa		+			+	+	+
N. pseudoreinhardtii(?) var. pseudoreinhardtii				+			
N. pupula var. pupula					+		
N. pupula var. mutata	+	+	1				
N. radiosa var. radiosa	+			+			
N. radiosa var. tenella	+	+	4	+			
N. rhynchocephala var. germainii							+
N. salinarum(?) var. salinarum					+		
N. salinarum var. intermedia				1			
N. sanctaecrucis var. sanctaecrucis							+
N. schroeteri var. escambia			+				
N. secreta(?) var. secreta						1	

Table 19 (Cont.)
Cibolo Creek Periphytic Diatoms (5/8/80)

Station	A	E	G	Z	N	T	X
	Percentage Composition						
Taxon							
N. secura var. secura			+		+		
N. seminulum(?) var. hustedtii	+	+	1				
N. texana(?) var. texana				+			
N. variostriata var. variostriata	+						
N. sp. a			+				
N. sp. b					+	+	1
N. sp. c					+		+
Navicula (girdle view)					2		
Neidium affine(?) var. humerus		+					
Nitzschia acicularis					+	+	+
N. acuminata						+	
N. amphibia	6	5	12	4	10	6	
N. angustata	+					+	
N. apiculata	+		+	1	+	+	1
N. clausii				+			
N. communis							+
N. dissipata			+	30	1		+
N. filiformis				+			
N. flexa(?)					+		
N. fonticola(?)			1	2	+	10	
N. frustulum(?)	2	2	7	6	24	8	32
N. gandersheimiensis						+	
N. gracilis						+	
N. hantzschiana(?)					+		
N. heufleriana			+			+	
N. hungarica			+				+
N. ignorata							+
N. linearis				1	+		
N. longissima var. reversa					1	1	2

Table 19 (Cont.)
Cibolo Creek Periphytic Diatoms (5/8/80)

on	A	E	G	Z	N	T	X
Taxon	Percentage Composition						
crocephala							+
lea	1	4	7	21	44	7	18
rvula	+						
cta(?)				+			
blinearis					+		
otilis				+			
⁄blionella var. debilis	+			+			
⁄blionella var. levidensis(?)			+		+	+	
'blionella var. victoriae							+
'blionella var. (?)				+			
micularis				+			
rea(?)							1
a						+	2
b						+	+
nia (girdle view)					1		
aria microstauron var. microstauron				+			
sphenia curvata var. curvata	18			+	+	1	1
odia gibba var. ventricosa					+		
odiscus(?) invisitatus			+				
a	+						
la spp.			+	+	+	1	1
. affinis	1						
sitica var. subconstricta	+						
var. amphirhynchus			11				
(girdle view)	+						
pe musica			+				

icate present but composed less than 1 percent of community.

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APPENDIX A

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FIELD AND LABORATORY PROCEDURES

The following methods are utilized for field and laboratory determinations of specified physical and chemical parameters. Unless otherwise indicated composite water samples are collected at each sampling station and stored in polyethylene containers on ice until delivery to the laboratory. Sediment samples are collected with a dredge or coring device, decanted, mixed, placed in appropriate containers (glass for pesticides analyses and plastic for metals analyses), and stored on ice until delivery to the laboratory. Laboratory chemical analyses are conducted by the Water Chemistry Laboratory of the Texas Department of Health unless otherwise noted.

WATER ANALYSES

Field Measurements

Parameter	Method
Temperature	Hand mercury thermometer, temperature probe of Hydrolab Model 60 Surveyor, or Hydrolab 4041.
Dissolved Oxygen	Azide modification of Winkler titration method, oxygen probe attachment of Hydrolab Model 60 Surveyor, or Hydrolab 4041
pH	Hydrolab Model 60 Surveyor, Hydrolab 4041 or Sargent-Welch portable pH meter.
Conductivity	Hydrolab Model 60 Surveyor, Hydrolab 4041, or Hydrolab TC-2 conductivity meter
Alkalinity	Titration as described in "Standard Methods for the Examination of Water and Wastewater" 13th Ed., using phenolphthalein and methyl red/bromcresol green indicators.

Laboratory Analyses

Parameter	Method
BOD_5, Nitrogen-Suppressed	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
BOD_{1-7}, Nitrogen-Suppressed	Membrane electrode method(1). Nitrogen Suppression using TCMP method(2).
BOD_{20}, Nitrogen-Suppressed	Membrane electrode method(1) Nitrogen Suppression using TCMP method(2).
TSS	Gooch crucibles and glass fiber discs(1).
VSS	Gooch crucibles and glass fiber discs(1).
Kjel-N	Micro-Kjeldahl digestion and automated colorimetric phenate method(3).
NH_3-N	Distillation and automated colorimetric phenate method(3).
NO_2-N	Colorimetric method(1).
NO_3-N	Automated cadmium reduction method(3).
T-PO_4	Persulfate digestion followed by ascorbic acid method(1).
O-PO_4	Ascorbic acid method(1).
Sulfates	Turbidimetric method(1).
Chlorides	Automated thiocyanate method(3).
TDS	Evaporation at 180°C(3).
TOC	Beckman TOC analyzer.
Conductivity	Wheatstone bridge utilizing 0.01 cell constant(1).

Parameter	Method
Chlorophyll *a*	Trichromatic method(1).
Pheophytin *a*	Pheophytin correction method(1).

SEDIMENT ANALYSES

Field Measurements

Immediate Dissolved Oxygen Demand (IDOD)

$$\text{mg/l IDOD} = \frac{D_0 p - D_1}{P}$$

where D_0 = D.O. to original dilution water

$$p = \frac{\text{dilution water used (ml)}}{\text{volume of BOD bottle (ml)}}$$

$$P = \frac{\text{amount of sample used (ml)}}{\text{volume of BOD bottle (ml)}}$$

D_1 = D.O. of diluted sample 15 min. after preparation using membrane electrode method

Laboratory Analyses

Parameter	Method
Arsenic	Colorimetric
Mercury	Potassium permanganate digestion followed by atomic absorption(4).
All other metals	Atomic absorption(4).
Volatile Solids	Ignition in a muffle furnace.
COD	Dichromate reflux method.
Kjel-N	Micro-Kjeldahl digestion and automated colorimetric method(3).
T-PO_4	Ammonium molybdate(4).
Pesticides	Gas chromatographic method(5).

BACTERIOLOGICAL

Bacteriological samples are collected in sterilized glass bottles provided by the Texas Department of Health and stored on ice until delivery to the laboratory or until cultures are set up by survey personnel (within 6 hours of collection). Bacteriological analyses are conducted by survey personnel or a suitable laboratory in the survey area.

Parameter	Method
Total Coliform	Membrane filter method(1)
Fecal Coliform	Membrane filter method(1)
Fecal Streptococci	Membrane filter method(1)

BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates are collected with a Surber sampler (1.0 ft.^{2}) in riffles and an Ekman dredge (0.25 ft.^{2}) in pools. Samples are preserved in 5% formalin, stained with Rose Bengal, and sorted, identified, and enumerated in the laboratory.

Diversity is calculated according to Wilhm's(6) equation:

$$\bar{d} = -\sum_{1}^{s} (n_i/n) \log_2 (n_i/n)$$

where n is the total number of individuals in the sample, n_i is the number of individuals per taxon, and s is the number of taxa in the sample.

Redundancy is calculated according to the equations derived by Young et al.(7)

(1) $$\bar{d}\ max = \log_2 s$$

(2) $$\bar{d}\ min = -\frac{s-1}{n} \log_2 \frac{1}{n} - \frac{n-(s-1)}{n} \log_2 \frac{n-(s-1)}{n}$$

(3) $$\bar{r} = \frac{\bar{d}\ max - \bar{d}}{\bar{d}\ max - \bar{d}\ min}$$

where s is the number of taxa in the sample and n is the total number of individuals in the sample.

The number of individuals per square meter is determined by dividing the total number of individuals by the area sampled.

PLANKTON

Phytoplankton

Stream phytoplankton are collected beneath the water surface. Sampling stations are located both upstream and downstream from pollution sources and care is taken to preclude confusing interferences such as contributions of plankton from reservoirs, from backwater areas, scouring of periphyton from the streambed, etc. Reservoir phytoplankton samples are collected with a tube device in which sample collection is vertically integrated throughout the depth of the euphotic zone (3 times Secchi disc measurement). In cases where the euphotic zone depth exceeds the tube length, samples are collected with an appropriate water sampler at depths evenly spaced throughout the euphotic zone.

Samples are stored in quart cubitainers on ice and transferred to the laboratory where representative small portions of each sample are analyzed live to aid in taxonomic identification. Samples (950 ml) are then preserved with 50 ml of 95% buffered formalin or 9.5 ml of Lugols solution and stored in the dark until examination is completed. Identification and enumeration of phytoplankton is conducted with an inverted microscope utilizing standard techniques. The diversity index ($\bar{d}$) is calculated as described previously.

Zooplankton

Zooplankton are concentrated at the site by either filtering a known volume of water through a No. 20 mesh standard Wisconsin plankton net or vertically towing the net a known distance. Concentrated samples are preserved with Lugols solution or in a final concentration of 5% buffered formalin. The organisms are identified to the lowest taxonomic level possible and counts are made utilizing a Sedgwick-Rafter cell. Diversity is calculated as described previously.

NEKTON

Nekton samples are collected by the following methods(1):

Common-sense minnow seine	- 20' x 6' with 1/4" mesh
Otter trawl	- 12' with 1 3/16" outer mesh and 1/2" mesh liner
Chemical fishing	- rotenone

Experimental gill nets	- 125' x 8' (five 25' sections ranging in mesh size of 3/4" to 2 1/2")
Electrofishing	- backpack and boat units (both equipped with AC or DC selection). Boat unit is equipped with variable voltage pulsator.

These organisms are collected to determine: (1) species present, (2) relative and absolute abundance of each species, (3) size distribution, (4) condition, (5) success of reproduction, (6) incidence of disease and/or parasitism, (7) palatability, and/or (8) presence or accumulations of toxins.

Nekton collected for palatability are iced or frozen immediately. Samples collected for heavy metals analyses are placed in leak-proof plastic bags and placed on ice. Samples collected for pesticides analyses are wrapped in aluminum foil, placed in a water proof plastic bag and placed on ice.

As special instances dictate, specimens necessary for positive identification, parasite examination, etc., are preserved in 10% formalin containing 3 grams borax and 50 ml glycerin per liter. Specimens over 7.5 cm in length are slit at least one-third of the length of the body to enhance preservation of the internal organs. Other specimens are weighed and measured before being returned to the reservoir or stream.

ALGAL ASSAYS

The "*Selenastrum capricornutum* Printz Algal Assay Bottle Test" procedure(8) is utilized in assaying nutrient limitation in fresh-water situations whereas the "Marine Algal Assay Procedure Bottle Test"(9) is utilized in marine and estuarine situations. Samples are collected according to the phytoplankton collection methodology. *Selenastrum capricornutum* is the freshwater assay organism and *Dunaliella tertiolecta* is the marine assay alga.

PRODUCTIVITY/RESPIRATION

Two methods are utilized to estimate productivity and respiration in the study area. In areas where restricted flow produces natural or artificial ponding of sufficient depth, standard light bottle-dark bottle techniques are used. In flowing water the diurnal curve analysis is utilized.

Light Bottle-Dark Bottle Analyses

The light and dark bottle technique is used to measure net production and respiration in the euphotic zone of a lentic environment. The depth of the euphotic zone is considered to be three times the Secchi disc transparency (3 x Z_{SD}). This region is subdivided into three sections. Duplicate light bottles (300 ml BOD bottles) and dark bottles (300 ml BOD bottles covered with electrical tape, wrapped in aluminum foil and enclosed in a plastic bag) are filled with water collected from the mid-point of each of the three vertical sections, placed on a horizontal metal rack and suspended from a flotation platform to the mid-point of each vertical section. The platform is oriented in a north-south direction to minimize shading of the bottles. An additional BOD bottle is filled at each depth for determining initial dissolved oxygen concentrations (modified Winkler method). The bottles are allowed to incubate for a varying time interval, depending on the expected productivity of the waters. A minimum of four hours incubation is considered necessary.

The following equations are used to calculate respiration and photosynthesis:

(1) For plankton community respiration (r), expressed as mg/l O_2/hour

$$R = \frac{DO_I - DO_{DB}}{\text{Hours incubated}}$$

where DO_I = initial dissolved oxygen concentration.

and DO_{DB} = average dissolved oxygen concentration of the duplicate dark bottles.

(2) For plankton net photosynthesis (P_N), expressed as mg/l O_2/hour

$$P_N = \frac{DO_{LB} - DO_I}{\text{Hours incubated}}$$

where DO_{LB} = average dissolved oxygen concentration of the duplicate light bottles.

(3) For plankton gross photosynthesis (P_G), expressed as mg/l O_2/hour

$$P_G = P_N + R$$

Conversion of respiration and photosynthesis may be accomplished by multiplying the depth of each of the three vertical zones (expressed in meters) by the measured dissolved oxygen levels expressed in grams/m^3. These products are added and the result is expressed as grams O_2/m^2/day by multiplying by the photoperiod. Conversions from oxygen to carbon may be accomplished by multiplying grams O_2 by 12/32.

Diurnal Curve Analysis

In situations where the stream is flowing, relatively shallow, and/or contains appreciable growths of macrophytes or filamentous algae, the diurnal curve analysis is utilized to determine productivity and respiration. The procedure is adopted from the U. S. Geological Survey (10).

Both the dual station and single station analyses are utilized, depending upon the various controlling circumstances.

Dissolved oxygen and temperature data are collected utilizing the Hydrolab surface units, sondes, data scanners, and strip chart recorders. Calibration of the instruments are conducted utilizing the azide modification of the Winkler dissolved oxygen method and hand mercury thermometers. Recalibration is conducted as often as necessary. Diffusion rate constants are directly measured in those instances where atmospheric reaeration rate studies have been conducted. In situations where direct measurements are not made, either the diffusion dome method is utilized, or an appropriate alternative. These alternatives are: (1) calculations from raw data, (2) substitution into various published formulas for determination of K_2, and (3) arbitrary selection of a value from tables of measured diffusion rates for similar streams.

Presently, the productivity and respiration rates are hand-calculated The capability exists for computer analyses in this program which may be utilized in the future.

BENTHAL OXYGEN DEMAND MEASUREMENTS

A benthic respirometer, constructed of clear plexiglass, is utilized on intensive surveys to measure benthal oxygen demand(11). Brass or stainless steel hardward is used to inhibit water-induced corrosion. A D.O. probe, paddle, solenoid valve and air diffuser are mounted inside the test chamber. The paddle which is magnetically driven by an electric motor is used to simulate stream velocity (and/or scour) and produce circulation over the probe. The solenoid valve allows air to escape from the test chamber during aeration. The air diffuser is connected by plastic tubing to a 12-volt air compressor which is used to pump air into the test chamber if required.

The paddle, solenoid valve, and air compressor are actuated by switches on a control panel which is housed in an aluminum box. The control box also contains two 12-volt batteries, the air compressor, a strip-chart recorder (for automatic recordings of D.O. meter readings), a battery charger, and a batter test meter.

Selection of a specific test site must be made in the field by the investigator with the depth, velocity, and benthic substrate taken into consideration. At the test site the D.O. meter, and strip-chart recorder are calibrated, the respirometer is dry tested by opening and closing switches, testing batteries, etc., a stream velocity measurement is taken (for paddle calibration and a water sample is collected just above the stream bottom near the sampling site. Portions of this water sample are poured into separate BOD bottles, one of which is opaque. The opaque bottle is placed on the respirometer and left for the remainder of the test. The initial D.O. value in the other bottle is measured when the test begins, while the D.O. in the opaque bottle is measured at the end of the benthic uptake test. The difference in the two D.O. values represents the oxygen demand of the water column.

The respirometer can be lowered from a boat or bridge, or can be placed by hand in shallow streams. Care is taken to insure that the sediment at the test location is not disturbed and that a good seal between the base of the instrument and bottom of the stream is made. After teh respirometer has been placed in the stream, the D.O. is recorded. If it is 5 mg/l or less the air compressor is actuated until a level in excess of 5 mg/l is attained in the test chamber. The test chamber is then closed and the paddle frequency adjusted. Recordings of D.O. are made until it drops to 0.5 mg/l or 6 hours has elapsed, whichever comes first.

<u>Paddle Frequency</u>

$$f = 36\ v$$

where: f = Paddle frequency in RPM

v = Velocity to be simulated in ft./sec. (measured with current meter)

<u>Benthic Oxygen Uptake</u>

$$B^{T}DO_1 - DO_2 = 196\ \frac{(DO_1 - DO_2) - BOD_t}{\Delta t}$$

where: $B^T DO_1 - DO_2$ = Oxygen uptake rate in $gm/m^2/day$ corresponding to the sample temperature, T

DO_1 = Initial DO reading in mg/l

DO_2 = Final DO reading in mq/l

Δt = Time interval between DO_1 and DO_2 readings in minutes

T = Temperature of sample in °C

BOD_t = Measured difference in DO between the two BOD bottles

HYDROLOGICAL

Parameter	Method
Flow Measurement	(1) Pygmy current meter (Weather Measure Corporation Model F583), (2) Marsh-McBirney Model 201 electronic flow meter, (3) Price Current Meter (Weather Measure Corporation Model F582)(4), or gage height readings at USGS gaging stations.
Time-of-Travel	Tracing of Rhodamine WT dye using a Turner Model 110 or 111 fluorometer(12).
Stream Cross-sections	Measure average width and average depth at each mainstream station. At least 4 cross-section measurements are made in the vicinity of each mainstream station.

STREAM REAERATION MEASUREMENTS

The stream reaeration technique, requiring the use of radioactive krypton-85 and hydrogen-3 (tritiated water molecules), is utilized to measure the physical reaeration capacity of a desired stream segment(13).

The method depends on the simultaneous release of three tracers in a single aqueous solution: a dispersion/dilution tracer (Tritiated water molecules), a dissolved gaseous tracer for oxygen (krypton-85) and Rhodamine WT dye to indicate when to sample for the radiotracers in the field. The tracer release location is chosen to meet two requirements: (1) must be upstream of the segment for which physical reaeration data is desired, (2) must be at least 2 ft. deep and where the most complete mixing takes place. Before the release, samples are collected at the release site and designated sampling stations to determine background levels of radiation. The first samples are collected 50-200 ft. downstream from the release site in order to establish the initial krypton-85/tritium ratio. Sampling sites are located downstream to monitor the dye cloud every 4-6 hours for 35-40 hours. The Rhodamine WT dye is detected with Turner 111 flow-through fluorometers. Samples are collected in glass bottles (1 oz.) equipped with polyseal caps which are sealed with black electrical tape. Samples are collected every 2-5 min. during the passage of the dye cloud peak. The three samples collected nearest the peak are designated for analysis in the lab (three alternates are also designated). Extreme caution is exercised throughout the field and laboratory handling of samples to prevent entrainment of air.

Samples are transferred within 24 hours of the collection time. Triplicate counting vials are prepared from each primary sample. All counting vials are counted in a Tracor Analytic 6892 LSC Liquid Scintillation Counter which has been calibrated. Each vial is counted a minimum of three, 10 min. cycles. The data obtained is analyzed to determine the changes in the krypton-85/tritium ratio as the tracers flow downstream.

The calculations utilized in determining the physical reaeration capacity of a stream segment from the liquid scintillation counter data are included here. Krypton-85 transfer in a well-mixed water system is described by the expression:

$$\frac{dC_{kr}}{dt} = -K_{kr}(C_{kr},t) \qquad (1)$$

where: C_{kr},t = concentration of krypton-85 in the water at time(t)

K_{kr} = gas transfer rate coefficient for krypton-85

The gas transfer rate coefficient for oxygen (K_{ox}) is related to K_{kr} by the equation;

$$\frac{K_{kr}}{K_{ox}} = 0.83 \pm 0.04 \qquad (2)$$

The krypton-85 coefficient (K_{kr}) is derived from the krypton-85 (C_{kr})/tritium (C_h) concentration ratio (R) in the samples collected at the time of peak concentrations;

$$R = \frac{C_{kr}}{C_h} \qquad (3)$$

Applying Eq. 3 to Eq. 1 gives;

$$\frac{dR}{dt} = -K_{kr}R \qquad (4)$$

Equation 4 can be transformed to;

$$K_{kr} = \frac{\text{In}(R_d/R_u)}{-t} \qquad (5)$$

where: R_u and R_d = peak krypton-85/tritium concentration ratios at an upstream and downstream station

t_f = peak-to-peak dye time of flow between the upstream and downstream station

Finally K_{ox} is determined by;

$$K_{ox} = \frac{K_{kr}}{0.83} \qquad (6)$$

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APPENDIX "G"

Simulation of Streamflow, Evapotranspiration, and Groundwater Recharge in Lower San Antonio River Watershed, South-Central Texas, 2000-2007 (USGS Scientific Investigations Report 2010-5027)

USGS
science for a changing world

In cooperation with the San Antonio River Authority, the Evergreen Underground Water Conservation District, and the Goliad County Groundwater Conservation District

Simulation of Streamflow, Evapotranspiration, and Groundwater Recharge in the Lower San Antonio River Watershed, South-Central Texas, 2000–2007

Scientific Investigations Report 2010–5027

U.S. Department of the Interior
U.S. Geological Survey

Front cover: Falls on the San Antonio River near Falls City, Texas (photograph courtesy of San Antonio River Authority).

Back cover: Cibolo Creek near Farm Road 775, Wilson County, Texas (photograph courtesy of San Antonio River Authority).

Simulation of Streamflow, Evapotranspiration, and Groundwater Recharge in the Lower San Antonio River Watershed, South-Central Texas, 2000–2007

By Joy S. Lizárraga and Darwin J. Ockerman

In cooperation with the San Antonio River Authority, the Evergreen Underground Water Conservation District, and the Goliad County Groundwater Conservation District

Scientific Investigations Report 2010–5027

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Contents

Figures

Tables

Conversion Factors and Datum

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Simulation of Streamflow, Evapotranspiration, and Groundwater Recharge in the Lower San Antonio River Watershed, South-Central Texas, 2000–2007

By Joy S. Lizárraga and Darwin J. Ockerman

Abstract

The U.S. Geological Survey (USGS), in cooperation with the San Antonio River Authority, the Evergreen Underground Water Conservation District, and the Goliad County Groundwater Conservation District, configured, calibrated, and tested a watershed model for a study area consisting of about 2,150 square miles of the lower San Antonio River watershed in Bexar, Guadalupe, Wilson, Karnes, DeWitt, Goliad, Victoria, and Refugio Counties in south-central Texas. The model simulates streamflow, evapotranspiration (ET), and groundwater recharge using rainfall, potential ET, and upstream discharge data obtained from National Weather Service meteorological stations and USGS streamflow-gaging stations. Additional time-series inputs to the model include wastewater treatment-plant discharges, withdrawals for cropland irrigation, and estimated inflows from springs.

Model simulations of streamflow, ET, and groundwater recharge were done for 2000–2007. Because of the complexity of the study area, the lower San Antonio River watershed was divided into four subwatersheds; separate HSPF models were developed for each subwatershed. Simulation of the overall study area involved running simulations of the three upstream models, then running the downstream model. The surficial geology was simplified as nine contiguous water-budget zones to meet model computational limitations and also to define zones for which ET, recharge, and other water-budget information would be output by the model. The model was calibrated and tested using streamflow data from 10 streamflow-gaging stations; additionally, simulated ET was compared with measured ET from a meteorological station west of the study area. The model calibration is considered very good; streamflow volumes were calibrated to within 10 percent of measured streamflow volumes.

During 2000–2007, the estimated annual mean rainfall for the water-budget zones ranged from 33.7 to 38.5 inches per year; the estimated annual mean rainfall for the entire watershed was 34.3 inches. Using the HSPF model it was estimated that for 2000–2007, less than 10 percent of the annual mean rainfall on the study watershed exited the watershed as streamflow, whereas about 82 percent, or an average of 28.2 inches per year, exited the watershed as ET. Estimated annual mean groundwater recharge for the entire study area was 3.0 inches, or about 9 percent of annual mean rainfall. Estimated annual mean recharge was largest in water-budget zone 3, the zone where the Carrizo Sand outcrops. In water-budget zone 3, the estimated annual mean recharge was 5.1 inches or about 15 percent of annual mean rainfall. Estimated annual mean recharge was smallest in water-budget zone 6, about 1.1 inches or about 3 percent of annual mean rainfall. The Cibolo Creek subwatershed and the subwatershed of the San Antonio River upstream from Cibolo Creek had the largest and smallest basin yields, about 4.8 inches and 1.2 inches, respectively. Estimated annual ET and annual recharge generally increased with increasing annual rainfall. Also, ET was larger in zones 8 and 9, the most downstream zones in the watershed.

Model limitations include possible errors related to model conceptualization and parameter variability, lack of data to quantify certain model inputs, and measurement errors. Uncertainty regarding the degree to which available rainfall data represent actual rainfall is potentially the most serious source of measurement error.

Introduction

The San Antonio River is in south-central Texas (fig. 1), and is within Region L in the State's regional water plans. Region L is expected to increase in population by 75 percent between 2010 and 2060, and water demands are expected to increase by 29 percent (Texas Water Development Board, 2006). Most of this anticipated population growth is upstream from the lower San Antonio River watershed in the San Antonio, Tex., area. Most of the water supplied to the San Antonio area comes from outside the lower San Antonio River watershed, but part of the water supply for San Antonio might be met with exported groundwater resources from Wilson County, which is within the study area. The lower San Antonio River watershed, defined as the contributing area to the San Antonio River south of U.S. Geological Survey (USGS) streamflow-gaging station 08181800 San Antonio River near Elmendorf, Tex. (site 8; fig. 1, table 1) in southeastern

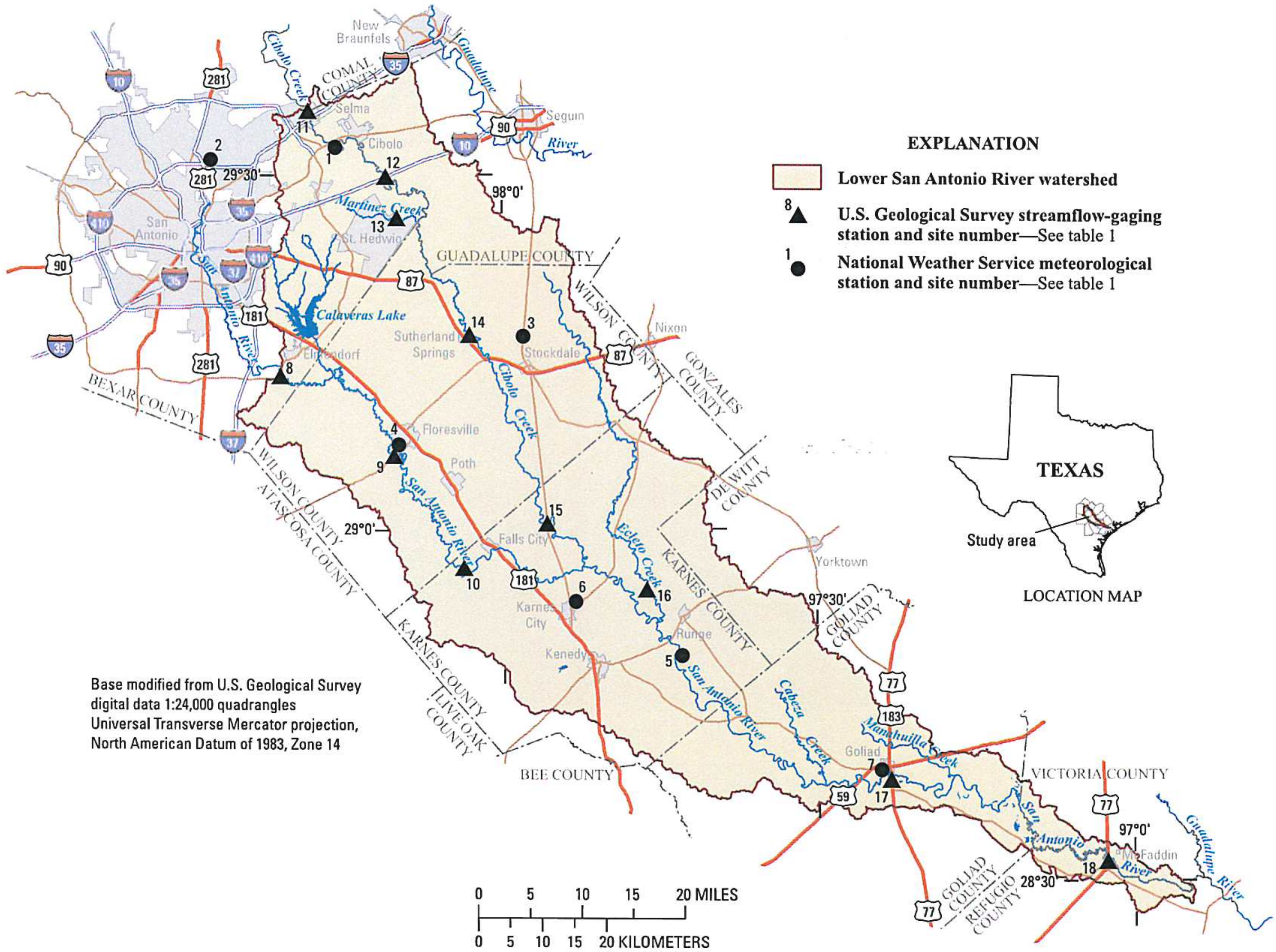


Figure 1. Location of data-collection stations that provided data for the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

Table 1. Description of U.S. Geological Survey and National Weather Service stations from which data were obtained for the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

[dd, degrees; mm, minutes; ss, seconds; NWS, National Weather Service; --, not available; USGS, U.S. Geological Survey]

Site number (fig. 1)	Station number and name	Latitude (dd mm ss)	Longitude (dd mm ss)	Type of data	Period of record used
1	NWS 417422 Randolph Field	29°33'--"	98°16'--"	Rainfall	2000 to 2007
2	NWS 417945 San Antonio International Airport	29°32'--"	98°28'--"	Rainfall, air temperature[1]	2000 to 2007
3	NWS 418658 Stockdale 4 N	29°17'--"	98°58'--"	Rainfall	2000 to 2007
4	NWS 413201 Floresville	29°08'--"	98°10'--"	Rainfall, air temperature[1]	2000 to 2007
5	NWS 417836 Runge	28°50'--"	97°43'--"	Rainfall	2000 to 2006
6	NWS 414696 Karnes City 2 N	29°54'--"	97°53'--"	Rainfall	2000 to 2007
7	NWS 413618 Goliad	28°40'--"	97°23'--"	Rainfall, air temperature[1]	2000 to 2007
8	USGS station 08181800 San Antonio River near Elmendorf, Tex.	29°13'19"	98°21'20"	Streamflow	2000 to 2007
9	USGS station 08183200 San Antonio River near Floresville, Tex.	29°06'36"	98°10'28"	Streamflow	2005 to 2007
10	USGS station 08183500 San Antonio River near Falls City, Tex.	29°57'05"	98°03'50"	Streamflow	2000 to 2007
11	USGS station 08185000 Cibolo Creek at Selma, Tex.	29°35'38"	98°18'39"	Streamflow	2000 to 2007
12	USGS station 08185065 Cibolo Creek near St. Hedwig, Tex.	29°30'05.2"	98°11'10.5"	Streamflow	2005 to 2007
13	USGS station 08185100 Martinez Creek near St. Hedwig, Tex.	29°26'38"	98°10'08"	Streamflow	2005 to 2007
14	USGS station 08185500 Cibolo Creek at Sutherland Springs, Tex.	29°16'47"	98°03'12"	Streamflow	2005 to 2007
15	USGS station 08186000 Cibolo Creek near Falls City, Tex.	29°00'50"	97°55'48"	Streamflow	2000 to 2007
16	USGS station 08186500 Ecleto Creek near Runge, Tex.	28°55'12"	97°46'19"	Streamflow	2002 to 2007
17	USGS station 08188500 San Antonio River at Goliad, Tex.	28°38'58"	97°23'04"	Streamflow	2000 to 2007
18	USGS station 08188570 San Antonio River near McFaddin, Tex.	28°31'52.5"	97°02'33.7"	Streamflow	2005 to 2007
19 (not on fig. 1)	USGS 290810099212100 SW Medina County meteorological station near D'Hanis, Tex.	29°08'10.3"	99°21'20.5"	Evapotranspiration[2]	2006 to 2007

[1] Air temperature data were used to derive estimates of potential evaporation using the Hamon method in Basins 4.0 (Paul Hummel, Aqua Terra Consultants, written commun., 2008).

[2] Evapotranspiration measured by eddy covariance method (Bidlake, 2002).

Bexar County and south of USGS streamflow-gaging station 08185000 Cibolo Creek at Selma, Tex. (site 11) in Guadalupe County, also receives a large amount of the wastewater discharged from the growing San Antonio metropolitan area.

To better understand the hydrology, including the relative contribution of the various water-budget components to the overall water budget, the USGS in cooperation with the San Antonio River Authority, the Evergreen Underground Water Conservation District, and the Goliad County Groundwater Conservation District, developed a watershed model for the lower San Antonio River watershed. As the region develops, the lower San Antonio River watershed model can be modified to simulate future scenarios of land-cover change and water use. The model-derived estimates of evapotranspiration (ET) and groundwater recharge could be used as inputs to regional groundwater flow models of the Gulf Coast aquifer system, Carrizo-Wilcox aquifer, Queen City aquifer, or Sparta aquifer (Texas Water Development Board, 2009). Additionally, the modular nature of the model will accommodate the simulation of water-quality constituents not reported here.

Purpose and Scope

The purpose of this report is to describe the simulation of streamflow, ET, and groundwater recharge in the lower San Antonio River watershed using a watershed model. The model was developed using input data collected during 2000–2007 to simulate streamflow, ET, and groundwater recharge first for four subwatersheds and nine contiguous water-budget zones and then for the overall area of the lower San Antonio River watershed. The functionality of the model and the input data are described, followed by the configuration, calibration, and testing of the model. The hydrologic and meteorological conditions in the four subwatersheds and nine contiguous water-budget zones of the lower San Antonio River watershed and the iterative process of developing the model are summarized. Annual mean inflows and outflows of the major water-budget components for the entire study area are presented, and finally, limitations of model-simulated estimates of streamflow, ET, and groundwater recharge are described.

Description of the Study Area

The San Antonio River extends about 240 miles from northwest of San Antonio, Tex., to the confluence of the San Antonio and Guadalupe Rivers. The drainage area of the lower San Antonio River is about 2,150 square miles (fig. 1); it is characterized by gently sloping topography and land cover consisting mostly of brush and grassland (Multi-Resolution Land Characteristics Consortium, 2008). The lower San Antonio River watershed encompasses parts of Bexar, Guadalupe, Wilson, Karnes, DeWitt, Goliad, Victoria, and Refugio Counties in south-central Texas.

The northern tip of the lower San Antonio River watershed overlies Cretaceous rocks of the Edwards-Trinity aquifer system. The remainder of the watershed overlies the Texas Coastal Uplands and Coastal Lowlands aquifer systems (Ryder, 1996) (fig. 2). The Texas Coastal Uplands aquifer system (Sparta, Queen City, and Carrizo-Wilcox aquifers) is composed of formations of Paleocene and Oligocene age, and the Texas Coastal Lowlands aquifer system (Chicot, Evangeline, and Jasper aquifers) is composed of younger formations from Oligocene through Holocene age. The Coastal Lowlands aquifer system comprises the same aquifers as the Gulf Coast aquifer system (Kasmarek and Robinson, 2004) and is equivalent to the Gulf Coast aquifer as defined by Ashworth and Hopkins (1995). In the Coastal Uplands aquifer system, the sediments, in order of dominance, consist mostly of sand, silt, and clay. The sediment deposits are distributed as relatively uniform sequences of predominantly fine- or coarse-grained material. In the Coastal Lowlands aquifer system, the aquifers dip and thicken toward the Gulf, and sediments exist in complex, overlapping mixtures of sand, silt, and clay as a result of numerous oscillations of ancient shorelines.

Rainfall amounts for the study area were derived from measured rainfall at five National Weather Service (NWS) meteorological stations (sites 1, 3, 4, 6, 7; fig. 1, table 1). Rainfall varied from year to year and throughout the lower San Antonio River watershed, which is typical of south-central Texas. During 2000–2007, annual mean rainfall measured at the five NWS stations in the lower San Antonio River watershed varied from 33.5 to 40.2 inches per year (table 2), similar to the long-term average rainfall of 31 to 39 inches per year for this area of Texas (Narasimhan and others, 2005). During the study, the smallest annual rainfall (18.4 inches) was recorded in 2005 at NWS 413201 Floresville, Tex. (site 4) and the largest (51.8 inches) was recorded in 2007 at NWS 413618 Goliad, Tex. (site 7). Years with above-average rainfall included 2002, 2004, and 2007.

During 2000–2007, annual mean streamflow volume measured at 08181800 San Antonio River near Elmendorf (site 8; fig. 1, table 1) ranged from 0.160 million acre-feet in 2006 to 1.41 million acre-feet in 2002. The average of daily streamflow during 2000–2007 was 886 cubic feet per second. According to Ockerman and McNamara (2003, p. 28), streamflow at site 8 averaged 0.40 million acre-feet annually during 1997–2001. During this period, streamflow at site 8 consisted primarily of base flow and runoff from the upstream drainage area (about 75 percent), treated wastewater discharge (about 20 percent), and Edwards aquifer springflow (about 5 percent). During 2000–2007, the average of daily streamflow increased slightly at the downstream USGS streamflow-gaging station 08183500 San Antonio River near Falls City, Tex. (site 10; fig. 1, table 1). Site 10 is upstream from the confluence of the San Antonio River and Cibolo and Ecleto Creeks. The average of daily streamflow during 2000–2007 at site 10 was 891 cubic feet per second. The streamflow data used for this report are available from the USGS National Water Information System (NWISWeb) (U.S. Geological Survey, 2009).

During 2000–2007, annual mean streamflow volume at USGS streamflow-gaging station 08185000 Cibolo Creek at Selma (site 11; fig. 1, table 1) ranged from no flow in 2003 and 2006 to 151,050 acre-feet in 2002. Flow at site 11 consists mostly of stormwater runoff from the Cibolo Creek contributing area upstream from Selma. The average of daily streamflow at site 11 during 2000–2007 was 59.4 cubic feet per second. About 10 miles downstream from site 11, Cibolo Creek starts to receive inflows of treated wastewater. These inflows are from one wastewater treatment plant on the main stem of Cibolo Creek and from three wastewater treatment plants on Martinez Creek, a tributary of Cibolo Creek. Downstream from the wastewater inflow and crossing the Carrizo Sand outcrop (fig. 2), Cibolo Creek gains flow from multiple springs, including those known collectively as Sutherland Springs. USGS streamflow-gaging station 08186000 Cibolo

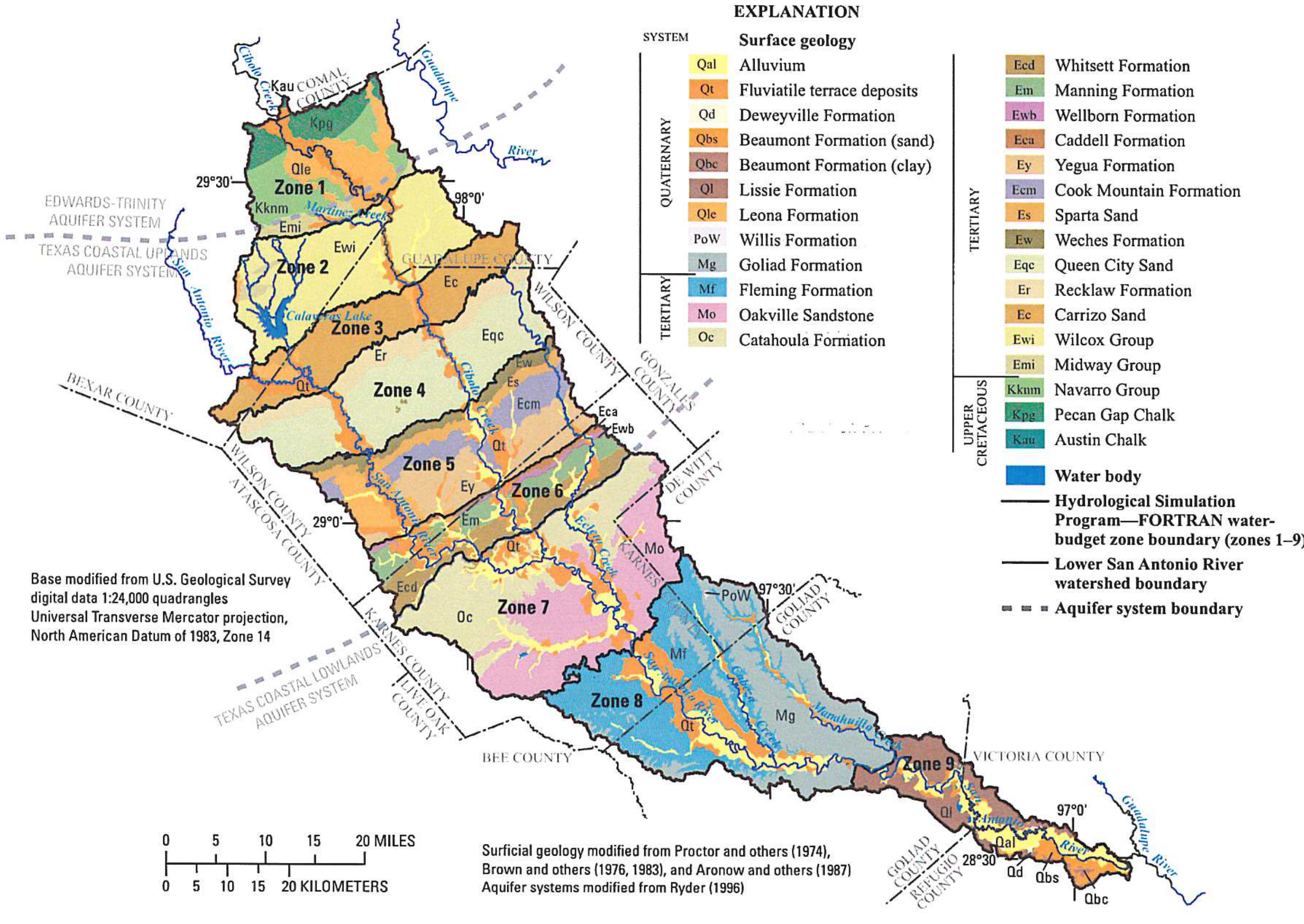


Figure 2. Aquifer systems, surficial geology, and delineation of water-budget zones for the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

Table 2. Rainfall at five National Weather Service stations in the lower San Antonio River watershed, south-central Texas, 2000–2007.

Year or period	National Weather Service station (fig. 1)				
	Randolph Field (site 1)	Stockdale 4 N (site 3)	Floresville (site 4)	Karnes City 2 N (site 6)	Goliad (site 7)
2000	33.9	34.4	31.6	35.6	37.1
2001	36.7	36.7	31.3	35.9	45.9
2002	40.0	40.1	41.1	39.0	42.4
2003	25.7	27.0	29.6	26.8	34.5
2004	[1]48.1	[1]46.0	41.3	44.4	47.9
2005	20.2	19.9	18.4	21.5	28.9
2006	24.1	[1]27.0	26.0	[1]21.7	32.7
2007	[1]48.0	[1]46.4	48.9	[1]44.9	51.8
2000–2007 annual mean	**34.6**	**34.7**	**33.5**	**33.7**	**40.2**

[1] Rainfall records during these years at these stations were supplemented with rainfall data from nearby National Weather Service stations—San Antonio International Airport and Runge (sites 2 and 5, respectively; fig. 1, table 1).

Creek near Falls City, Tex. (site 15; fig. 1, table 1) records streamflow upstream from the confluence of Cibolo Creek and the San Antonio River. During 2000–2007, the annual mean volume of streamflow at site 15 ranged from 25,416 acre-feet in 2006 to 398,262 acre-feet in 2002, whereas the average of daily streamflow was 250 cubic feet per second.

Streamflow data are recorded near the Ecleto Creek outlet to the lower San Antonio River at USGS streamflow-gaging station 08186500 Ecleto Creek near Runge, Tex. (site 16; fig. 1, table 1). Ecleto Creek originates in the outcrop of the Carrizo Sand and joins the San Antonio River over the Texas Coastal Lowlands aquifer system, downstream from the confluence of the San Antonio River and Cibolo Creek. Although the streamflow record at site 16 began in March 1962, the station was not in service during October 1989–September 2002. For the period when the station was in operation relevant to this report (October 2002–December 2007), the average of daily streamflow was 52.3 cubic feet per second.

Downstream from the confluence of Cabeza Creek and the lower San Antonio River, streamflow in the lower San Antonio River is recorded at USGS streamflow-gaging station 08188500 San Antonio River at Goliad, Tex. (site 17; fig. 1, table 1). During 2000–2007, annual mean streamflow volume at site 17 ranged from 226,068 acre-feet in 2006 to 2.06 million acre-feet in 2002, whereas the average of daily streamflow was 1,370 cubic feet per second.

Previous Studies

The lower San Antonio River and its tributaries include gaining and losing reaches. North of the study area, over the Edwards aquifer recharge area, streams in the San Antonio River watershed typically lose water to the groundwater system. Rainfall on the Edwards aquifer outcrop and instream channel losses contribute to recharge of the Edwards aquifer (Ockerman, 2002). Conversely, the Carrizo Sand outcrop is an area where Anders (1957) reported the San Antonio River and Cibolo Creek gained "large" amounts of groundwater. Water was considered to be discharging from the groundwater system into the river system in many places. However, large losses from this discharged groundwater also were suspected to be occurring because of ET in the riparian zones.

Evaporation and transpiration are major components of the water budget in Texas. Evaporation occurs directly from free-water surfaces, such as lakes, streams, and temporary rainfall accumulations (for example, puddles in depressions or droplets on leaves); transpiration occurs as plant roots extract water from the soil and release water vapor into the atmosphere through plant-leaf stomata. ET is a combination of evaporation and transpiration. ET rates can vary depending on meteorological conditions, the type of land cover (paved, wetland, wooded, agricultural, and others), the time of day, the time of year, and soil moisture.

Strategic water management requires quantification of ET for reliable hydrologic analyses and calibration of hydrologic models (Sumner and Tihansky, 2007). In spite of the relative importance of ET within the hydrologic cycle—after rainfall, it is the largest component of the water budget—reliable data for actual ET have historically been scarce in Texas (Scanlon and others, 2005). Information on ET in Texas is generally limited to measured pan evaporation and computed estimates of potential evapotranspiration (PEVT) derived from meteorological data. The meteorological data used to compute PEVT are obtained from NWS meteorological stations throughout Texas and from other ET networks, such as the Texas High Plains Evapotranspiration Network (Texas A&M University, 2005). Pan evaporation and PEVT are measures of the ability of the atmosphere to remove water from the surface assuming an unlimited water supply (Pidwirny, 2006). These estimates are generally used as input to hydrological models, and then the models use other spatial and temporal factors such as rainfall and land-cover information to simulate actual ET. Actual ET data have rarely been available for model calibration. Recently, advanced micrometeorological stations have been instrumented to measure actual ET data at some locations in Texas, including several on the Edwards Plateau since the early 2000s. In 2006, the USGS installed a station (290810099212100 SW Medina County meteorological station near D'Hanis, Tex.) where data are collected to measure actual ET continuously using the eddy covariance method (Bidlake, 2002). This station (not shown in fig. 1) is in Medina County about 70 miles west of the study area on the Carrizo

Sand, one of the formations that outcrop in the lower San Antonio River watershed.

The University of Texas Bureau of Economic Geology has compiled published information on groundwater recharge rates to the major aquifers of Texas for the Texas Water Development Board (Scanlon and Dutton, 2003). These compiled estimates of recharge rates range from 0.1 to 5.8 inches per year in the Carrizo-Wilcox aquifer. Higher recharge rates occur in the sandy parts of the aquifer (such as the Carrizo Sand). Reported recharge rates for the Gulf Coast aquifer system (0.0004 to 2 inches per year) are generally lower than those for the Carrizo-Wilcox aquifer.

Simulation of Streamflow, Evapotranspiration, and Groundwater Recharge

To simulate streamflow, ET, and recharge in the lower San Antonio River watershed, a continuous simulation watershed model was needed that would take into account all of the water-budget components and processes. The Hydrological Simulation Program—FORTRAN (HSPF), version 12 (Bicknell and others, 2001), was selected for modeling the study watershed because it is one of the most comprehensive watershed models available and can simulate a wide variety of stream and watershed conditions with reasonable accuracy (Donigian and others, 1995). HSPF has been used successfully in south-central Texas to represent complex hydrologic systems, simulate streamflow, and estimate groundwater recharge to the Trinity and Edwards aquifers (Ockerman, 2002, 2007; Ockerman and McNamara, 2003).

Functional Description of Hydrological Simulation Program—FORTRAN

The HSPF model software is distributed as part of the BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) system. BASINS 4.0 was developed by the U.S. Environmental Protection Agency (2007) to support watershed management. BASINS serves as an umbrella-like package, interfacing with pertinent geodatabases, ancillary datasets, and software programs to facilitate user interaction with the model and to help the user better understand the hydrological characteristics of a watershed. Time-series data and model output-generated time-series data are stored in a Watershed Data Management (WDM) file. The WDM database is a binary file accessed by GenScn (GENeration and analysis of model simulation SCeNarios) (Kittle and others, 1998) or by WDMUtil (Hummel and others, 2001). These programs are provided in BASINS and are used to manage, display, transform, plot, and analyze time-series data stored in the WDM file. Time-series data are organized in the WDM database by dataset number (DSN). Each DSN has attribute information that describes the data type, time step, location, and other important characteristics of the data. The HSPF model is the primary surface-water modeling component of BASINS. HSPF also exists as a stand-alone program as do the other tools and programs included in BASINS, such as WDMUtil and GenScN. The HSPF users' manual provides model documentation, underlying model theory, and model parameterization guidance (Bicknell and others, 2001). HSPF is an integrated basin-scale model that combines watershed processes with in-stream fate and transport in one-dimensional characterizations of stream channels.

In HSPF, a watershed is represented by a group of hydrologically similar areas referred to as hydrologic response units (HRUs) that drain to a stream segment, lake, or reservoir referred to as a RCHRES (ReaCH RESservoir); each RCHRES has an associated drainage area that was partitioned into HRUs. HRUs are areas with similar land cover, surficial geology, and other factors deemed important to produce a similar hydrologic response to rainfall and PEVT. HRUs are categorized as either pervious or impervious land segments, termed PERLND (PERvious LaND) or IMPLND (IMPervious LaND), respectively. A PERLND is represented conceptually within HSPF by three interconnected water storage zones—an upper zone, a lower zone, and a groundwater zone. An IMPLND is represented by surface storage, evaporation, and runoff processes. Water is moved through this network of HRUs and RCHRESs for each time step specified in the model while conserving water mass—that is, inflow equals outflow plus or minus any change in storage. The water budget for the overall model (as well as the smaller HRUs and RCHRES drainage areas) can be stated as

$$P + Q_{in} = \mathrm{ET} + Q_{out} + \Delta S, \tag{1}$$

where

P is precipitation (rainfall [might also include irrigation or other special applications]);

Q_{in} and Q_{out} are water flow into and out of the model, respectively;

ET is evapotranspiration; and

ΔS is change in water storage.

Individual components can be broken down into subcomponents (for example, water flow into an HRU [Q_{in}] is the sum of surface flow and interflow). A simplified water-budget equation for the overall model to incorporate some of these subcomponents, and assuming that the change in storage over time is minimal, results in

$$P + Q_{in}^{sw} + Q_{in}^{gw} = ET^{sw} + ET^{uz} + ET^{gw} + Q_{out}^{sw} + R, \tag{2}$$

where

P is precipitation (rainfall);

Q_{in}^{sw} is surface-water flow from upstream and other surface-water discharges (such as wastewater treatment plants);

Q_{in}^{gw} is groundwater discharge to streams (such as springflow);

ET^{sw} is *ET* from the surface water;

ET^{uz} is *ET* from the unsaturated zone (upper zone; fig. 3);

ET^{gw} is *ET* from the active groundwater (lower zone, fig. 3);

Q_{out}^{sw} is surface-water flow out of the model as runoff and withdrawals; and

R is groundwater recharge (recharge is defined as including any infiltrating water that reaches the inactive groundwater, bottom of fig. 3).

While maintaining the overall water balance, the model continuously simulates the interaction among subcomponents of the water-budget equation and variations of these subcomponents over time. The conceptualization of the complex hydrologic processes is depicted in figure 3. The hydrologic processes are described by empirical equations in the model code. Model parameters used in the empirical equations (table 3) are estimated and then adjusted during the calibration of the model. Typical values and ranges of model parameters from Donigian and others (1984), as well as watershed characteristics, were used to develop initial values for model parameters.

HSPF has some limited functionality for characterizing groundwater and surface-water interactions. HSPF simulates groundwater inflow—base flow and interflow—to a RCHRES that originates from infiltration of rainfall. HSPF also accounts for groundwater leaving the system as recharge. ET simulations also are included for water stored in upper and lower storage zones and active groundwater. However, groundwater entering the system from springs or regional groundwater inflow can be input to HSPF only as an external time series.

Model output can include time series of any of the simulated subcomponents at any designated outlet or HRU. HSPF is calibrated by adjusting the process-related model parameters for each HRU or RCHRES until there is acceptable correlation between measured data and model output (simulated data). Generally, regardless of the relative magnitude of streamflow compared to that of precipitation and ET, streamflow is used for calibration because measured streamflow data are most readily available. However, errors in the estimation of any of the individual components of the water budget will affect the estimation of other components.

Model Development

The HSPF model of the lower San Antonio River watershed was developed by (1) defining subwatersheds, RCHRESs, and water-budget zones for the study area; (2) classifying HRUs on the basis of surficial geology, land cover, and location of rainfall gages; (3) developing the input time series of meteorological and streamflow data; and (4) determining initial (uncalibrated) values of associated model parameters. Initial estimates of parameters were determined or estimated from default values, previous studies, and available data.

Subwatershed and Stream Reach Delineations

Because the study area is large, the lower San Antonio River watershed was divided into four subwatersheds: (1) San Antonio River upstream from Cibolo Creek; (2) Cibolo Creek; (3) Ecleto Creek; and (4) San Antonio River downstream from Cibolo Creek (fig. 4). The subwatershed of the San Antonio River upstream from Cibolo Creek includes the drainage area extending from 08181800 San Antonio River near Elmendorf (site 8) to the confluence of the San Antonio River and Cibolo Creek. The Cibolo Creek subwatershed includes the drainage area extending from 08185000 Cibolo Creek at Selma (site 11) to the confluence of Cibolo Creek and the San Antonio River. The Ecleto Creek subwatershed includes the drainage area extending from the headwaters of Ecleto Creek to the confluence of Ecleto Creek and the San Antonio River. The subwatershed of the San Antonio River downstream from Cibolo Creek includes the drainage area extending immediately downstream from the confluence of the San Antonio River and Cibolo Creek to the confluence of the San Antonio and Guadalupe Rivers.

Separate HSPF models were developed for each subwatershed. The most downstream subwatershed model, San Antonio River downstream from Cibolo Creek, receives the simulated streamflow from the outlets of the three other subwatershed models. A simulation of the overall study area involves running simulations of the three upstream models, then running the downstream model. Each subwatershed model area was further subdivided into stream reaches (RCHRESs) with associated drainage areas. Considerations in developing the subwatershed and stream-reach delineations included (1) defining reaches with streamflows such that travel times through RCHRESs approximate the simulation time step; and (2) locating outlets of RCHRESs at strategic points, such as streamflow-gaging stations, tributary confluences, and geologic outcrop boundaries (Donigian and others, 1984).

USGS 7.5-minute digital elevation models (U.S. Geological Survey, 2001) were used to delineate the RCHRESs and to calculate watershed topography (slope). Channel characteristics for each RCHRES (surface area, volume, and discharge as a function of depth) were entered into HSPF FTABLES (tables of stream-channel parameters). For gaged stream reaches, FTABLES parameters were based on discharge measurements made at USGS streamflow-gaging stations. FTABLE parameters for ungaged reaches were estimated. A 1-hour time step was used to accurately simulate storm events. Subwatershed and stream-reach delineation is shown in figure 4.

Classification of Hydrologic Response Units

HRUs for the watershed were defined on the basis of surficial geology, land-cover classification, and raingage locations. Spatial information was compiled and analyzed using the geographical information system software ArcGIS (ESRI, 2009) to determine the acreage of each HRU within

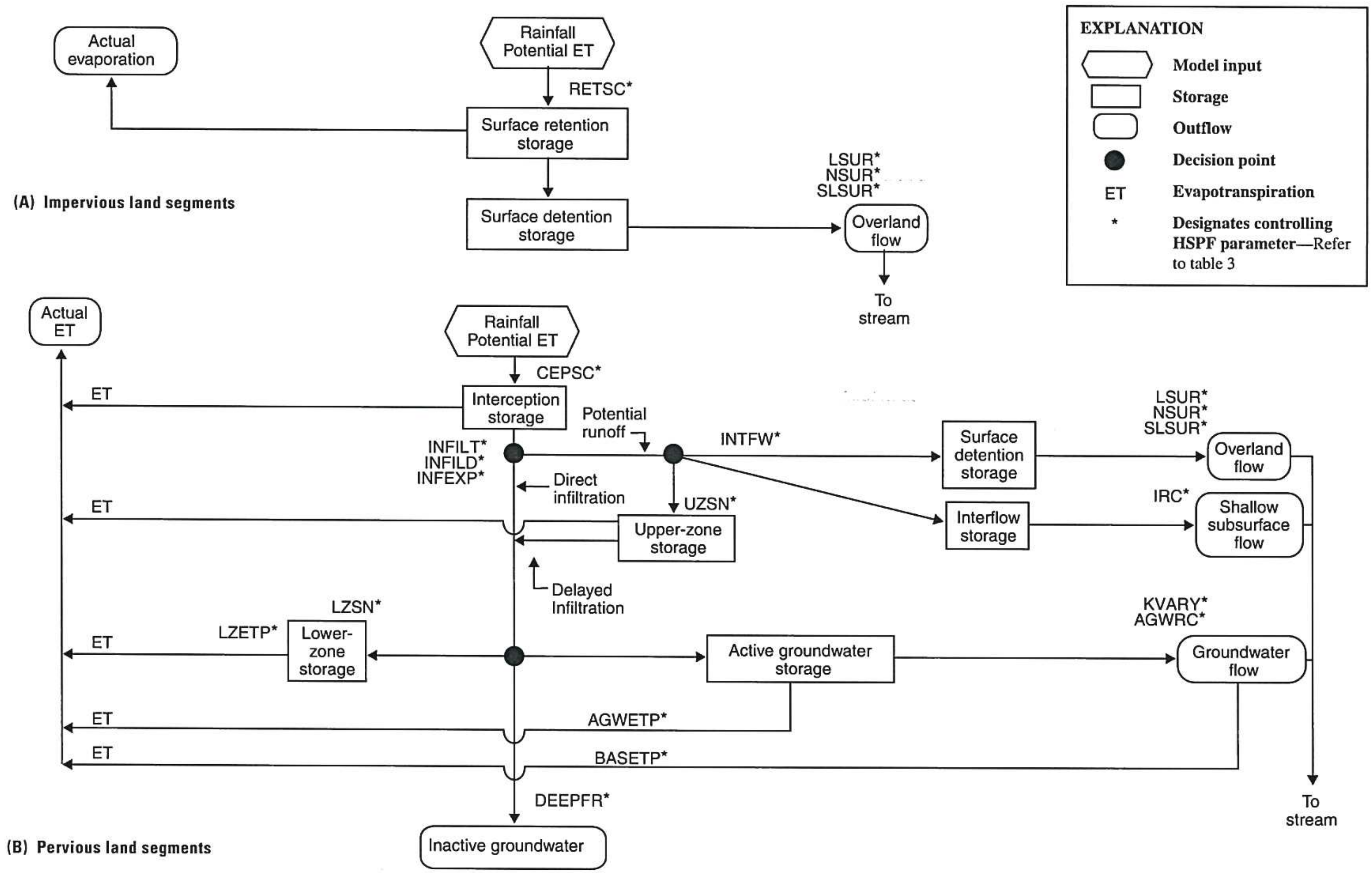


Figure 3. Hydrological Simulation Program—FORTRAN (HSPF) flowchart for hydrologic processes for (A) impervious and (B) pervious land segments (modified from Wicklein and Schiffer, 2002, fig. 3).

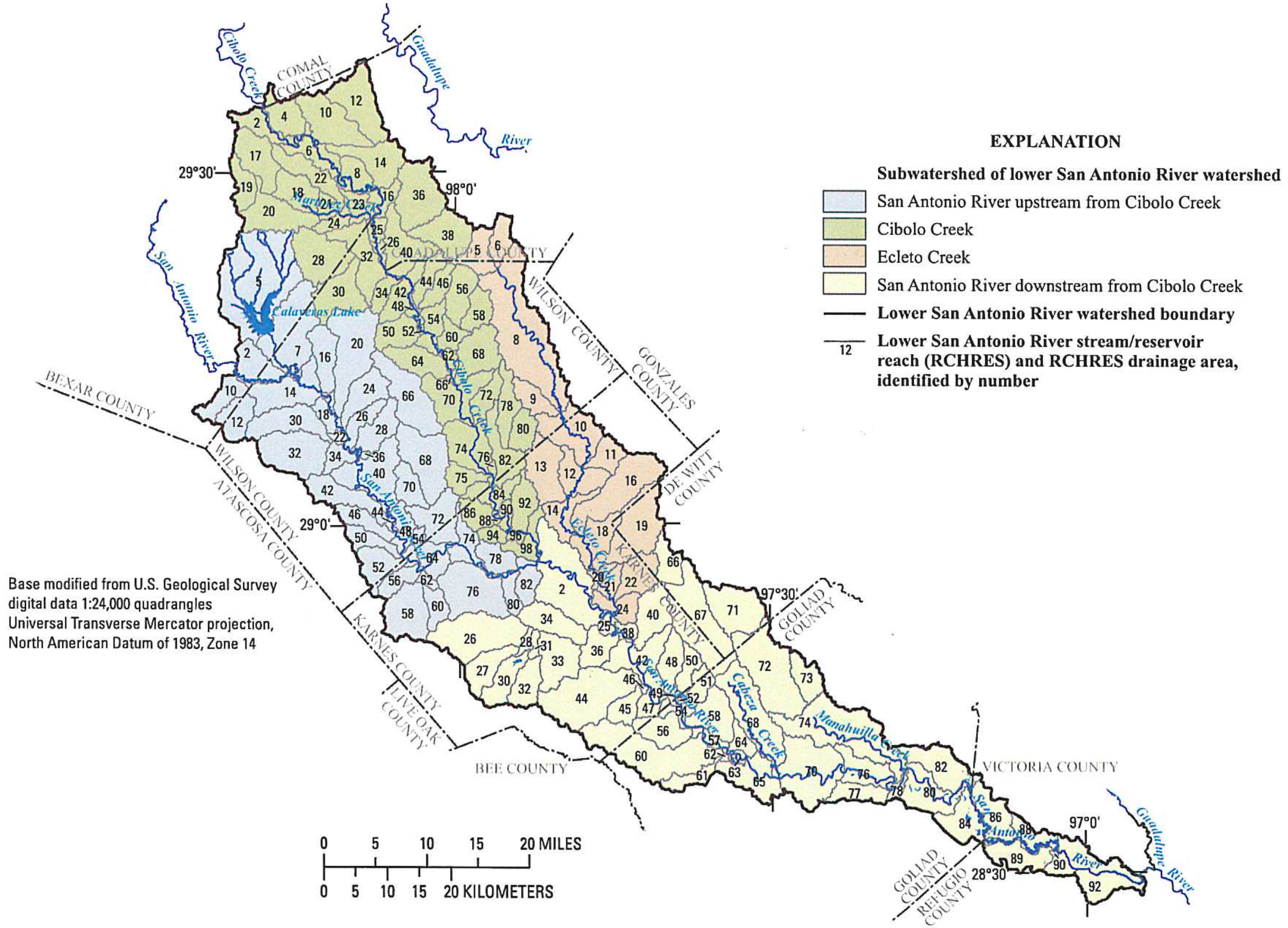


Figure 4. Subwatershed and stream/reservoir reach delineation for the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

Table 3. Parameters for hydrologic processes in the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

[PERLND, pervious land; IMPLND, impervious land]

Parameter	Description[1]	Units	Land segment
AGWS	Initial active groundwater storage	inches	PERLND
AGWETP	Fraction of available potential evapotranspiration demand that can be met from stored groundwater	none	PERLND
AGWRC	Groundwater recession parameter; an index of rate at which groundwater drains from land	1/day	PERLND
BASETP	Fraction of available potential evapotranspiration demand that can be met from groundwater outflow; simulates evapotranspiration from riparian vegetation	none	PERLND
CEPSC	Interception storage capacity	inches	PERLND
DEEPFR	Fraction of groundwater that does not discharge to surface within boundaries of modeled area	none	PERLND
INFEXP	Infiltration equation exponent; controls rate of infiltration decrease as a function of increasing soil moisture	none	PERLND
INFILD	Ratio of maximum and mean infiltration capacities	none	PERLND
INFILT	Index to infiltration capacity of soil; also affects percolation to groundwater zone	inches/hour	PERLND
INTFW	Interflow index; controls amount of infiltrated water that flows as shallow subsurface runoff	none	PERLND
IRC	Interflow recession coefficient; index for rate of shallow subsurface runoff	1/day	PERLND
KVARY	Groundwater outflow modifier; index of how much effect recent recharge has on groundwater outflow	1/inch	PERLND
LSUR	Length of assumed overland flow plane	feet	PERLND or IMPLND
LZETP	Lower-zone evapotranspiration; index value (ranging from 0 to 0.99) representing the density of deep-rooted vegetation	none	PERLND
LZS	Initial lower-zone storage	inches	PERLND
LZSN	Lower-zone nominal storage; index to soil moisture holding capacity of unsaturated zone	inches	PERLND
NSUR	Manning's n for assumed overland flow plane	none	PERLND or IMPLND
RETSC	Impervious retention storage capacity	inches	IMPLND
SLSUR	Slope of assumed overland flow plane	feet	PERLND or IMPLND
UZS	Initial upper-zone storage	inches	PERLND
UZSN	Upper-zone nominal storage; index to amount of surface storage in depressions and the upper few inches of soil	inches	PERLND

[1] The user's manual for Hydrological Simulation Program—FORTRAN (Bicknell and others, 2001) provides a detailed description of each parameter.

a RCHRES drainage area. The surficial geology of the study area was simplified as nine contiguous water-budget zones (fig. 2). This simplification was necessary to meet model computational limitations and also to define zones for which ET, recharge, and other water-budget information would be output by the model.

In addition to surficial geology, county soil data from the Natural Resources Conservation Service (2008) were compiled for the study area (fig. 5). As expected, the attributes of the soils correlated fairly closely with the surficial geology. Attributes associated with the soils in these geodatabases aided in the selection of initial estimates for HSPF parameters, such as the HSPF soil-infiltration rate (INFILT). As an example, the largest value for INFILT in the model was assigned to water-budget zone 3, characterizing the soil-infiltration rate of the Carrizo Sand.

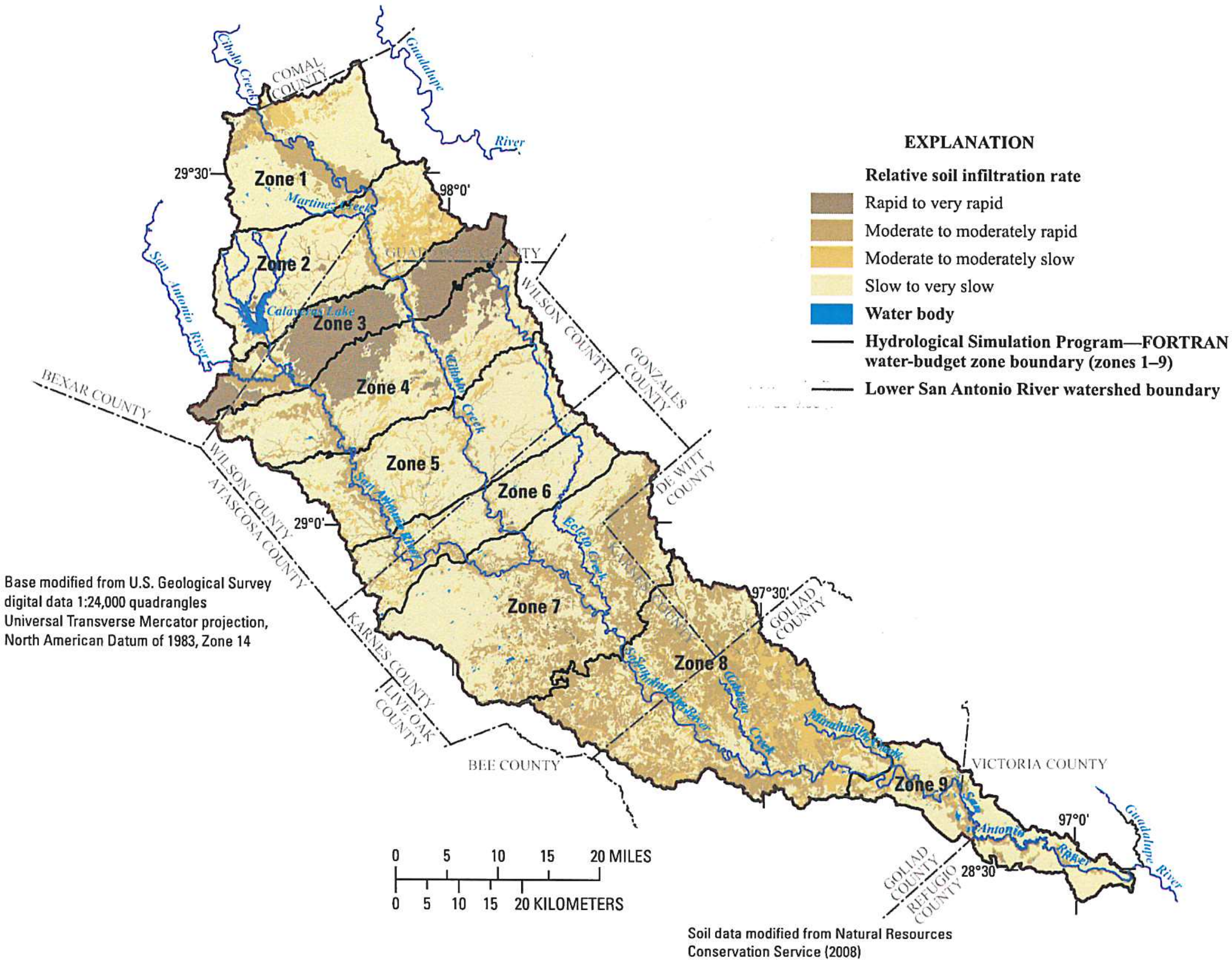


Figure 5. Relative soil infiltration rates in the lower San Antonio River watershed, south-central Texas.

Land-cover data were also compiled to define HRUs. Land-cover data for 2001 were available from the "National Land Cover Database 2001" (Multi-Resolution Land Characteristics Consortium, 2008). The lower San Antonio River watershed contains 15 of the 29 possible land-cover classes in the database. The 15 land-cover classes were consolidated into eight land-cover categories to simplify the model configuration (table 4). For example, barren land (class 31) was grouped with developed open space (class 21) to create one land-cover category called open space. Figure 6 shows seven of the eight categories; small amounts of open space (class 21) and barren land (class 31) were grouped with proximate developed and grass land cover. In the consolidated open space category, 15 percent of the acreage was considered impervious. The developed land-cover category includes low, medium, and high intensity development (classes 22, 23, and 24). The study area acreage was predominantly low intensity development (class 22), listed as 20 to 49 percent impervious in the database. In the consolidated developed land-cover category, 25 percent of the acreage was considered impervious. The acreage from the model land-cover categories "open space" and "developed" (table 4) was assigned as PERLND and IMPLND areas, respectively. Area categorized as open water is not part of an HRU. Instead this area is considered to be modeled as part of the stream reach and might vary slightly during model simulation on the basis of streamflow and channel dimensions.

Finally, the definition of each HRU depends on its location relative to available rainfall data. Data from the seven NWS meteorological stations (sites 1–7; fig. 1, table 1) were consolidated into five hourly rainfall time series and then were assigned areal significance (fig. 7) using the Thiessen method (Linsley and others, 1982). Of the seven NWS meteorological stations, sites 2 and 5 were only used to fill in missing record at nearby sites, thus the consolidation of data from seven stations into five hourly rainfall time series. The Thiessen rainfall areas were used to determine HRU acreages, as well as to determine where to apply the rainfall time-series data in the HSPF model. Rainfall was aggregated by water-budget zone by overlaying the Thiessen area rainfall amounts on the water-budget zone areas (table 5). During 2000–2007, annual mean rainfall estimates for the water-budget zones ranged from 33.7 to 38.5 inches per year; for the entire watershed the estimated annual mean rainfall was 34.3 inches (table 5).

Using ArcGIS, a spatial data intersection of water-budget zones, land-cover data, Thiessen rainfall areas, and RCHRES drainage areas was done to determine PERLND and IMPLND acreages for the HSPF models. The ArcGIS intersection resulted in a set of 77 unique PERLNDs classified using rainfall from Thiessen rainfall areas, nine water-budget zones, and seven land-cover categories. Ten unique IMPLNDs were classified using rainfall from Thiessen rainfall areas and two impervious land-cover categories (impervious acreages of open space and developed land-cover categories; table 4). Water-budget zones are not relevant for IMPLNDs. For example, RCHRES 2 in the subwatershed of the San Antonio River upstream from Cibolo Creek has a drainage area of about 8,920 acres and contains 16 unique HRUs. One HRU in the drainage area of RCHRES 2 represents pervious cropland in water-budget zone 2 and rainfall amounts measured at NWS 413201 Floresville (site 4; fig. 1, table 2). This same HRU also is present in RCHRES 7.

Time-Series Development

Streamflow from the USGS streamflow-gaging stations at the study area boundary, meteorological data, wastewater discharges, springflows, and surface-water withdrawals for irrigation are input to the lower San Antonio River model as time-series data. Streamflow data from USGS streamflow-gaging stations in the study area were used for calibration and testing. The data for each time series were compiled from national databases and local agencies.

Streamflow

The streamflow data used for this report are available from the USGS NWISWeb (U.S. Geological Survey, 2009). Wastewater discharges (fig. 8, table 6) have an appreciable effect on streamflow in the lower San Antonio River. A previous study reported that wastewater discharge accounted for about 20 percent of streamflow at the San Antonio River near Elmendorf during 1997–2001 (Ockerman and McNamara, 2003). Wastewater discharge entering the San Antonio River upstream from the study area is accounted for by 08181800 San Antonio River near Elmendorf (site 8). The total streamflow at this station is input to the model as a boundary condition.

Downstream from 08185000 Cibolo Creek at Selma (site 11), discharges from three wastewater treatment plants on Martinez Creek and one on the main stem of Cibolo Creek change Cibolo Creek from an ephemeral to perennial stream. The wastewater discharges during 2000–2007 from these four plants, OJ Riedel–Martinez II (table 6), were available from plant operators as average monthly discharges (Daniel Flores, San Antonio River Authority, written commun., 2009; David Humphrey and Robert Dabney, Cibolo Creek Municipal Authority, written commun., 2009). Locations and discharge amounts for eight additional smaller wastewater treatment plants (each serving populations of less than 10,000), La Vernia–Goliad (table 6), were obtained from the U.S. Environmental Protection Agency (2004).

Inflow to Cibolo Creek from springs upstream of the USGS streamflow-gaging station 08185500 Cibolo Creek at Sutherland Springs, Tex. (fig. 1) was simulated in the model as a time series input to stream reaches (RCHRES) 34, 42, 48, and 52 of the Cibolo Creek model (fig. 4). The time-series representing springflow was developed from data collected during gain/loss streamflow measurements in 2006–07. Streamflow gains, attributed to springs (Brune, 1975), were observed from the differences between measurements made at the USGS station 08185085 Cibolo Creek at Farm Road 2538 near St. Hedwig, Tex. (not a continuous gaging station, but a

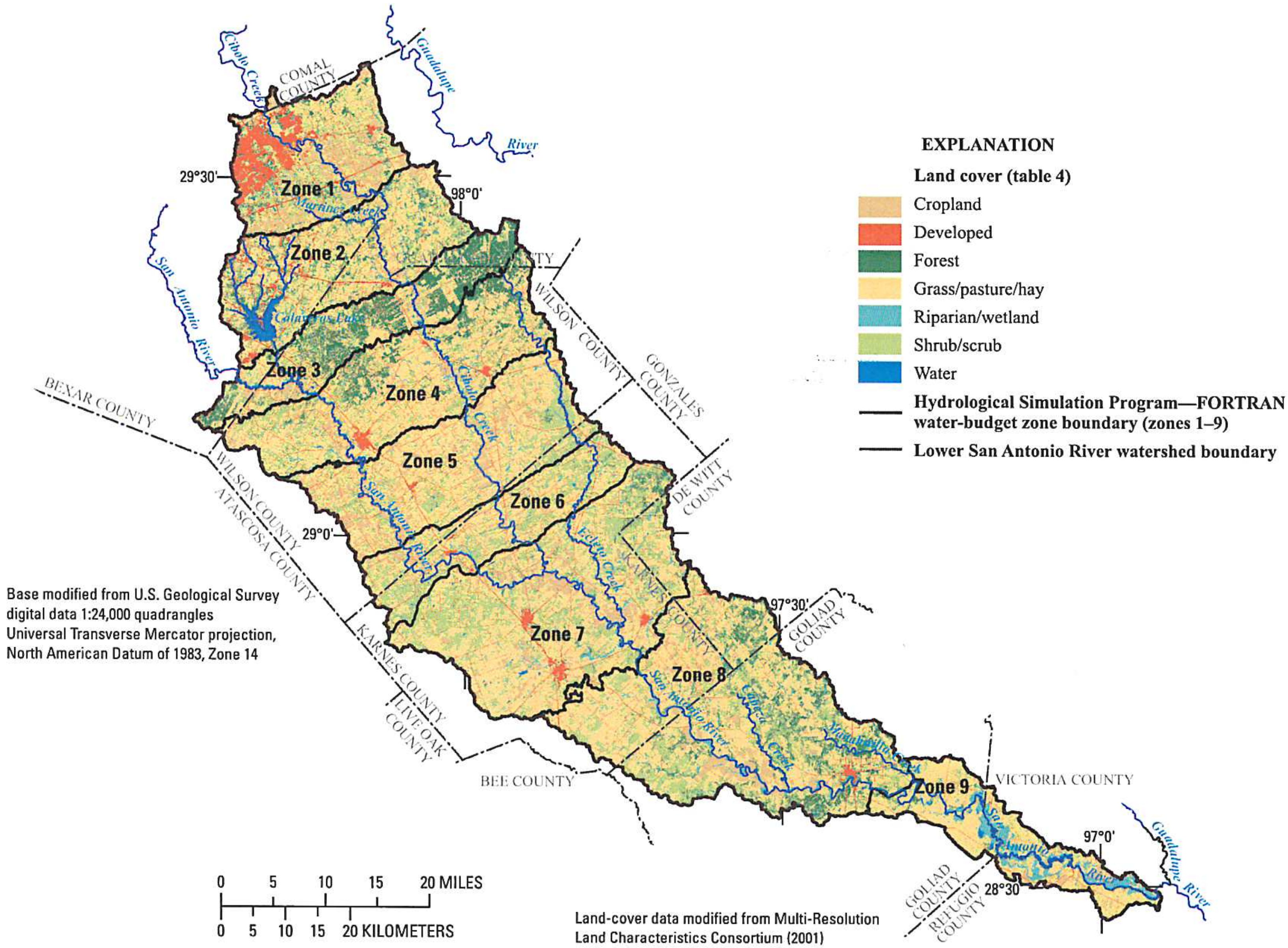


Figure 6. Land cover in the lower San Antonio River watershed, south-central Texas.

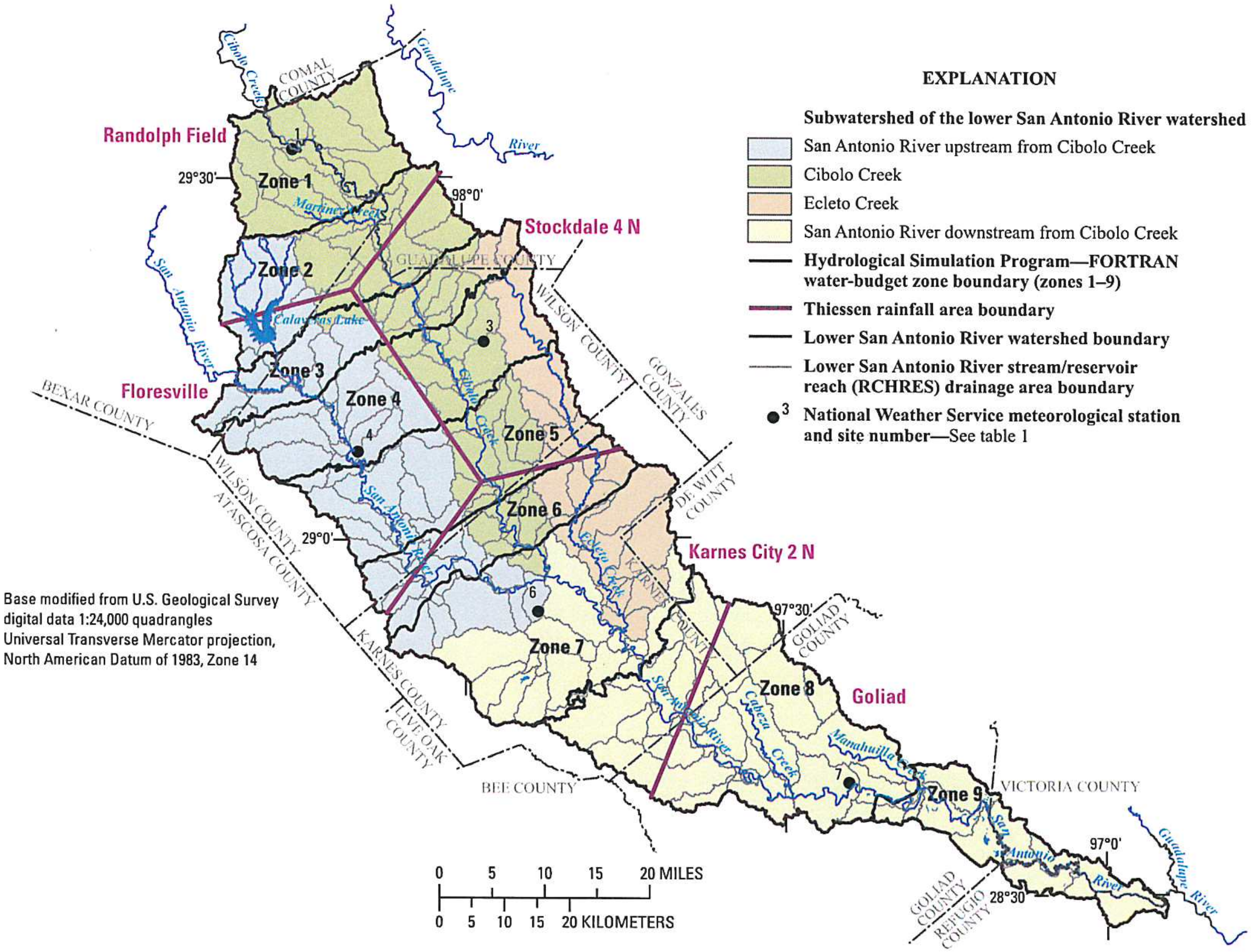
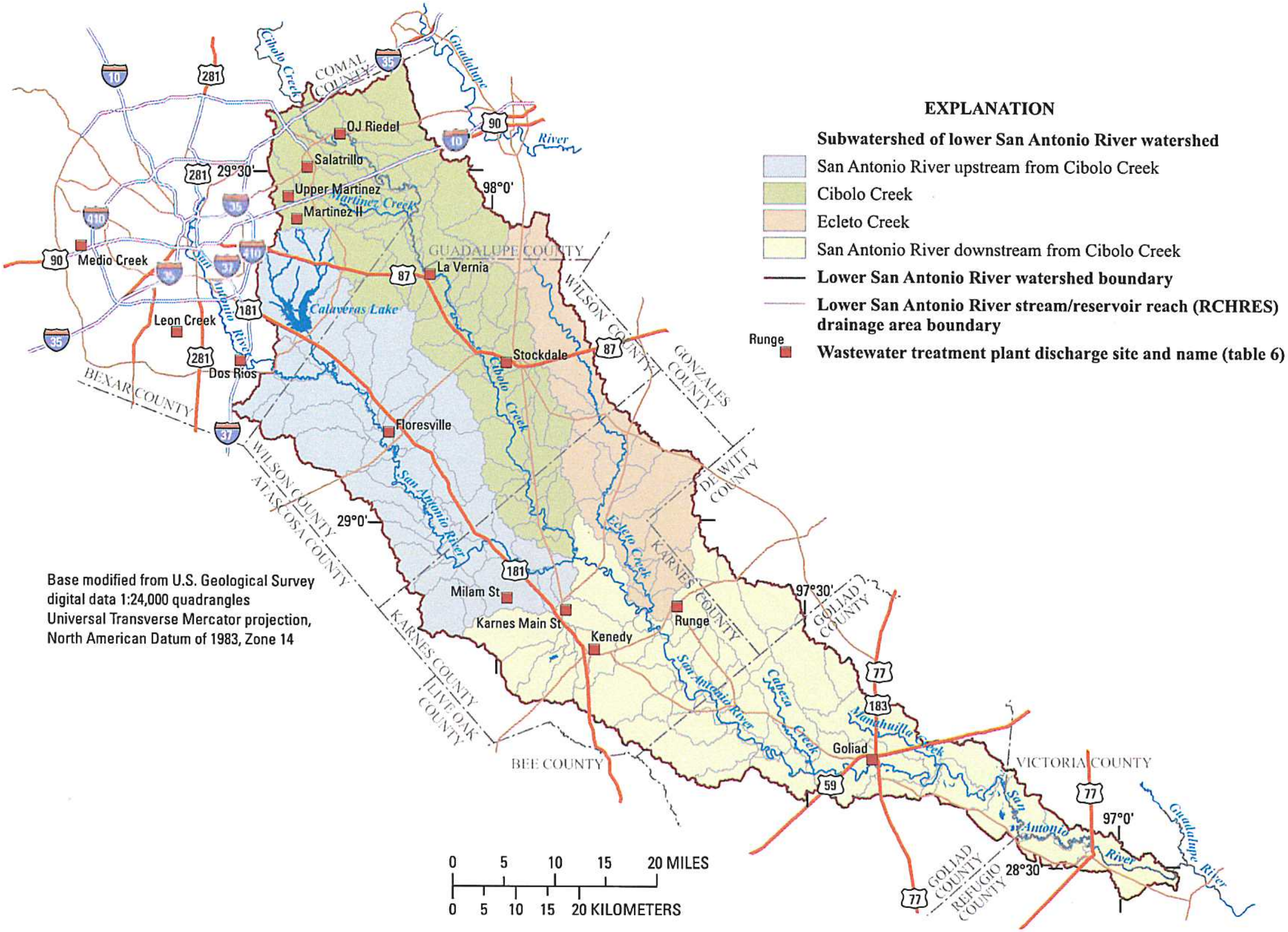


Figure 7. Location of National Weather Service meteorological stations and associated Thiessen rainfall areas for the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.



Base modified from U.S. Geological Survey digital data 1:24,000 quadrangles
Universal Transverse Mercator projection,
North American Datum of 1983, Zone 14

Figure 8. Location of wastewater treatment plant discharge sites, lower San Antonio River watershed, south-central Texas.

Table 4. Land-cover categories represented in the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

[HSPF, Hydrological Simulation Program—FORTRAN; --, not applicable]

HSPF model land-cover category (fig. 6)	Corresponding classification from National Land Cover Database 2001[1]	Percent impervious land cover
Water	11	--
Open space (not on fig. 6)	21, 31	15
Developed	22, 23, 24	25
Forest	41, 42, 43	0
Shrub/scrub	52	0
Grass/pasture/hay	71, 81	0
Cropland	82	0
Riparian/wetland	90, 91	0

[1] Multi-Resolution Land Characteristics Consortium (2008).

Table 5. Rainfall calculated for water-budget zones of the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas, 2000–2007.

Water-budget zone (fig. 2)	Area (acres)	Rainfall (inches)								
		2000	2001	2002	2003	2004	2005	2006	2007	Annual mean
1	108,716	33.9	36.7	40.0	25.7	48.1	20.2	24.1	48.0	34.6
2	133,447	33.9	36.2	40.2	26.4	47.0	20.0	25.1	47.7	34.6
3	97,342	32.9	33.9	40.6	28.2	43.6	19.1	26.3	47.7	34.0
4	161,944	33.0	33.9	40.7	28.4	43.6	19.1	26.5	47.8	34.1
5	158,316	33.2	34.1	40.5	28.2	43.6	19.3	26.1	47.5	34.0
6	92,595	34.9	35.3	39.3	27.1	44.1	21.0	22.6	45.5	33.7
7	236,723	35.5	35.9	39.0	26.8	44.4	21.5	21.7	44.9	33.7
8	276,464	35.5	35.9	39.0	26.8	44.4	21.5	21.7	44.9	33.7
9	82,207	36.6	43.3	41.4	32.5	46.9	27.0	30.0	49.9	38.5
Area weighted[1]		**34.5**	**35.8**	**39.8**	**27.5**	**44.8**	**20.8**	**24.2**	**46.6**	**34.3**

[1] For entire lower San Antonio River watershed (normalized to amount of pervious land in water-budget zones 1–9).

Table 6. Wastewater discharges included in the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

[HSPF, Hydrological Simulation Program—FORTRAN; RCHRES, stream reach or reservoir]

Wastewater treatment plant (fig. 8)	Receiving stream	Receiving HSPF RCHRES	Average discharge[1] (million gallons per day)
Medio Creek	Medio Creek[2]	Upstream from study area	6
Leon Creek	Leon Creek[2]	Upstream from study area	35
Dos Rios	Medina River[2]	Upstream from study area	54
Salado Creek[3]	Salado Creek[2]	Upstream from study area	31
OJ Riedel	Cibolo Creek	6	4.5
Salatrillo	Cibolo Creek	17	3.8
Upper Martinez	Cibolo Creek	20	1.7
Martinez II	Cibolo Creek	20	1.7
La Vernia	Cibolo Creek	34	.04
Stockdale	Cibolo Creek	68	.10
Floresville	San Antonio upstream from Cibolo Creek	26	.60
Milam St.	San Antonio upstream from Cibolo Creek	76	.20
Karnes Main St.	San Antonio downstream from Cibolo Creek	18	.05
Kenedy	San Antonio downstream from Cibolo Creek	16	.80
Runge	San Antonio downstream from Cibolo Creek	26	.06
Goliad	San Antonio downstream from Cibolo Creek	78	.20

[1] Reported discharges for Medio Creek, Leon Creek, Dos Rios, and Salado Creek facilities from Pablo Martinez (San Antonio Water System, written commun., 2007); reported discharges from other facilities from U.S. Environmental Protection Agency (2004).

[2] Discharge is upstream from U.S. Geological Survey station 08181800 San Antonio River near Elmendorf, Texas, and included in measured streamflow at the station.

[3] Salado Creek facility (not on fig. 8) decommissioned in 2007; influent previously treated by Salado Creek facility now treated by Dos Rios facility.

miscellaneous measurement site) and streamflow-gaging station 08185500 Cibolo Creek at Sutherland Springs. During four sets of synoptic measurements made during base-flow conditions (April 2006, August 2006, February 2007, and October 2007), streamflow gains between stations 08185085 and 08185500 ranged between 4 and 29 cubic feet per second (U.S. Geological Survey, 2009). To develop a continuous daily time series of springflow for input to the model, the observed streamflow gains were related to daily water level, measured on the same day as the streamflow measurements, at the J–17 regional index well (Edwards Aquifer Authority, 2009). This well (state well number AY–68–37–203) is located approximately 27 miles northwest of station 08185500, on the Fort Sam Houston military base in San Antonio (not shown in fig. 1). A linear regression relation of measured streamflow gains and J–17 daily water levels was developed and used to estimate daily springflow input to Cibolo Creek for 2000–2007. The resulting regression equation was:

$$Q_{springflow} = 0.482 \times L - 305.2, \quad (3)$$

where

$Q_{springflow}$ is estimated mean daily spring discharge to Cibolo Creek, in cubic feet per second, and

L is mean daily water level of the J–17 well, in feet.

The coefficient of determination of the regression equation was 0.868. The springflow estimated by the regression equation was divided among the four model RCHRESs in proportion to the stream length of each stream reach.

Surface-water withdrawals from the San Antonio River and Cibolo Creek for irrigation were determined from data provided by the Texas Commission on Environmental Quality (TCEQ) (Ceasar Alvarado, Texas Commission on Environmental Quality, written commun., 2009). These data were provided in the form of monthly volumes, for TCEQ defined stream reach segments, for 1997–2005. For input to the HSPF model the data were disaggregated to average hourly values, based on the monthly totals. Monthly average withdrawals for each stream reach during 1997–2005 were used to estimate monthly values for the period when withdrawal data were not available (2006–07). Also, TCEQ defined stream reaches do not correspond directly with the HSPF RCHRESs; each TCEQ reach typically includes several HSPF RCHRESs. Total withdrawals from each TCEQ stream reach were allocated to the appropriate HSPF RCHRES in proportion to the amount of cropland included in the area draining to each RCHRES. Cropland acreage (fig. 6) was assumed constant for the simulation period, 2000–2007.

Meteorological Data

BASINS 4.0 was used to download and pre-process rainfall and air temperature data from the NWS sites (table 1). These data were used to create the hourly time series of rainfall and PEVT for the HSPF model—downloading and formatting regional meteorological data from national datasets. The algorithms in this version of BASINS (U.S. Environmental Protection Agency, 2007) download and process national datasets through 2006. To extend the record through 2007 for this model, available rainfall and air temperature data for the same or nearby NWS sites were downloaded from the National Climatic Data Center (2009). These data were reviewed, processed, and appended to the input WDM files using the same processing steps available in BASINS 4.0. HSPF uses BASINS-computed PEVT estimates with other model input (rainfall, storage, lower-zone parameters) to simulate actual ET. Three of the NWS meteorological stations (sites 2, 4, and 7; table 1) had air temperature data that BASINS used to compute PEVT estimates through 2006. Air temperature data at these sites were used to extend the PEVT time series through 2007 for the model. The Hamon method (Bidlake, 2002), a subroutine available in the WDMUtil program of BASINS 4.0, was used on the 2007 maximum and minimum daily air temperature data to estimate computed PEVT for 2007.

Model Calibration and Testing

Model calibration is an inherently iterative process of parameter evaluation and adjustment. Initial estimates of model parameters (such as INFILT and LZSN in HSPF) are adjusted until the simulated streamflow and ET data compare favorably to measured data, and predefined calibration criteria are satisfied. Various acceptance criteria are used. Comparisons of simulated data with measured data are facilitated through the use of descriptive statistics such as means, medians, and variances, and by the use of graphs. Jain and Sudheer (2008, p. 981) note, "Many times, the parameters of the hydrologic models are not measurable in the field or there [might] be a dearth of field measurements. In such cases, initial parameter values are assigned [on the basis of] relevant measurable catchment properties—[for example] soil properties, vegetation characteristics or by experience." Model testing involves using the calibrated model to simulate data for another time period. These simulated data are compared with additional measured data that were not used in the initial calibration.

Model parameters were adjusted to meet acceptance criteria for streamflow at various USGS streamflow-gaging stations in the watershed. Effort was also made to minimize the difference between simulated ET in the water-budget zones representing the Carrizo Sand and the measured ET at USGS 290810099212100 SW Medina County meteorological station. Model parameters were adjusted while maintaining recharge rates within the range of literature values reported by Scanlon and Dutton (2003). In addition, initial estimates of irrigation withdrawals were adjusted by as much as ±100 percent.

Streamflow

A primary goal of hydrologic model calibration is to adjust model-simulated streamflow to match streamflow measured at a nearby streamflow-gaging station. The lower San Antonio River model was calibrated in accordance with guidelines by Donigian and others (1984) and Lumb and others (1994). These guidelines involved comparing measured and simulated streamflow data and minimizing the difference between the total volumes of streamflow, largest 10 percent of streamflows, and smallest 50 percent of base flows. In addition, model-fit statistics generated by the software program GenScn (U.S. Environmental Protection Agency, 2007) were used to examine the quality of the model fit on an annual, monthly, daily, and hourly basis for the (1) coefficient of determination (R-squared) of the linear regression between measured and simulated streamflow; (2) Nash-Sutcliff coefficient of model-fit efficiency (NSE), which measures the amount of variance in the measured streamflow explained by the simulated streamflow (Nash and Sutcliff, 1970); (3) mean absolute error (MAE); and (4) root mean square error (RMSE). The R-squared and NSE are similar; each provides a measure of the variability in a dataset accounted for by the statistical model. The NSE, however, provides a generally preferable evaluation of the fit quality because the NSE measures the magnitude of the differences between measured and simulated values, whereas the R-squared measures the difference between mean values (Zarriello and Ries, 2000). The MAE and RMSE statistics express the difference between measured and simulated streamflow in original units (cubic feet per second). Because a large NSE can be achieved with a less-than-adequate model, it is important to also evaluate the model performance using other methods (Jain and Sudheer, 2008), such as scatter plots.

Eleven USGS streamflow-gaging stations are in the lower San Antonio River watershed. Two stations—08181800 San Antonio River near Elmendorf and 08185000 Cibolo Creek at Selma (sites 8 and 11, respectively; fig. 1, table 1)—provided streamflow data that were used as boundary condition data to represent streamflow entering the study area. Data from eight of the nine remaining stations were used for calibration or testing, or both. Three of the eight stations—08183500 San Antonio River near Falls City, 08186000 Cibolo Creek near Falls City, and 08188500 San Antonio River at Goliad (sites 10, 15, and 17, respectively; fig. 1, table 1)—had streamflow records for the entire 2000–2007 study period; data for 2004–07 were used for model calibration and the remaining data, 2000–2003, for testing.

Five of the eight stations had data for only part of the study period; data from these stations were used for either calibration or testing. Data from three stations—08185100 Martinez Creek near St. Hedwig, Tex., 08186500 Ecleto Creek near Runge, Tex., and 08188570 San Antonio River near McFaddin, Tex. (sites 13, 16, and 18, respectively; fig. 1, table 1)—were used for calibration. Data from two stations—08183200 San Antonio River near Floresville, Tex., and 08185500 Cibolo Creek at Sutherland Springs, Tex. (sites 9 and 14, respectively; fig. 1, table 1)—were not used for calibration but were used for additional testing of model streamflow simulation.

The streamflow calibration process was accomplished beginning with the most upstream subwatersheds, using available streamflow-gaging data to adjust model process parameters. For example, data from 08183500 San Antonio River near Falls City were used to calibrate model streamflow for the drainage area upstream from the station (through RCHRES 54) in the subwatershed of the San Antonio River upstream from Cibolo Creek. Similarly, data from 08185100 Martinez Creek near St. Hedwig, were used to calibrate the drainage area associated with RCHRESs 17–23 in the Cibolo Creek subwatershed. Using data from the next downstream stations, further calibration was performed by adjusting process-related parameters for the intervening area downstream from the previously calibrated drainage area. For model RCHRES outlets representing locations of streamflow-gaging stations, measured streamflow data rather than simulated streamflow data were routed to the next downstream RCHRES. In this way, simulation errors (differences between measured and simulated streamflows) were not propagated downstream. Measured and simulated streamflows and model-fit statistics for all stations used in the calibration and testing process are listed in table 7.

Simulated flows also were evaluated graphically by comparing measured and simulated daily time series and exceedance-probability (flow-duration) curves. General agreement between the measured and simulated exceedance-probability curves indicate adequate calibration over the range of flow conditions. Daily time series, exceedance-probability curves, and scatter plots of measured daily and simulated daily streamflow are shown graphically for calibration stations 08183500 San Antonio River near Falls City (fig. 9), 08185100 Martinez Creek near St. Hedwig (fig. 10), 08186000 Cibolo Creek near Falls City (fig. 11), 08186500 Ecleto Creek near Runge (fig. 12), 08188500 San Antonio River at Goliad (fig. 13), and 08188570 San Antonio River near McFaddin (fig. 14). Simulated streamflow agreed reasonably well with measured streamflow for the range of streamflow observed during the study.

Donigian and others (1984) provide general guidelines for characterizing HSPF calibrations. For annual and monthly streamflow volumes, model calibration is considered very good when the error is less than 10 percent, good when the error is within 10 to 15 percent, and fair when the error is within 15 to 25 percent. According to these guidelines, calibration results for annual streamflow volumes at all of the calibration stations are considered very good or good. The R-squared and NSE values are considered acceptable for annual, monthly, and daily statistics (table 7). The NSE for daily streamflows ranged from 0.57 to 0.93 for the calibration periods at all stations. Generally, R-squared and NSE values were lower for hourly streamflow values, especially for Cibolo Creek near Falls City. The NSE for hourly simulations ranged from 0.29 to 0.90 for the calibration periods at all stations.

Simulated streamflow volumes, streamflow extremes, and the model-fit statistics were considered good at 08183200 San Antonio River near Floresville. The simulated streamflows exceeded measured streamflows at 08185500 Cibolo Creek at Sutherland Springs, and the model-fit statistics were considered poor, most likely because of less-than-optimal modeling of groundwater and wastewater contributions to flow.

Evapotranspiration and Groundwater Recharge

Besides accurate simulation of streamflow, another goal of watershed model calibration is to accurately simulate the overall water budget in the watershed, including ET and groundwater recharge. The nearest measured ET data for comparison with HSPF-simulated ET values are collected at USGS 290810099212100 SW Medina County meteorological station near D'Hanis, about 70 miles west of the lower San Antonio River study area. This station was installed in September 2006 on shrub/scrub land on the Carrizo Sand outcrop (Richard Slattery, U.S. Geological Survey, written commun., 2008). ET data are computed by the eddy covariance method, a statistical method that measures and calculates vertical turbulent fluxes within atmospheric boundary layers on the basis of micrometeorological data, including wind and scalar atmospheric data series, and yields values of fluxes for these properties that are then used to estimate ET (Bidlake, 2002).

HSPF-simulated ET from the Carrizo Sand outcrop in the lower San Antonio River watershed was compared with ET measured at the SW Medina County meteorological station during October 2006–December 2007 (fig. 15). Because local conditions such as rainfall, cloud cover, and humidity are highly variable, direct comparison of measured and HSPF-simulated ET on a short time scale is of limited use. Overall, however, HSPF-simulated ET compared fairly well with measured ET during the comparison period. Total HSPF-simulated ET from the pervious area of water-budget zone 3 for October 2006–November 2007 was 38.4 inches, and total measured ET at the SW Medina County meteorological

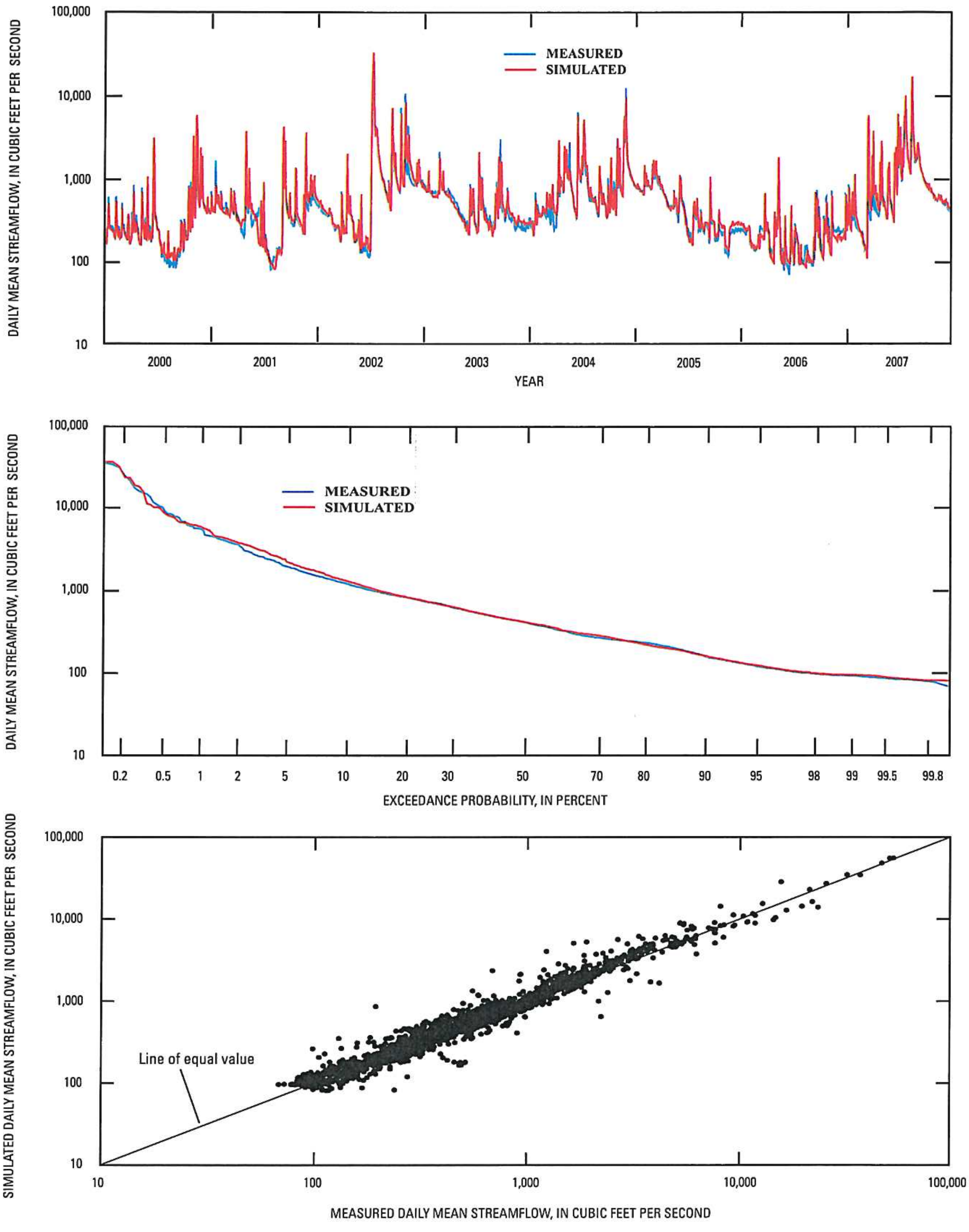


Figure 9. Measured and simulated daily mean streamflow at 08183500 San Antonio River near Falls City, Texas, 2000–2007.

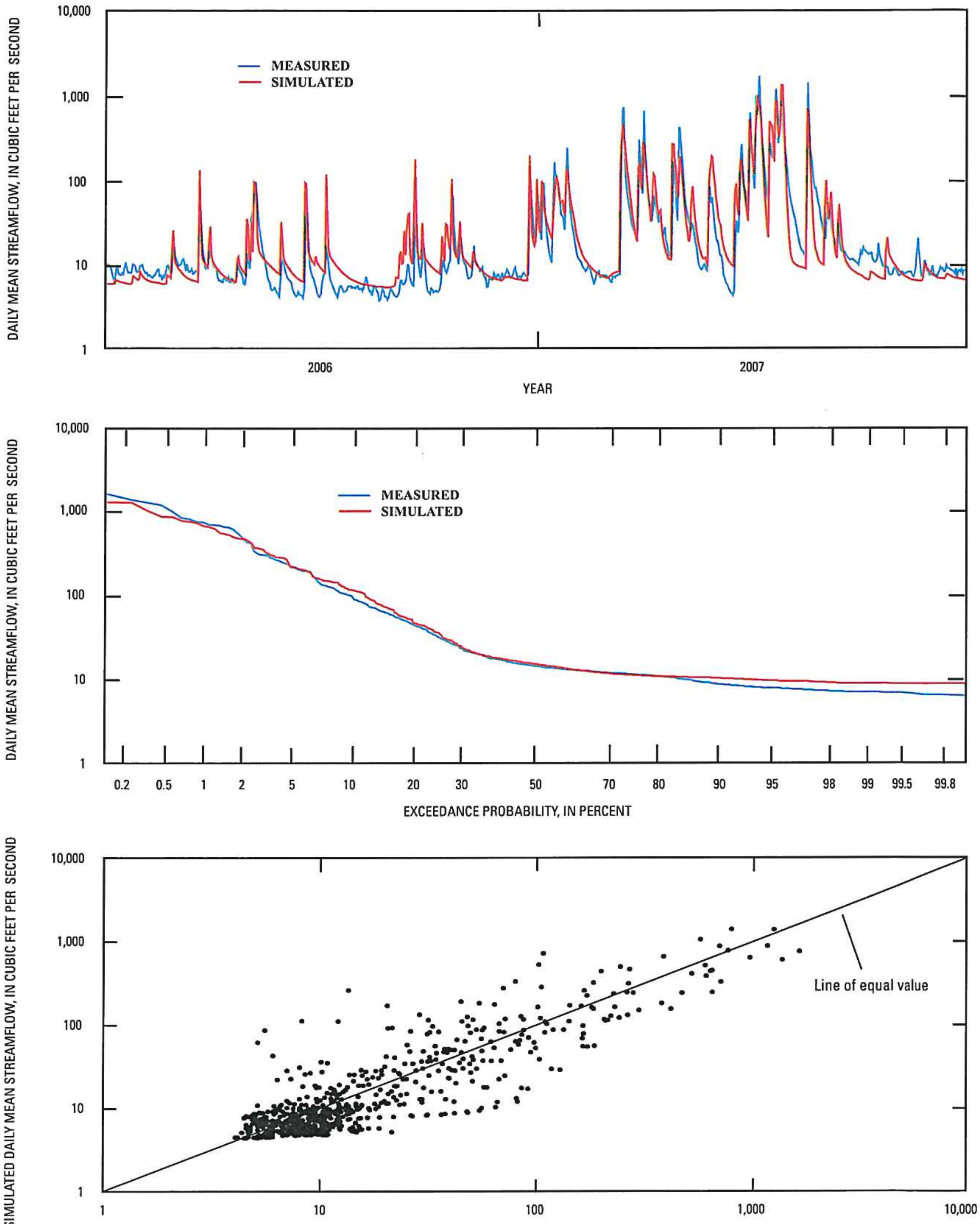


Figure 10. Measured and simulated daily mean streamflow at 08185100 Martinez Creek near St. Hedwig, Texas, 2006–07.

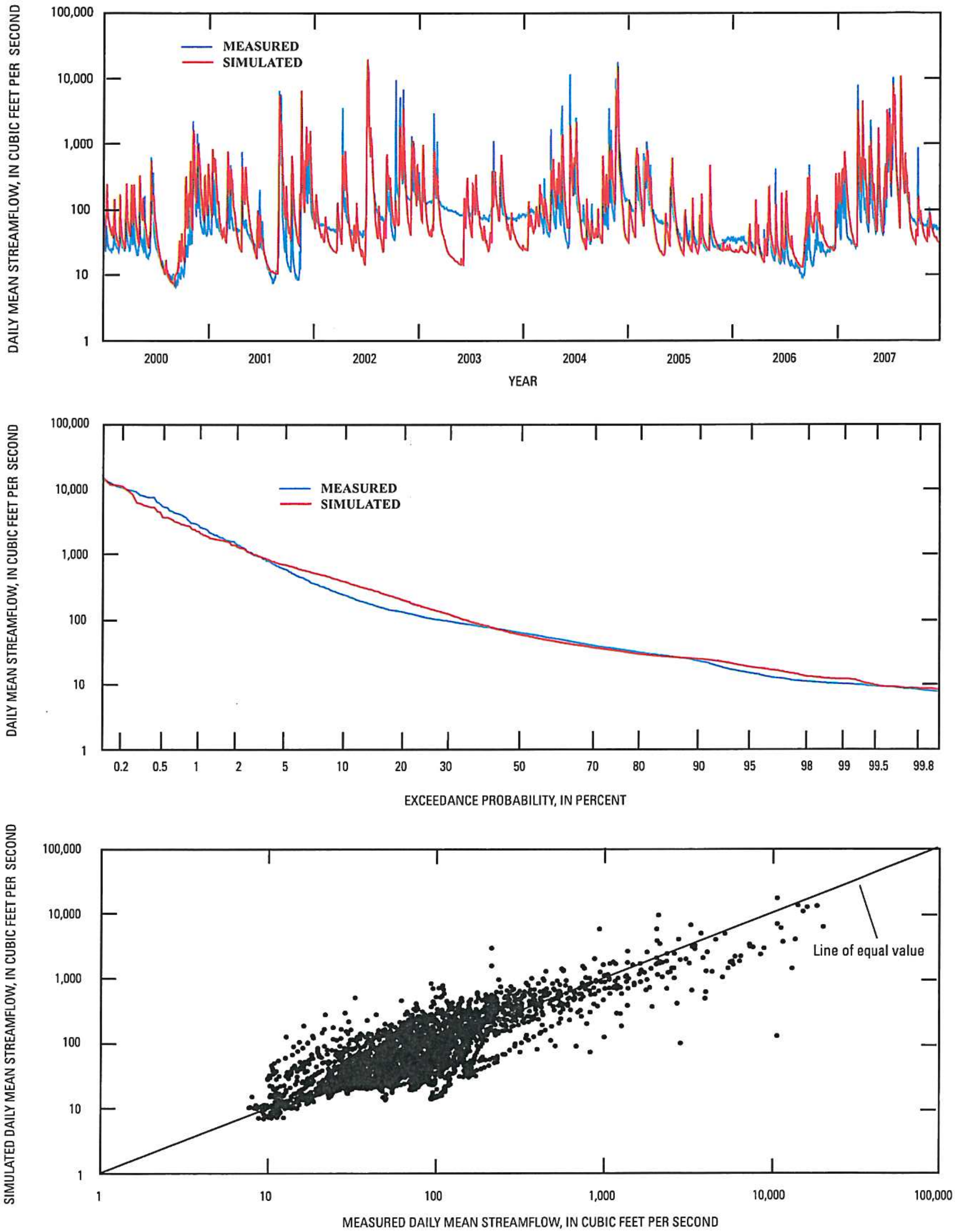


Figure 11. Measured and simulated daily mean streamflow at 08186000 Cibolo Creek near Falls City, Texas, 2000–2007.

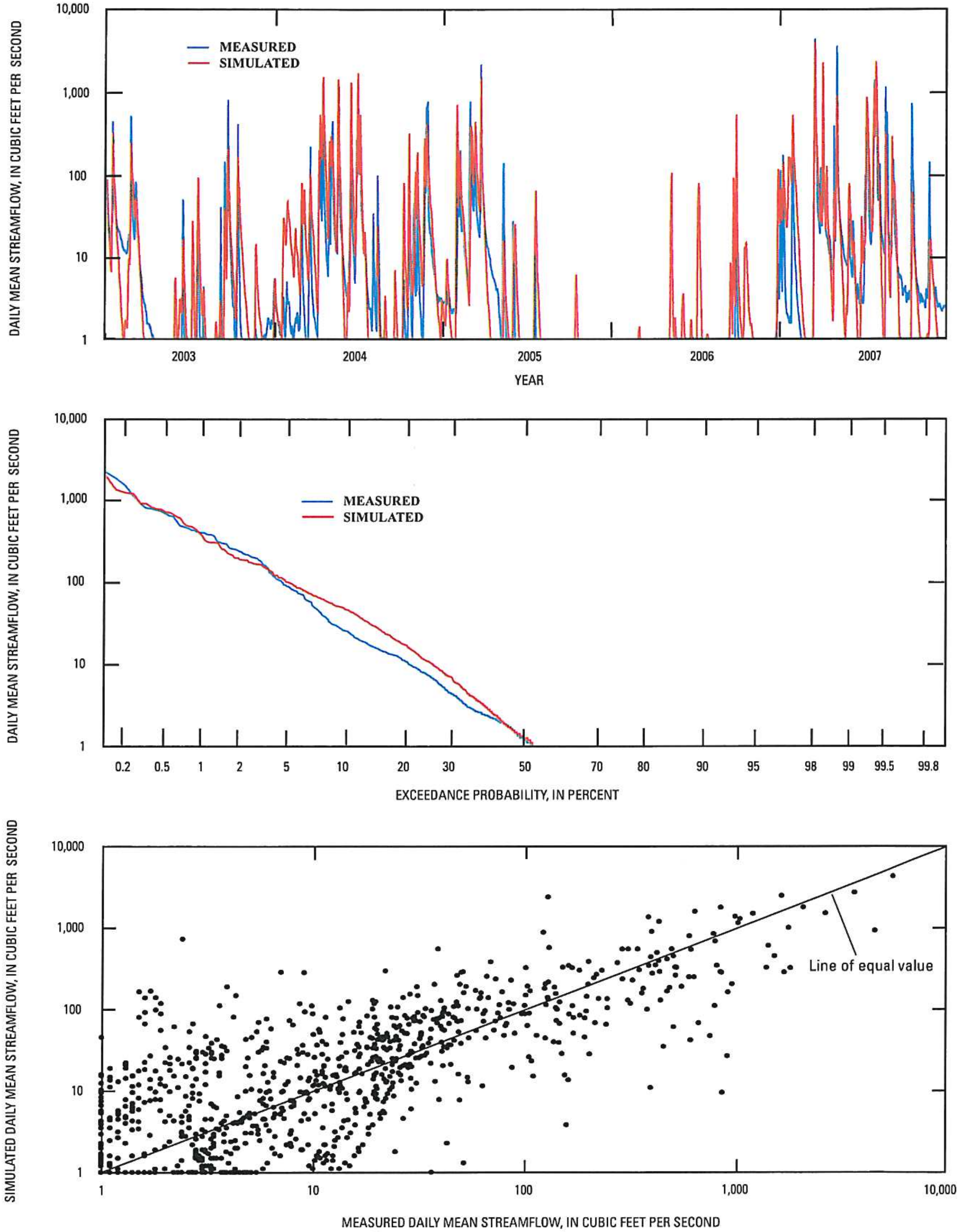


Figure 12. Measured and simulated daily mean streamflow at 08186500 Ecleto Creek near Runge, Texas, 2003–07.

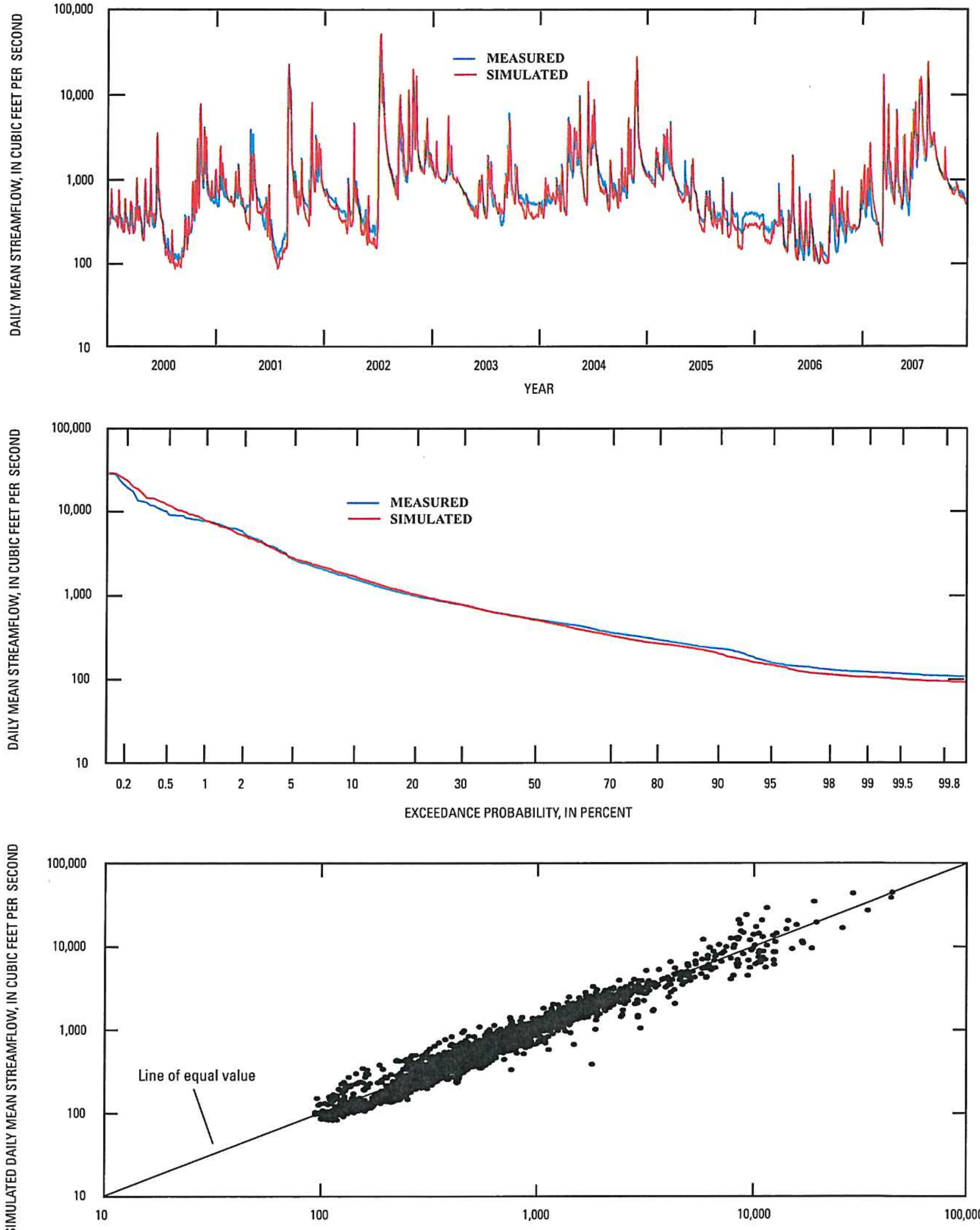


Figure 13. Measured and simulated daily mean streamflow at 08188500 San Antonio River at Goliad, Texas, 2000–2007.

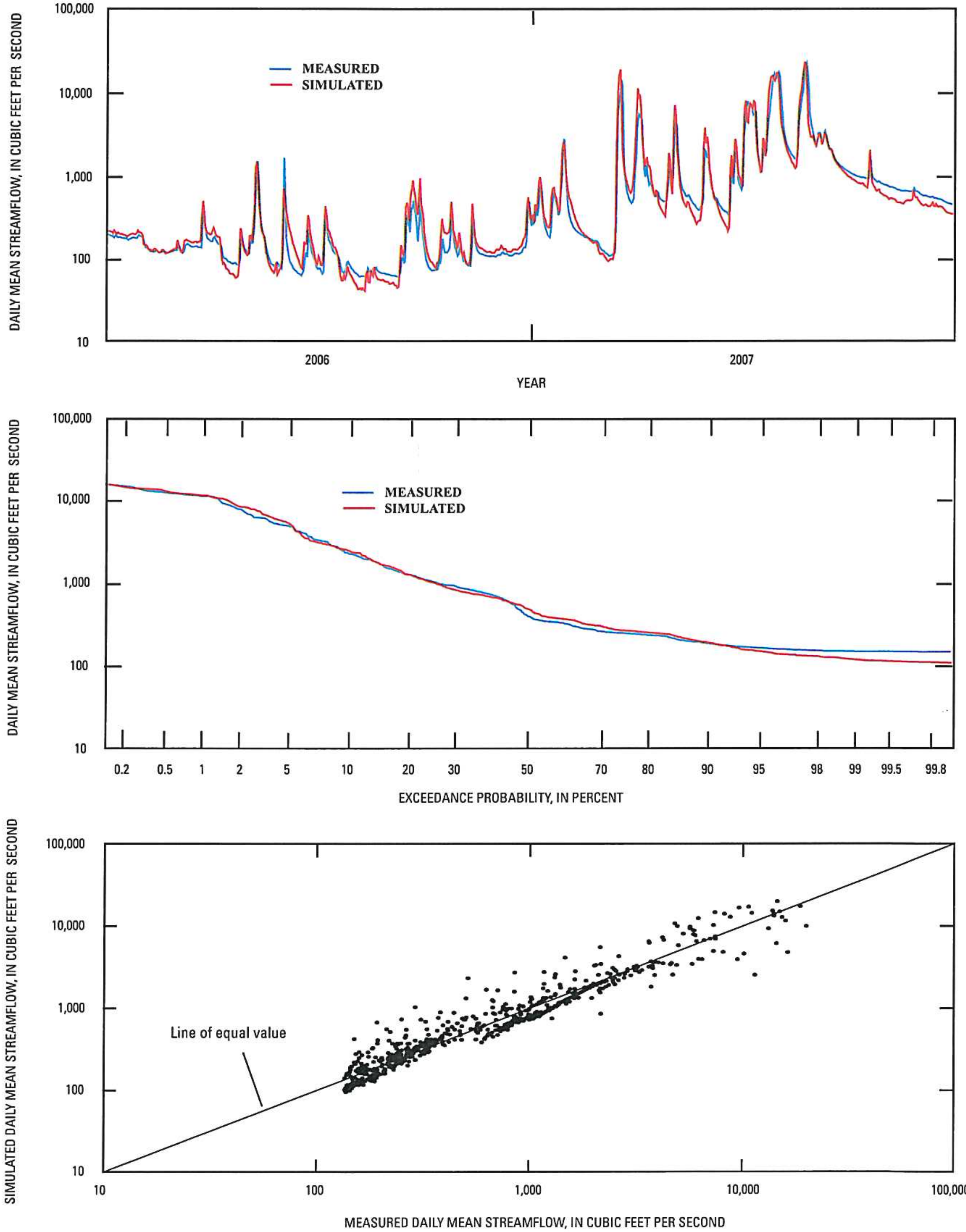


Figure 14. Measured and simulated daily mean streamflow at 08188570 San Antonio River near McFaddin, Texas, 2006–07.

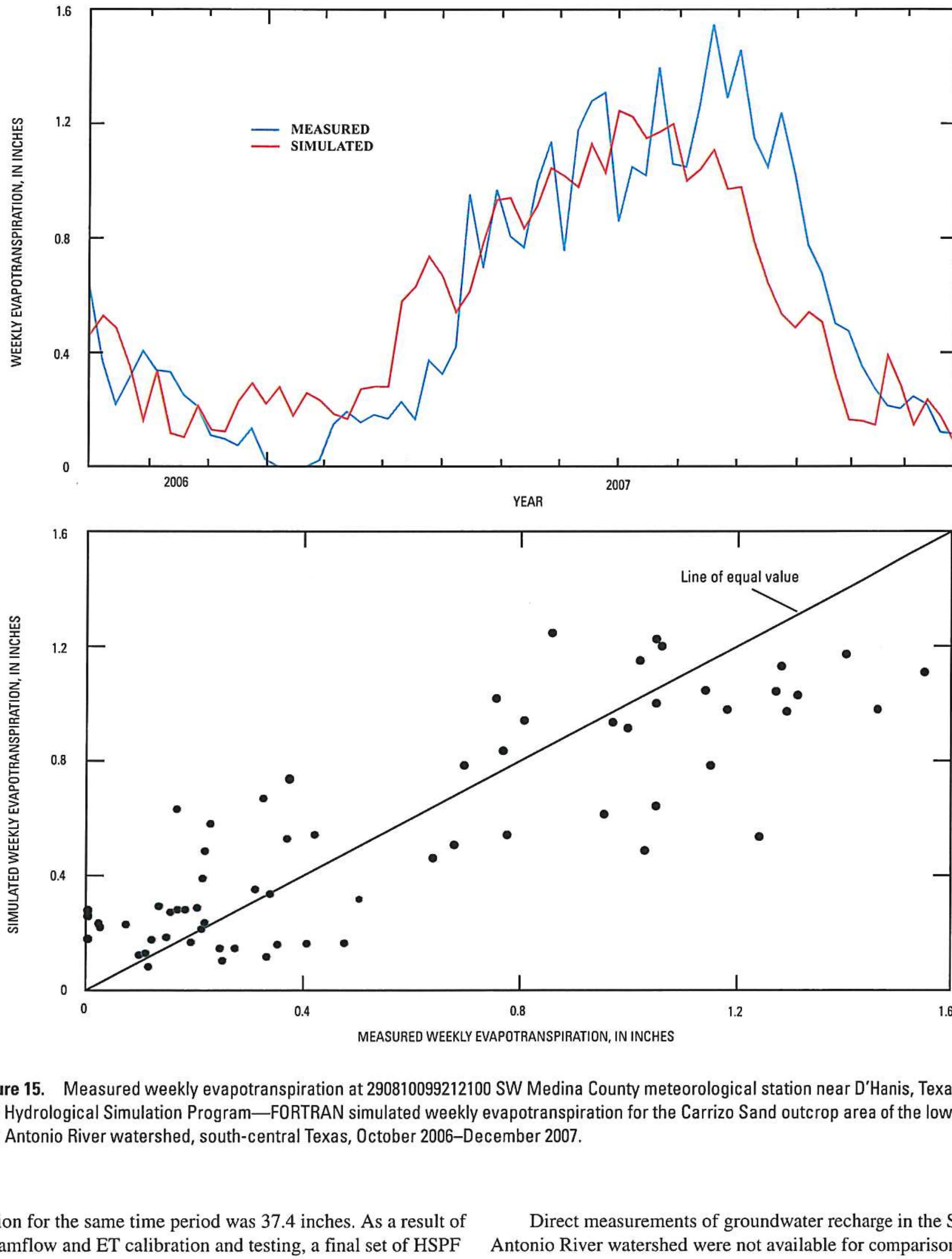


Figure 15. Measured weekly evapotranspiration at 290810099212100 SW Medina County meteorological station near D'Hanis, Texas, and Hydrological Simulation Program—FORTRAN simulated weekly evapotranspiration for the Carrizo Sand outcrop area of the lower San Antonio River watershed, south-central Texas, October 2006–December 2007.

station for the same time period was 37.4 inches. As a result of streamflow and ET calibration and testing, a final set of HSPF hydrologic parameters was obtained for the model; values for selected parameters are listed by water-budget zone in table 8.

Direct measurements of groundwater recharge in the San Antonio River watershed were not available for comparison with model simulations of recharge. Therefore, model simulations, or estimates, of groundwater recharge depended on accurate model representations of the remaining water-budget

Table 7. Streamflow calibration and testing results, Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

[acre-ft, acre-feet; ft³/s, cubic feet per second; --, not determined]

08183500 San Antonio River near Falls City, Texas

Calibration period 2004–07

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	2.558	2.718	6.2	10
Mean flow rate (ft³/s)	883	938	6.2	10
Total of highest 10 percent of daily flows (million acre-ft)	1.135	1.236	8.9	10
Total of lowest 50 percent of daily flows (acre-ft)	383,000	399,000	4.2	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	4	48	1,461	35,064
Coefficient of determination (R-squared)	.99	.98	.93	.92
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.98	.98	.93	.92
Mean absolute error (ft³/s)	46	83	128	137
Root mean square error (ft³/s)	78	153	426	475

Testing period 2000–2003

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	2.608	2.691	3.2	10
Mean flow rate (ft³/s)	900	929	3.2	10
Total of highest 10 percent of daily flows (million acre-ft)	1.404	1.476	5.1	10
Total of lowest 50 percent of daily flows (acre-ft)	379,000	377,000	-.5	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	4	48	1,461	35,064
Coefficient of determination (R-squared)	1.00	1.00	.97	.97
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	1.00	1.00	.97	.97
Mean absolute error (ft³/s)	35	70	132	138
Root mean square error (ft³/s)	39	116	488	536

Simulation period 2000–2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	5.167	5.363	3.8	10
Mean flow rate (ft³/s)	891	925	3.8	10
Total of highest 10 percent of daily flows (million acre-ft)	2.557	2.723	6.5	10
Total of lowest 50 percent of daily flows (acre-ft)	758,000	769,000	1.5	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	8	96	2,922	70,128
Coefficient of determination (R-squared)	.99	.99	.96	.96
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.99	.99	.96	.96
Mean absolute error (ft³/s)	40	76	130	138
Root mean square error (ft³/s)	61	136	458	506

[1] Error = [(simulated-measured)/measured] x 100.

[2] Default error criteria from HSPEXP (Lumb and others, 1994).

Table 7. Streamflow calibration and testing results, Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas—Continued.

08186000 Cibolo Creek near Falls City, Texas

Calibration period 2004–07

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (acre-ft)	722,000	738,000	2.2	10
Mean flow rate (ft³/s)	249	254	2.2	10
Total of highest 10 percent of daily flows (acre-ft)	526,000	492,000	-6.5	10
Total of lowest 50 percent of daily flows (acre-ft)	51,800	49,100	-5.2	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	4	48	1,461	35,064
Coefficient of determination (R-squared)	1.00	.99	.70	.50
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.99	.98	.58	.29
Mean absolute error (ft³/s)	11	39	117	143
Root mean square error (ft³/s)	13	63	584	826

Testing period 2000–2003

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (acre-ft)	728,000	778,000	6.8	10
Mean flow rate (ft³/s)	251	268	6.8	10
Total of highest 10 percent of daily flows (acre-ft)	534,000	522,000	-2.2	10
Total of lowest 50 percent of daily flows (acre-ft)	53,400	49,300	-7.7	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	4	48	1,461	35,063
Coefficient of determination (R-squared)	.91	.91	.68	.53
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.87	.91	.64	.47
Mean absolute error (ft³/s)	54	94	156	175
Root mean square error (ft³/s)	58	161	653	866

Simulation period 2000–2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	1.450	1.515	4.5	10
Mean flow rate (ft³/s)	250	261	4.5	10
Total of highest 10 percent of daily flows (million acre-ft)	1.062	1.014	-4.5	10
Total of lowest 50 percent of daily flows (acre-ft)	105,000	98,400	-6.3	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	8	96	2,922	70,127
Coefficient of determination (R-squared)	.95	.94	.69	.51
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.94	.94	.62	.39
Mean absolute error (ft³/s)	33	67	137	159
Root mean square error (ft³/s)	42	122	619	846

[1] Error = [(simulated-measured)/measured] x 100.

[2] Default error criteria from HSPEXP (Lumb and others, 1994).

Table 7. Streamflow calibration and testing results, Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas—Continued.

08188500 San Antonio River at Goliad, Texas

Calibration period 2004–07

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	3.842	4.130	7.5	10
Mean flow rate (ft^3/s)	1,330	1,430	7.5	10
Total of highest 10 percent of daily flows (million acre-ft)	1.852	2.038	10.0	10
Total of lowest 50 percent of daily flows (acre-ft)	542,000	527,000	-2.8	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	4	48	1,461	35,064
Coefficient of determination (R-squared)	1.00	.99	.83	.81
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.97	.98	.82	.80
Mean absolute error (ft^3/s)	108	165	304	317
Root mean square error (ft^3/s)	146	258	1,117	1,192

Testing period 2000–2003

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	4.106	4.135	0.7	10
Mean flow rate (ft^3/s)	1,420	1,430	.7	10
Total of highest 10 percent of daily flows (million acre-ft)	2.315	2.350	1.5	10
Total of lowest 50 percent of daily flows (acre-ft)	563,000	511,000	-9.2	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	4	48	1,461	35,064
Coefficient of determination (R-squared)	1.00	.99	.86	.85
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.99	.99	.86	.85
Mean absolute error (ft^3/s)	60	140	323	336
Root mean square error (ft^3/s)	74	254	1,501	1,560

Simulation period 2000–2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	7.934	8.281	4.4	10
Mean flow rate (ft^3/s)	1,370	1,430	4.4	10
Total of highest 10 percent of daily flows (million acre-ft)	4.177	4.405	5.5	10
Total of lowest 50 percent of daily flows (million acre-ft)	1.105	1.074	-2.8	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	8	96	2,922	70,128
Coefficient of determination (R-squared)	.99	.99	.85	.84
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.98	.99	.85	.84
Mean absolute error (ft^3/s)	81	153	313	327
Root mean square error (ft^3/s)	116	256	1,320	1,388

[1] Error = [(simulated-measured)/measured] x 100.

[2] Default error criteria from HSPEXP (Lumb and others, 1994).

Table 7. Streamflow calibration and testing results, Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas—Continued.

08183200 San Antonio River near Floresville, Texas
Testing period 01/05/2006–12/31/2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	1.307	1.303	-0.3	10
Mean flow rate (ft³/s)	908	905	-.3	10
Total of highest 10 percent of daily flows (acre-ft)	720,000	724,000	.6	10
Total of lowest 50 percent of daily flows (acre-ft)	138,000	130,000	-5.8	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	1	23	726	17,424
Coefficient of determination (R-squared)	--	1.00	.98	.98
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	--	1.00	.98	.97
Mean absolute error (ft³/s)	16	35	87	102
Root mean square error (ft³/s)	16	51	270	338

08185100 Martinez Creek near St. Hedwig, Texas
Calibration period 11/17/2005–12/31/2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (acre-ft)	67,200	71,800	6.9	10
Mean flow rate (ft³/s)	43.7	46.7	6.9	10
Total of highest 10 percent of daily flows (acre-ft)	46,800	49,100	4.9	10
Total of lowest 50 percent of daily flows (acre-ft)	5,810	5,750	-1.0	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	2	25	775	18,600
Coefficient of determination (R-squared)	1.00	.96	.72	.50
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.99	.96	.67	.37
Mean absolute error (ft³/s)	3.3	8.6	22	26
Root mean square error (ft³/s)	3.4	14	71	112

08185500 Cibolo Creek at Sutherland Springs, Texas
Testing period 12/21/2005–12/31/2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (acre-ft)	256,000	355,000	39	10
Mean flow rate (ft³/s)	174	241	39	10
Total of highest 10 percent of daily flows (acre-ft)	189,000	252,000	33	10
Total of lowest 50 percent of daily flows (acre-ft)	18,700	21,400	14	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	2	24	741	17,784
Coefficient of determination (R-squared)	1.00	.95	.42	.29
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.82	.91	.32	.18
Mean absolute error (ft³/s)	67	72	132	146
Root mean square error (ft³/s)	85	125	635	827

[1] Error = [(simulated-measured)/measured] x 100.

[2] Default error criteria from HSPEXP (Lumb and others, 1994).

Table 7. Streamflow calibration and testing results, Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas—Continued.

08186500 Ecleto Creek near Runge, Texas
Calibration period 10/02/2002–12/31/2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	0.199	0.208	4.6	10
Mean flow rate (ft^3/s)	52.3	54.7	4.6	10
Total of highest 10 percent of daily flows (acre-ft)	178,000	173,000	-2.8	10
Total of lowest 50 percent of daily flows (acre-ft)	728	716	-1.6	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	5	50	1,918	35,032
Coefficient of determination (R-squared)	.89	.84	.65	.52
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	.87	.84	.57	.43
Mean absolute error (ft^3/s)	8.7	22	37	43
Root mean square error (ft^3/s)	13	43	161	208

08188570 San Antonio River near McFaddin, Texas
Testing period 11/24/2005–12/31/2007

Comparison of streamflow volumes and peaks	Measured streamflow	Simulated streamflow	Error[1] (percent)	Criteria[2] (percent)
Total flow volume (million acre-ft)	1.971	2.032	3.1	10
Mean flow rate (ft^3/s)	1,290	1,330	3.1	10
Total of highest 10 percent of daily flows (million acre-ft)	1.083	1.116	3.0	10
Total of lowest 50 percent of daily flows (acre-ft)	201,000	221,000	10.0	10
Model-fit statistics	**Annual**	**Monthly**	**Daily**	**Hourly**
Number of years, months, days, or hours	2	25	768	18,432
Coefficient of determination (R-squared)	1.00	.97	.79	.77
Nash-Sutcliff coefficient of model-fit efficiency (NSE)	1.00	.97	.78	.76
Mean absolute error (ft^3/s)	48	180	373	388
Root mean square error (ft^3/s)	50	311	1,180	1,240

[1] Error = [(simulated-measured)/measured] x 100.

[2] Default error criteria from HSPEXP (Lumb and others, 1994).

components not associated with recharge (primarily streamflow and ET).

Simulated Streamflow, 2000–2007

Boundary inflows to the study area were obtained from 08181800 San Antonio River near Elmendorf and 08185000 Cibolo Creek at Selma. These flows and other streamflow additions and withdrawals, including measured or reported volumes of streamflow, springflow, wastewater discharge, and irrigation withdrawals, are routed downstream concurrently with the meteorological data. The lower San Antonio River watershed HSPF model can then be used to simulate streamflow at the outlet of any RCHRES (fig. 4) for calibration or testing, or for comparison purposes. Using model input and output, streamflow amounts and sources can be compared for each subwatershed. Annual mean streamflow volumes and basin yields generated in each subwatershed were compiled (table 9). The annual mean streamflow volumes represent the streamflow generated in each subwatershed from all inputs to that subwatershed but do not include upstream inflows. The simulated streamflow volumes from each subwatershed include runoff from pervious and impervious areas and all streamflow additions and withdrawals that can be quantified. Runoff from precipitation is the largest source of streamflow generated in each subwatershed in the study area. Other contributions to streamflow in each subwatershed listed in table 9 are relatively small compared with the total simulated streamflow volumes. During 2000–2007, annual mean streamflow volumes from the four subwatersheds totaled 0.381 million acre-feet. Annual mean basin yields for each of the subwatersheds and for the upstream watersheds were

Table 8. Calibrated values for selected parameters, by water-budget zone, for the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas.

Parameter[1]	Units	Calibrated values by water-budget zone (fig. 2)								
		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
AGWETP	none	0	0.01–0.05	0.01–0.05	0.01–0.05	0.01–0.05	0.01–0.05	0.01–0.05	0.01	0.05
AGWRC	1/day	.92	.92–.94	.85–.94	.92–.97	.95–.97	.95–.97	.95–.98	.98	.98
BASETP	none	.01	.01	.01–.20	.01–.20	.01–.15	.01–.10	.01–.15	.01	.10
CEPSC	inches	.1–.3	.1–.3	.1–.3	.1–.3	.1–.3	.1–.3	.1–.3	.1–.3	.1–.3
DEEPFR	none	.35	.40–.60	.70–.85	.60–.85	.55–.60	.10–.25	.20–.45	.32	.20
INFEXP	none	2	2	2	2	2	2	2	2	2
INFILD	none	2	2	2	2	2	2	2	2	2
INFILT	inches/hour	.50–.55	.40–.60	.45–.90	.35–.65	.15–.55	.10–.50	.25–.55	.60–.64	.37–.40
INTFW	none	8.5	1.0–8.5	1.0–1.50	1.0–2.50	1.0–2.50	1.0–2.50	1.0–2.50	1.5	1.5
IRC	1/day	.5	.5	.1–.5	.1–.5	.1–.5	.1–.5	.1–.5	.5	.5
KVARY	1/inch	4.0	2.0–4.0	2.0–4.0	2.0–4.0	2.0–4.0	2.0–4.0	2.0–4.0	2.0	2.0
LSUR	feet	250–300	250–300	250–300	250–300	250–300	250–300	250–300	300	300
LZETP	none	.2–.8	.2–.8	.2–.8	.2–.8	.2–.8	.2–.8	.2–.8	.4–.8	.4–.8
LZSN	inches	8.5	8.0–8.5	8.0–9.5	8.0–8.5	8.0–8.5	8.0–8.5	8.0–8.5	8.0–8.5	8.0–8.5
NSUR	none	.15–.20	.15–.31	.15–31	.15–.31	.15–.31	.15–.31	.15–.31	.20–.31	.20–.31
RETSC	inches	.1	.1	.05–.1	.05–.1	.05–.1	.05–.1	.05–.1	.1	.1
SLSUR	feet	.03	.03	.03	.03	.03	.03	.03	.03	.03
UZSN	inches	.54–.56	.54–.76	.54–.76	.54–.76	.54–.76	.54–.76	.54–.86	.84–.86	.84–.86

[1] See table 3 for description of parameters.

computed by dividing the generated streamflow volume at the outlets by the corresponding subwatershed area. Of the four subwatersheds in the lower San Antonio River watershed, the Cibolo Creek subwatershed had the largest annual mean basin yield, about 4.8 inches per year. Springflow and wastewater discharges were larger in this subwatershed compared with the other subwatersheds. The smallest annual mean basin yield was from the subwatershed of the San Antonio River upstream from Cibolo Creek, about 1.2 inches per year. This lower yield might be caused partly by the way the model represents retention and subsequent evaporation of overland flow in Calaveras Lake from RCHRES 5 (fig. 4). Possible reasons for the differences in yields have not been fully studied. The measured (gaged) annual mean volume of streamflow entering the lower San Antonio River watershed during 2000–2007 was 0.685 million acre-feet (table 10). The overall annual mean basin yield from the upstream contributing area to the model was 6.4 inches (table 10), or 3.1 inches higher than the overall annual mean basin yield of 3.3 inches (table 9) from the lower San Antonio River watershed.

The simulated (modeled) annual mean volume of streamflow exiting the lower San Antonio River watershed during 2000–2007 was 1.07 million acre-feet. This volume includes the annual mean inflow from the streamflow-gaging stations at the study area boundary (0.685 million acre-feet [table 10]) and the annual mean streamflow generated from the study area (0.381 million acre-feet [table 9]). Compared with the annual mean volume of streamflow entering the lower San Antonio River watershed from upstream (0.685 million acre-feet), the annual mean volume of streamflow exiting the lower San Antonio River watershed (1.07 million acre-feet) represents an increase of about 56 percent. Annual mean streamflow

Table 9. Simulated streamflow volumes and basin yields generated from subwatersheds in the Hydrological Simulation Program—FORTRAN model of the lower San Antonio River watershed, south-central Texas, 2000–2007.

[--, no flow]

Subwatershed	Drainage area (square miles)	Annual mean wastewater discharge (thousand acre-feet)[1]	Annual mean springflow (thousand acre-feet)[2]	Annual mean irrigation withdrawals (thousand acre-feet)[3]	Annual mean streamflow (million acre-feet)	Annual mean basin yield (inches)[4]
San Antonio River upstream from Cibolo Creek	554	0.86	0	3.8	0.035	1.2
Cibolo Creek	579	9.7	12.6	--	.149	4.8
Ecleto Creek	266	--	--	--	.042	3.0
San Antonio River downstream from Cibolo Creek	749	1.2	--	1.6	.155	3.9
Total, all subwatersheds		**11.8**	**12.6**	**5.4**	**.381**	**3.3**

[1] Wastewater discharge input derived from reported wastewater discharges (table 6).

[2] Springflow input derived from correlation developed between streamflow gains and nearby groundwater levels.

[3] Calculated from reported surface-water withdrawals to irrigated cropland (Ceasar Alvarado, Texas Commission on Environmental Quality, written commun., 2009).

[4] Calculated by dividing annual mean streamflow volume by drainage area.

originating in the lower San Antonio River watershed during 2000–2007 (estimated as annual mean simulated streamflow at the outlet minus annual mean streamflow at the inlet boundaries, 08181800 San Antonio River near Elmendorf and 08185000 Cibolo Creek at Selma) is less than 10 percent of the annual mean rainfall supplied. About 90 percent of the rainfall on the watershed is either evapotranspired or recharged.

Simulated Evapotranspiration, 2000–2007

Parameters in the HSPF model representing final model runs were synthesized for each of the subwatersheds to produce estimated annual ET from the pervious land in each water-budget zone (table 11). Evaporation also occurred directly from water surfaces in IMPLNDs and RCHRESs, but the amount was small compared with ET from pervious land. About 2 percent of the study area consisted of impervious land; the evaporation from surficial waters in IMPLNDs and RCHRESs was about 1 percent of the total ET.

For the entire study area, annual mean ET from PERLNDs was 28.2 inches per year (table 11). The smallest annual mean ET during 2000–2007 was 20.1 inches during 2006, following a relatively dry year. The largest annual mean ET during 2000–2007 was 34.8 inches during 2007. Simulated ET was largest in water-budget zones 8 and 9, with annual mean amounts of 30.6 and 32.8 inches per year, respectively. These water-budget zones included a larger percentage of riparian/wetland land cover than the other zones in the study area. Land cover was used to adjust several HSPF parameters in the model. The larger percentage of riparian/wetland land cover in water-budget zones 8 and 9 might be partly responsible for the larger amounts of ET in these zones compared with ET in other zones. Also, rainfall was larger in zones 8 and 9 than in the other zones, so more water was available to be evapotranspired.

The annual mean rainfall for the study area during 2000–2007 was 34.3 inches (table 5). An annual mean ET of 28.2 inches indicates that, on average, about 82 percent of the rainfall supplied to the study area was evapotranspired. If the annual rainfall is above average, a smaller percentage of the annual rainfall usually evapotranspires. For example, 2004 and 2007, with rainfall of 44.8 and 46.6 inches, respectively, were relatively wet years. In 2004 and 2007, an estimated 74 and 75 percent, respectively, of rainfall evapotranspired on the basis of model simulations. The largest percentage of rainfall evapotranspired in years with lower-than-average rainfall and follow years with greater-than-average rainfall. For 2005, a very dry

Table 10. Annual mean streamflow volumes and basin yields at streamflow-gaging stations at upstream boundary of the lower San Antonio River watershed, south-central Texas, 2000–2007.

U.S. Geological Survey streamflow-gaging station (fig. 1)	Drainage area (square miles)	Annual mean streamflow (million acre-feet)	Annual mean basin yield (inches)[1]
08181800 San Antonio River near Elmendorf, Tex. (site 8)	1,750	0.642	6.9
08185000 Cibolo Creek near Selma, Tex. (site 11)	274	.043	2.9
Total at upstream boundary	**2,020**	**.685**	**6.4**

[1] Calculated by dividing annual mean streamflow volume by drainage area.

Table 11. Estimated evapotranspiration for pervious land in water-budget zones of the lower San Antonio River watershed, south-central, Texas, 2000–2007.

Water-budget zone (fig. 2)	Pervious land (acres)	Estimated evapotranspiration (inches)								
		2000	2001	2002	2003	2004	2005	2006	2007	Annual mean
1	108,716	22.5	24.4	30.1	26.7	30.5	23.6	21.2	32.3	26.4
2	133,447	23.0	25.7	30.4	27.8	31.7	23.9	20.5	33.3	27.0
3	97,342	23.8	26.4	29.7	28.9	32.2	23.0	19.3	34.1	27.2
4	161,944	23.9	26.7	29.6	29.0	32.4	22.9	19.4	34.3	27.3
5	158,316	24.2	27.1	29.8	29.1	32.9	23.0	19.2	34.5	27.5
6	92,595	24.1	27.2	27.3	28.5	32.4	23.4	16.4	34.0	26.7
7	236,723	24.7	29.0	28.1	29.4	33.4	24.7	16.0	35.1	27.6
8	276,464	28.1	29.5	30.5	33.2	35.2	28.7	23.6	36.3	30.6
9	82,207	30.5	30.4	31.9	35.9	37.7	31.2	26.7	38.3	32.8
Area weighted[1]		**25.1**	**27.7**	**29.7**	**30.0**	**33.3**	**25.1**	**20.1**	**34.8**	**28.2**

[1] For entire lower San Antonio River watershed (normalized to amount of pervious land in water-budget zones 1–9).

year (rainfall of 20.8 inches), simulated ET was 121 percent of the annual rainfall. Simulated ET can exceed rainfall in a given year when extra water that has been stored in the unsaturated zones during the preceding year is available to satisfy potential ET demand.

Estimated Groundwater Recharge, 2000–2007

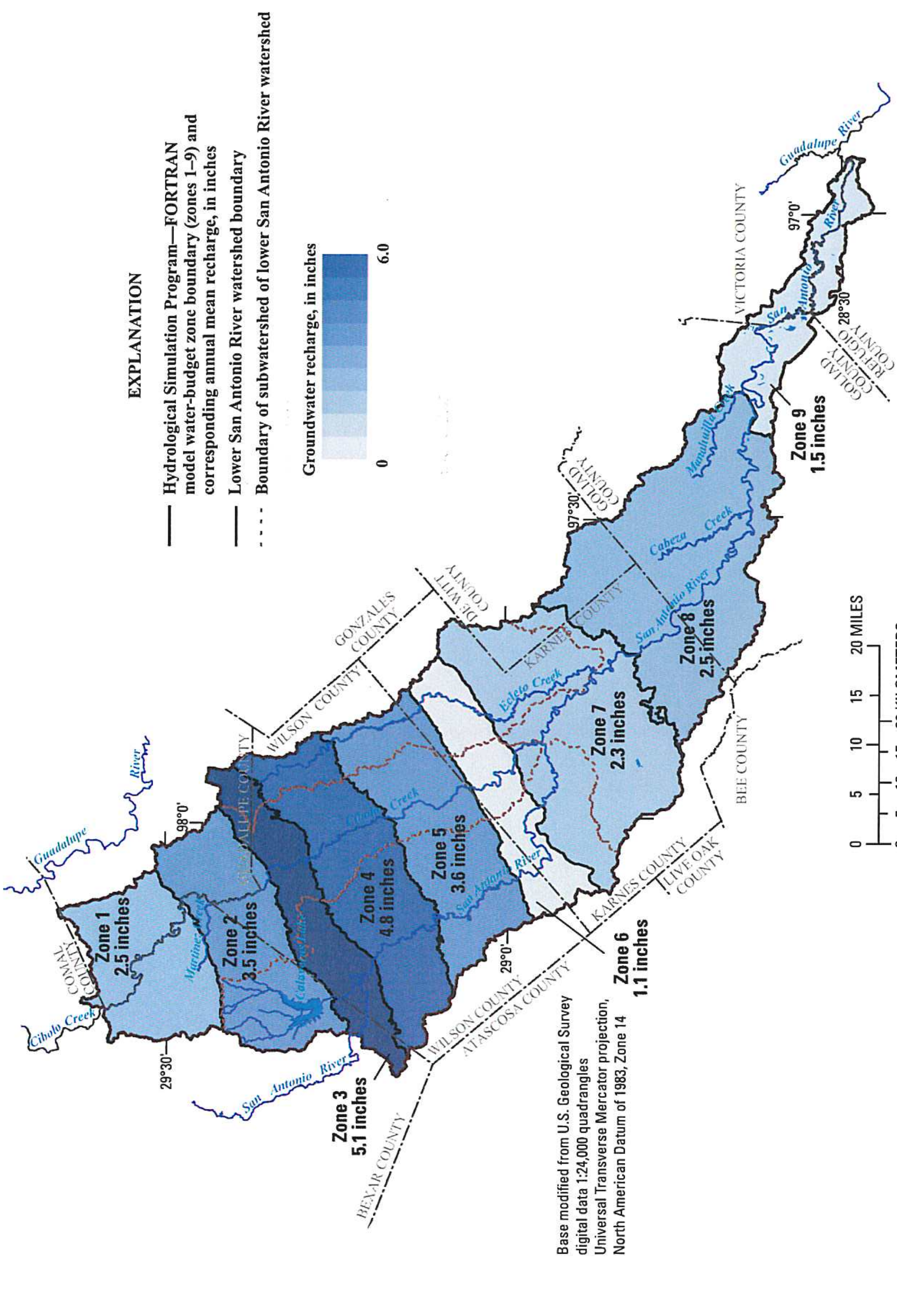
Similar to the procedure for generating ET estimates by water-budget zones, the output from the final model runs were synthesized to produce estimates of annual groundwater recharge into the pervious land of each water-budget zone. These subwatershed estimates from each model were area-weighted by the amount of pervious area of each subwatershed to produce estimated annual recharge rates by water-budget zone (fig. 16, table 12).

The largest groundwater recharge estimates were in water-budget zones 3 and 4, with annual estimates of 5.1 and 4.8 inches, respectively. Water-budget zone 3 overlies the Carrizo Sand; zone 4 overlies the Recklaw Formation and Queen City Sand. The annual mean rainfall on zone 3 during 2000–2007 was 34.0 inches (table 5). On average, an estimated 15 percent of rainfall went to groundwater recharge in zone 3. The smallest groundwater recharge estimates were in water-budget zones 6 and 9, with annual mean estimates of about 1.1 and 1.5 inches, respectively (fig. 16, table 12). The annual mean groundwater recharge estimate in zone 6 represents about 3.3 percent of the annual mean rainfall of 33.7 inches in this zone during 2000–2007 (table 5). These recharge estimates are generally within the ranges reported by Scanlon and Dutton (2003).

Estimated annual groundwater recharge in the lower San Antonio watershed during 2000–2007 varied from year to year but generally increased as precipitation increased. The smallest annual estimate of groundwater recharge was 0.7 inch in 2006 (table 12); 2006 rainfall was about 24.2 inches (table 5). The largest annual estimate of groundwater recharge was 6.1 inches in 2007 (table 12); 2007 rainfall was about 46.6 inches (table 5). During 2000–2007, groundwater recharge estimates as a percentage of rainfall varied from about 3 percent (2006) to 13 percent (2007). The annual mean estimated recharge rate for all pervious land in the study area was 3.0 inches per year (table 12). This recharge rate represents about 9 percent of annual mean rainfall for 2000–2007.

Water-Budget Summary, 2000–2007

The inflows to the lower San Antonio River watershed are represented by the terms on the left-hand side of equation 2. The modeled inflows include rainfall (*P*, precipitation), streamflow entering the study area from upstream as measured at 08181800 San Antonio River near Elmendorf (site 8) and 08185000 Cibolo Creek at Selma (site 11), estimated discharge of treated wastewater, and estimated springflow. Using the Thiessen diagrams, the average area-weighted rainfall in the lower San Antonio River watershed was computed as 34.3 inches per year (3.92 million acre-feet per year) during the study period. The measured streamflow volume entering the study area from upstream averaged 0.685 million acre-feet per year. The combined volume of wastewater and springflow entering the study area averaged



Base modified from U.S. Geological Survey digital data 1:24,000 quadrangles
Universal Transverse Mercator projection, North American Datum of 1983, Zone 14

Figure 16. Estimated annual mean groundwater recharge in water-budget zones of the lower San Antonio River watershed, 2000–2007.

Table 12. Estimated groundwater recharge for pervious land in water-budget zones of the lower San Antonio River watershed, south-central Texas, 2000–2007.

Water-budget zone (fig. 2)	Pervious land (acres)	Estimated recharge (inches)								
		2000	2001	2002	2003	2004	2005	2006	2007	Annual mean
1	108,716	1.4	3.5	3.3	1.3	4.0	1.1	0.4	5.4	2.5
2	133,447	1.8	4.6	4.6	1.8	5.3	1.7	.6	7.2	3.5
3	97,342	2.4	5.4	7.1	3.4	7.3	2.9	1.3	11.3	5.1
4	161,944	2.4	5.0	6.7	3.2	6.7	2.7	1.3	10.3	4.8
5	158,316	1.9	3.8	4.9	2.4	5.1	2.0	.9	7.4	3.6
6	92,595	.8	1.2	1.4	0.7	1.8	.6	.2	2.1	1.1
7	236,723	1.6	2.9	2.8	1.3	3.9	1.2	.3	4.3	2.3
8	276,464	1.2	3.3	3.2	1.5	3.5	1.6	.8	4.8	2.5
9	82,207	.7	2.0	1.8	.9	2.1	1.1	.6	2.9	1.5
Area weighted[1]		**1.6**	**3.6**	**4.0**	**1.8**	**4.4**	**1.7**	**.7**	**6.1**	**3.0**

[1] For entire lower San Antonio River watershed (normalized to amount of pervious land in water-budget zones 1–9).

24,400 acre-feet per year. Total inflow volumes from measured or estimated inputs were 4.63 million acre-feet per year.

The simulated outflows from the lower San Antonio River watershed are represented by the terms on the right side of equation 2 and can be summarized as total ET, streamflow exiting the study area, and groundwater recharge. Total ET averaged 3.20 million acre-feet per year and includes ET from the surface, ET from the unsaturated zone, and ET derived from groundwater discharging to streams. The average volume of simulated streamflow outflows from the study area was 1.07 million acre-feet per year, which included simulated surface-water diversions for irrigation. Simulated surface-water withdrawals for irrigation averaged about 5,470 acre-feet per year. Simulated groundwater recharge averaged 3.0 inches per year across the watershed, which is equivalent to about 340,000 acre-feet per year. Total outflows equaled 4.61 million acre-feet per year, obtained by adding the simulated total volumes of ET, streamflow exiting the study area, and groundwater recharge.

For the overall water budget, the largest inflow to the study area is rainfall; the largest outflow is ET. Wastewater discharges, springflow, and irrigation withdrawals in the study area make up only a small percentage of the overall water budget in the study area. Despite the relatively small contribution of wastewater discharges, springflow, and irrigation to the overall water budget, taking their contributions to local streamflow into account proved necessary to achieve acceptable model calibration results.

Sensitivity Analysis

A sensitivity analysis of selected HSPF model parameters was performed to determine the effects of systematic changes to the values of the parameters on simulated recharge, ET, and surface runoff from the PERLND areas in water-budget zone 3, the Carrizo Sand. Zone 3 crosses three subwatersheds of the model—San Antonio River upstream from Cibolo, Cibolo Creek, and Ecleto Creek (fig. 4). Each parameter was changed by a hydrologically reasonable amount while keeping the other parameters unchanged, and the simulations were run for each subwatershed. The results were areally weighted by the total PERLND area in each subwatershed. The resulting areally weighted changes in recharge, ET, and surface runoff exiting the PERLND area of the zone are listed in table 13.

The parameters to which simulated water balance components of zone 3 were most sensitive for the given changes were lower-zone ET (LZETP) and the fraction of ground water that does not discharge to the surface within the boundaries of the modeled area (DEEPFR). Increasing the LZETP values by between 12.5 and 50 percent resulted in a 12-percent decrease in recharge, a 15-percent decrease in surface runoff from PERLNDs, and a 3.3-percent increase in ET. Reducing the DEEPFR values by between 23.5 and 28.5 percent resulted in a 25-percent decrease in recharge and an 85-percent increase in runoff. Reducing the initial amount of water in the RCHRESs does not change the water balance components of zone 3.

Table 13. Sensitivity of the water balance in water-budget zone 3 to changes in selected process-related parameters of the Hydrological Simulation Program—Fortran (HSPF) model of the lower San Antonio River watershed, south-central Texas, 2000–2007.

Parameter[1]	Initial values	Adjusted values	Change in recharge (percent)	Change in evaptranspiration (percent)	Change in runoff from pervious area (percent)
LZSN	8.0–9.5	Increase to 12.0	-10	1.1	-15
UZSN	.54–.66	Increase to 1.5	-2	.7	-15
LZETP	.2–.8	Increase by 0.1 (0.3–0.9)	-12	3.3	-15
INFILT	.45–.90	Decrease by 20 percent	-2	.4	0
DEEPFR	.70–.85	Decrease by 0.2	-25	.4	85
AGWRC	.85–.94	Increase by 0.05	0	.4	-15
CEPSC	.1–.3	Increase by 0.05 (0.15–0.35)	-3	.7	-8

[1] See table 3 for description of parameters.

Model Limitations

Model limitations include possible errors related to model conceptualization and parameter variability, lack of data to quantify certain model inputs, and measurement errors. HSPF is a complex watershed model that can handle multiple hydrological scenarios; however, the model that was developed still represents a simplified understanding of the hydrological processes of the lower San Antonio River watershed. Natural hydrological processes are infinitely more complex than the simulations possible using empirical equations embedded in modeling software such as HSPF. The modelers' conceptualization of the watershed—FTABLES, stream dimensions, and so forth, and the variation in model parameters among water budget zones—based on decisions as to which watershed factors drive the hydrologic responses of the watershed might not be accurate or might be oversimplified. HSPF distributes inflows and outflows to maintain a balanced water budget as calibration parameters are changed. The accuracy of the modeled distribution of water within the watershed depends on the adequacy of the measured data used to calibrate the model. ET is by far the most dominant part of the water budget yet few ET data are available for most places, including the study area. The lack of measured ET in the study area for the different surficial geologic units, land covers, vegetative types, and seasons is particularly limiting, because it is not always clear how model parameters for ET should be varied. The lack of adequate ET data could cause systematic errors in representing the hydrological processes of the watershed (Raines, 1996).

Groundwater and surface-water interactions are modeled in a relatively simple way by HSPF. Over the past decades, this has led to the coupling of HSPF with groundwater models to better represent the complexity of groundwater and surface-water interactions. Within the limited functionality of HSPF for determining recharge, the authors have defined water-budget zones that they believe vary in soil infiltration and other modeled parameters available in HSPF. This variability has been introduced and is maintained by the overall calibration. However, across individual water-budget zones and on smaller spatial scales, measured streamflow or ET data are not sufficient to further verify the resulting gradients in ET and recharge rates.

Measurement errors are introduced as a result of inaccurate or missing data. Because large, isolated storms are common in south-central Texas, rainfall can vary greatly over a short distance. The degree to which available rainfall data represent the actual rainfall is potentially the most serious source of measurement error for the study. Rainfall input to the study area, derived from measured rainfall at five NWS meteorological stations, is represented by five areas of assumed homogeneous rainfall; each meteorological station represents, on average, an area of about 430 square miles. Also, four of the five NWS meteorological stations record daily rainfall data. Because of the highly localized nature of rainfall in south-central Texas, the disaggregation of daily rainfall data to hourly data does not always accurately represent rainfall duration or intensity.

The emphasis of the watershed-model calibration was accurate simulation of streamflow. Streamflow accounts for a relatively small percentage of the water budget in the study area and, in the main stem of the lower San Antonio River, is largely determined from upstream flows. Although an accurate simulation of the hydrograph relates to the accurate simulation of all the components of the water cycle, the accuracy of groundwater recharge estimation depends on accurate simulation of other water-budget components as well, especially ET. Few or no measured data were available to calibrate or test ET and groundwater recharge. Much of the surficial geology in zone 3 consists primarily of the Carrizo Sand. Where the surficial geology also consists primarily of the Carrizo Sand (outside the study area), measured ET data were available to compare with simulated ET data from water-budget zone 3; differences between the measured and simulated ET data were small and the simulated ET data appear reasonable.

Simulations for other types of surficial geology and land cover are even less certain because of the lack of measured ET data for comparison purposes. Additional ET datasets (if available) could be used to improve the calibration. To further understand the groundwater components of the model, linkages of this watershed model with groundwater models for the region would be useful.

Summary

The U.S. Geological Survey (USGS), in cooperation with the San Antonio River Authority, the Evergreen Underground Water Conservation District, and the Goliad County Groundwater Conservation District, configured, calibrated, and tested a Hydrological Simulation Program—FORTRAN (HSPF) watershed model for the approximately 2,150-square-mile lower San Antonio River watershed in Bexar, Guadalupe, Wilson, Karnes, DeWitt, Goliad, Victoria, and Refugio Counties in south-central Texas. Because of the complexity of the study area, the lower San Antonio River watershed was divided into four subwatershed models; separate HSPF models were developed for each subwatershed. The most downstream subwatershed model, San Antonio River downstream from Cibolo Creek, receives the simulated streamflow from the outlets of the other three subwatershed models. Simulation of the overall study area involved running simulations of the three upstream models, then running the downstream model. The surficial geology was simplified as nine contiguous water-budget zones to meet model computational limitations and also to define zones for which ET, recharge, and other water-budget information would be output by the model. The model was used to simulate streamflow, evapotranspiration (ET), and groundwater recharge in the lower San Antonio River watershed in south-central Texas during 2000–2007 to gain a better understanding of the water budget. HSPF was used to simulate streamflow, ET, and groundwater recharge in each water-budget zone and for the watershed as a whole.

Rainfall data used as input for the model were obtained from seven National Weather Service (NWS) meteorological stations in or near the study area. Air temperature data from three of the NWS stations were used to estimate potential ET in the model. Other time-series datasets for the model were developed for wastewater discharges, surface-water withdrawals for irrigation, and springflow at Sutherland Springs.

The model was calibrated and tested using streamflow data obtained from 10 of the 11 USGS streamflow-gaging stations in the study area. Using various graphical and statistical methods, the calibration was characterized as very good; streamflow volumes were calibrated to within 10 percent of the measured streamflow volumes. Additionally, for calibration, ET simulations were compared with ET measured continuously at a USGS meteorological station in Medina County, about 70 miles west of the study area. The total HSPF-simulated ET from the pervious area of water-budget zone 3 for October 2006–November 2007 was 38.4 inches, and total measured ET at the Medina County station for this same time period was 37.4 inches.

Streamflow volumes and basin yields for the four subwatersheds in the study area were compiled. The measured annual mean volume of streamflow entering the study area from upstream during 2000–2007 was 0.685 million acre-feet. The simulated annual mean volume of streamflow exiting at the downstream outlet of the study area during 2000–2007 was 1.07 million acre-feet, an increase of 56 percent between the upstream contributing area and the downstream outlet of the study area. Of the four subwatersheds in the lower San Antonio River watershed, the Cibolo Creek subwatershed had the largest annual mean basin yield, about 4.8 inches per year. The annual mean basin yield of 6.4 inches from the San Antonio River drainage area upstream from the study area is 3.1 inches higher than the annual mean basin yield of 3.3 inches from the lower San Antonio River watershed.

During 2000–2007, annual mean rainfall estimates for the nine water-budget zones ranged from 33.7 to 38.5 inches per year; for the entire watershed the estimated annual mean rainfall was 34.3 inches. Most of the rainfall does not become streamflow but is either lost to the atmosphere as ET or stored as recharge. Using the HSPF model, it was estimated on the basis of simulation results that, for 2000–2007, less than 10 percent of the annual mean rainfall on the study watershed exited the watershed as streamflow. Using the HSPF model, it was also estimated that about 82 percent, or an average of 28.2 inches per year, exited the watershed as ET, primarily from pervious land. The Cibolo Creek subwatershed and the subwatershed of the San Antonio River upstream from Cibolo Creek had the largest and smallest basin yields, about 4.8 inches and 1.2 inches, respectively. Estimated annual ET and annual recharge generally increased with increasing annual rainfall. Also, ET was larger in zones 8 and 9, the most downstream zones in the watershed. These zones included larger percentages of riparian/wetland land cover, which exhibit larger ET rates than other land covers simulated in the model. Zones 8 and 9 also had more rainfall than the other zones, thus more water to satisfy potential ET demand.

The HSPF model also was used to estimate groundwater recharge for nine selected water-budget zones. The largest estimated annual mean groundwater recharge, about 5.1 inches, was in water-budget zone 3, the zone where the Carrizo Sand outcrops. On average, an estimated 15 percent of annual mean rainfall in water-budget zone 3 was converted to recharge. The smallest estimated annual mean recharge, about 1.1 inches (about 3 percent of annual mean rainfall), was in water-budget zone 6. For the entire watershed study area, annual mean recharge was about 3.0 inches or about 9 percent of annual mean rainfall.

Model limitations include possible errors related to model conceptualization and parameter variability, lack of data to quantify certain model inputs, and measurement errors. The conceptualization of the watershed and the variation in model parameters among water-budget zones, as well as the decisions as to which watershed factors drive the hydrologic responses of the watershed, might not be accurate or might be oversimplified. The lack of measured ET data for different surficial geologic units, land covers, vegetative types, and seasons is limiting because it is not always clear how model parameters for ET should be varied. Rainfall can vary greatly over a short distance; uncertainty regarding the degree to which available rainfall data represent actual rainfall is potentially the most serious source of measurement error.

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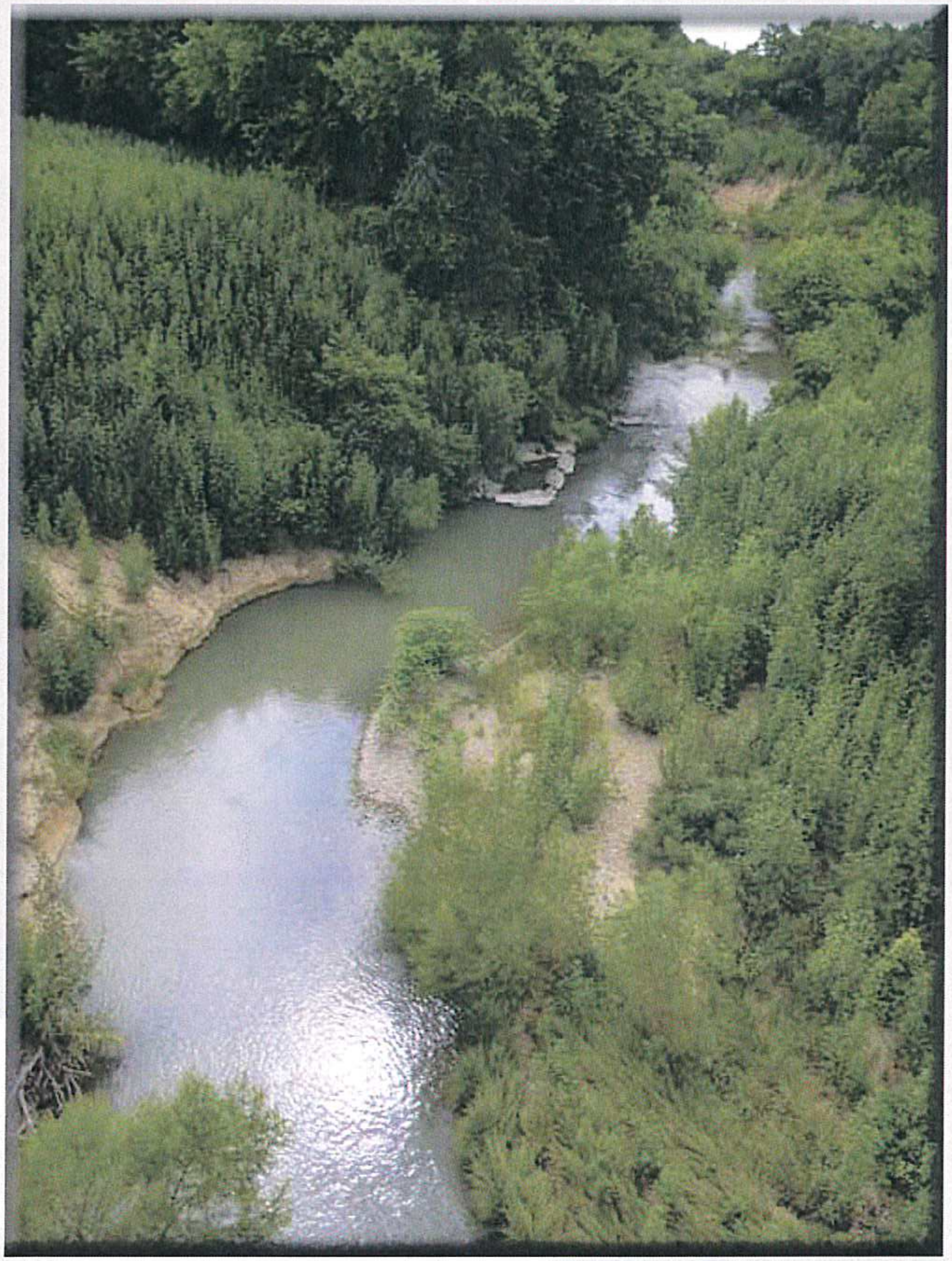

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1918 - 1958

INTRODUCTION

Of the water that reaches a stream channel, part is discharged by evaporation and transpiration, and by seepage into the ground along the stream channel where the water table is lower than the surface of the stream. The part lost by seepage may return later to the same channel at a point downstream; it may flow through underground channels to be discharged in distant springs or even into another river channel; it may become a part of ground water which will appear, perhaps years later, in wells that furnish water for domestic or industrial use, for irrigation, or for other uses.

The determination of available water in Texas streams cannot be made entirely from runoff records at the regular streamflow stations maintained on streams throughout the State. Special investigations must be made to locate, identify, and determine gains or reductions in streamflow. Investigations have been made on many Texas streams to determine flow conditions during periods of base flow, to identify interchange of surface water and ground water, to determine losses of water in irrigation systems, and to determine the change in the pattern of flow and amount of water released from a reservoir as it is conveyed in a stream channel to a point downstream. Such investigations are of basic importance in consideration of problems that involve supply and use of water for almost any purpose.

This publication combines in one volume the results of all special investigations that have been made by the Texas Board of Water Engineers and the U. S. Geological Survey from 1918 through 1958 to determine quantitative gains and losses of stream flow through long reaches of natural stream channels and canals in Texas; and it also includes results of an investigation on the Rio Grande made in 1928 by the U. S. Geological Survey in cooperation with the International Boundary and Water Commission. This bulletin compiles two types of studies; low-flow investigations, many of which have been published in Geological Survey water-supply papers in Parts 7 and 8 of the annual series, "Surface Water Supply of the United States"; and delivery-of-water investigations, which in most cases have been published as open-file reports with very limited distribution. The first of these special investigations was made in 1918. Since that date nearly 150 investigations of channel gains and losses have been made.

LOW-FLOW INVESTIGATIONS

Purpose and Scope

The low-flow investigations were made to show gains and losses of flow in a selected reach of stream during a period of base flow; that is, when the total flow of the stream was contributed by springs or seeps from aquifers with no direct runoff from recent storms. The aquifers that contribute to streamflow may be alluvial beds in the stream channel, other deposits of sand and gravel in the watershed, areas of cavernous rock even outside the watershed, or any other geologic formations that are capable of transmitting water. Water enters these aquifers by percolation from rainfall on the outcrop area, by seepage on flood plains during periods of over-bank flow, or by seepage into permeable streambeds at elevations higher than that of the area under investigation. The quantity of water that may enter an aquifer depends on various geologic and hydraulic factors. Permeability of the formation and hydraulic gradient are two of the factors that affect the quantity of water transmitted by aquifers.

Base streamflow will disappear into a permeable streambed where the water level is below stream level; the water may reappear downstream or may flow through the bed of the stream into a ground-water reservoir which transmits the water away from the stream. This process effects a substantial interchange of surface water and ground water in many areas of Texas. A good example of such interchange is found along the south edge of the Edwards Plateau in west-central Texas. In this region most of the streams obtain their base flow from springs that flow from porous limestone aquifers. The water flows in channels cut into the Glen Rose limestone, which may add significantly to the base flow, and then plows into the Edwards limestone through cracks and fissures in the streambed along the Balcones fault zone; the line along which the Edwards has been dropped several hundred feet by faulting. The water flows underground in the Edwards limestone many miles to the east, where much of it emerges as spring flow and sustains substantial base flow in streams all the way to the Gulf of Mexico. Comal Springs, San Marcos Springs, and San Antonio Springs all flow from the Edwards limestone, which is recharged largely from streams in the upper Nueces River basin within the limits of the Edwards Plateau.

Description of Investigations

The low-flow investigations have ranged from a reconnaissance type study, with a few discharge measurements on the main stream, to comprehensive types of studies with many measurements of main-stream flow, tributary inflow, and diversions. Recent, more comprehensive investigations have been made as follows: streamflow measurements were made with a Price current meter at sites on the main stream, the sites being selected on basis of stream mileage, on changes in geology, or on changes in pattern of flow as determined from previous investigations; tributary inflow and diversions were measured by current meter or were estimated; particular attention was paid to bank seepage and to springs, additional measurements being made to determine the exact point where natural gains or losses occurred; and notes were made of channel conditions, streambed composition, and vegetation in the streambed, on the banks, and in the stream valley.

The first low-flow or seepage investigations were made along the Colorado River, along tributaries of the Colorado River above Austin, and along the Pecos River during a very dry period in the summer of 1918. A second series of investigations in the Colorado River basin was made in 1925, another drought year. The investigations along the Colorado River in 1918 covered 593 miles, from the town of Robert Lee to the river's mouth. The numerous seepage investigations in the Pecos River basin were made for the purpose of determining conveyance losses in irrigation canals.

Since December 1954 a number of low-flow investigations have been made along the upper reaches of all large streams from the Guadalupe to the Nueces Rivers that recharge the Edwards limestone in the Balcones fault zone. One such investigation made along the Guadalupe River in 1955 included chemical analysis of water samples and water temperatures which helped solve a complex problem of surface and ground water interchange.

An intensive investigation of the low-flow characteristics of the Pedernales River was made during a drought period in January 1956. The field investigation was made and the report was prepared by a party of three: an engineer from the Texas Board of Water Engineers, who interviewed landowners to determine point of and the amount of diversions for irrigation and other uses; and a geologist and an engineer from the U. S. Geological Survey, who made streamflow measurements and flow analyses on the basis of geology and other stream characteristics.

During the period from 1918 to 1958, 138 separate low-flow investigations were made, most of them in the basins of the Colorado, Guadalupe, and Nueces Rivers and the Rio Grande. The data in the early investigations are especially valuable, having been obtained before major river developments took place, flows generally represented natural conditions; although even in 1918, there were large diversions for rice irrigation from the lower Colorado River. Certainly, the series of hydroelectric plants and storage reservoirs completed on the Colorado River in recent years have so altered the pattern of low flow as to make future low-flow investigations meaningless insofar as natural river conditions are concerned.

DELIVERY-OF-WATER INVESTIGATIONS

Purpose and Scope

Delivery-of-water investigations have been made during periods when water was being released from a reservoir and allowed to flow down the natural stream channel to a point of diversion or use. These investigations provide information on time of travel of released water, losses encountered in conveying water downstream, peak-flow reductions, and changes in rate of flow of released water as it progressed downstream--information essential to enable the water user to compute the rate of release which will effect maximum recovery of released water at the point of diversion or use.

Generally, these investigations have been made when reservoir water was being released to meet water demands during drought periods. At such times channel reaches through which the released water was conveyed were usually dry or nearly dry; consequently bank storage, prior to the release, was at a minimum. In such water deliveries water was lost in varying amounts through evapotranspiration and bank storage, and seepage losses or recharge to ground-water reservoirs occurred only where geology favored such loss.

The first delivery-of-water investigation was made during the 1918 drought and recorded the movement of a special release of stored water from Lake Austin down the Colorado River to irrigators in the vicinity of Bay City. The second investigation, made in 1934, recorded the movement of water released from Brownwood Reservoir down Pecan Bayou and thence down the Colorado River to Wharton. The other investigations involved the diversion of Red River water to Lake Dallas in the Trinity River basin in 1954; and delivery of water from reservoirs in the Brazos River basin, namely, Possum Kingdom, Whitney, and Belton Reservoirs, to Richmond in 1948, 1954, and 1956. These investigations are the forerunners of similar ones that will be required as other reservoirs are provided.

Description of Investigations

Data collected at regular stream-gaging stations in the reach of river being investigated provided the basic information for studying the movement of released water. For some of the investigations, special visits and additional discharge measurements were made at the stream-gaging stations during the release period. When necessary, temporary recording gages were installed and records of stage and discharge at other points were obtained to supplement the regular gaging-station records. Where major pumping plants diverted water in the reach under study, inspections and discharge measurements were made to assure an accurate record of the diversions. In some of the investigations, discharge measurements of ungaged tributary streams were made to provide information for identifying and defining base streamflow.

PRESENTATION OF DATA

The investigations included in this report are presented in two sections: (1) low-flow investigations and (2) delivery-of-water investigations. The investigations in each section are arranged geographically according to basin from east to west across the State and in downstream order of tributaries or diversions within the basin.

The data presented for each low-flow investigation include a tabulation of measurements, text and any substantiating information available. The table of measurements gives the following information: river basin, name of the stream investigated, a precise description of the location of the reach under investigation, period of the investigation, date of each flow determination, river miles below the starting point, a short description of the location of the determination, stream discharge in cubic feet per second (cfs) at each point, and water temperature if available. Data for the recent, more comprehensive investigations may include field notes concerning conditions that affect the flow, description of streambed composition at a measuring section, or references to important changes in geology.

The information presented for each delivery-of-water investigation includes a discussion of the purpose and scope, a summary of results, and a presentation of results in the form of discharge hydrographs and time-of-travel curves.

The basic data and original field notes for all the investigations in this report are available for examination in the files of the Surface Water Branch District office of the U. S. Geological Survey in Austin, Texas.

Low-flow Investigations

LOW-FLOW INVESTIGATIONS - RED RIVER BASIN

Tierra Blanca Creek   Aug. 31, Sept. 28, 1941

Reach: From Buffalo Lake (Umbarger Reservoir) near Umbarger to a point about 18 miles downstream, near Canyon, Tex.

A series of discharge measurements was made on Aug. 31 and Sept. 28, 1941 on Tierra Blanca Creek, Tex., between Buffalo Lake (Umbarger Reservoir) and a point 17.9 miles downstream in the vicinity of Canyon. The measurements represent natural conditions and were made during a constant discharge release from Buffalo Lake. No diversions were found in the reach and no inflow was found from tributaries.

On Aug. 31 total flow of the creek is released water from Buffalo Lake. This discharge varied from 2.0 to 0.97 cfs from Aug. 24-29 but was increased from 0.97 to 4.4 cfs at 1:40 p.m. Aug. 29. A constant release of 4.4 cfs was held from Aug. 29-31. Field inspection revealed that flow had stabilized from dam to a point 10.9 miles downstream but below this point flow was fluctuating due to fluctuating releases prior to Aug. 29. Estimate of discharge at mile 17.9 indicated that at least the minimum release (0.97 cfs) was lost by seepage, evaporation or by storage in several small reservoirs in the reach. The investigation was not continued because rainfall occurring a few days later did not permit the flow to stabilize.

On Sept. 28 the above investigation was continued. According to records of the Soil Conservation Service, 3.19 cfs were being released from Buffalo Lake on Sept. 28 and the released discharge had ranged from 3.08 to 3.27 cfs for the period Sept. 24-27. Field inspection indicated that the stage was constant throughout the reach on Sept. 28 and that a total loss of 2.6 cfs was found in the 17.9 miles of channel investigated.

Date 1941	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Discharge, in cfs: Tributary	Discharge, in cfs: Diversion	Remarks
Aug. 31	Tierra Blanca Creek	600 ft below dam at Buffalo Lake	0		4.54			
31	Tierra Blanca Creek	NE ¼ of sec. 87, Block B-5, 2½ mi SE of Umbarger	2.0		4.54			
31	Tierra Blanca Creek	SW ¼ of sec. 72, Block B-5, 3½ mi SE of Umbarger	3.8		4.34			
31	Tierra Blanca Creek	NE ¼ of sec. 72, Block B-5, 4½ mi S of Umbarger	5.0		3.98			
31	Tierra Blanca Creek	SE ¼ of sec. 58, Block B-5, 300 ft below new Gordon-Cummings Dam and 5½ mi S of Umbarger	6.6		3.78			
31	Tierra Blanca Creek	SE ¼ of sec. 37, Block B-5, 2 mi SW of Canyon	9.2		3.75			
31	Tierra Blanca Creek	NW ¼ of sec. 62, Block B-5, ½ mi S of Canyon	10.9		2.92			

Date 1941	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
	From Buffalo Lake (Umbarger Reservoir) near Umbarger to a point about 18 miles downstream, continued							
Aug. 31	Seepage investigation discontinued at this point due to unstabilized conditions.							
31	Tierra Blanca Creek	SW $\frac{1}{4}$ of sec. 12, Block B-6, 1 mi SE of Canyon, just below McSpaddens Dam	17.9		0.01			Estimate.
	Investigation continued on Sept. 28							
Sept. 28	Tierra Blanca Creek	600 ft below dam at Buffalo Lake	0		*3.19			*Computed by wier formula.
28	Tierra Blanca Creek	SE $\frac{1}{4}$ of sec. 37, Block B-5, 2 mi SW of Canyon	9.2		2.57			
28	Tierra Blanca Creek	NW $\frac{1}{4}$ of sec. 62, Block B-5, $\frac{1}{2}$ mi S of Canyon	10.9		2.09			
28	Tierra Blanca Creek	NW $\frac{1}{4}$ of sec. 63, Block B-5, 3/4 mi S of Canyon	12.6		1.55			
28	Tierra Blanca Creek	SW $\frac{1}{4}$ of sec. 64, Block B-5, 1 mi S of Canyon at Highway 87	15.8		1.51			
28	Tierra Blanca Creek	SW $\frac{1}{4}$ of sec. 12, Block B-6, 1 mi SE of Canyon just below McSpaddens Dam	17.9		.59			

LOW-FLOW INVESTIGATIONS - NECHES RIVER BASIN

Bowles Creek   October 28, 1942

Reach: From a point 1.8 miles west of Old London to mouth of Horsepen Branch near Carlisle, Tex.

A series of discharge measurements on Bowles Creek (tributary to Striker Creek) and tributaries, in Rusk and Smith Counties, Tex., was made between county-road bridge on West Fork Bowles Creek 1.8 miles west of Old London, Rusk County, and a point just upstream from Horsepen Branch, 2.6 miles northwest of Carlisle, Rusk County. The measurements were made during a period of constant stage of the creek, in order to determine seepage. All tributaries and diversions were measured. The seepage investigation was made in connection with a study of oil-field waste.

Date 1942	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Oct. 28	W.Fk.Bowles Cr	At county road crossing ½ mi above mouth	0		1.4			
28	E.Fk.Bowles Cr	At county road crossing ½ mi above W. Fork	.5			1.0		
28	Bowles Cr	Just below confluence of E.and W. Fork	.5		2.8			
28	Bowles Cr	.7 mi above Allen Branch	1.3		2.7			
28	Allen Branch	.6 mi above mouth 2.1 mi SW Old London	2.0			1.1		
28	Bowles Cr	Just above Wright Branch	3.7		3.3			
28	Wright Branch	Just above mouth .8 mi SE of Wright City	3.7			1.3		
28	Henson Cr	Just above mouth 2.1 mi south of Wright City	5.2			.5		
28	Bowles Cr	.2 mi above Denton Creek	5.6		8.2			
28	Denton Cr	Just above mouth 2.7 mi NW of Carlisle	5.8			.6		
28	Bowles Cr	Just above Horsepen Branch	6.5		8.9			
28	Horsepen Branch	Just above mouth 2.4 mi NW of Carlisle	6.6			1.3		

LOW-FLOW INVESTIGATIONS - TRINITY RIVER BASIN

Trinity River November 1-8, 1952

Reach: From Riverside to Liberty, Tex.

A seepage investigation was made on Trinity River and its tributaries between the gaging station at Riverside, Tex., and a point 8.7 miles upstream from the gaging station at Liberty, Tex. This investigation was made to determine the seepage gains or losses in the 133.5 river mile reach from Riverside to head of tide water above Liberty.

During the investigation the rate of flow at any point was practically constant throughout the reach. The gage-height records at Riverside and Romayor show slight variations in stage, which are of small percentage and well within the accuracy range of the discharge measurements when translated into discharge.

For complete report on this investigation see U. S. Geological Survey Open File Release No. 44, November 1952, Austin, Texas (SW).

Date 1952	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Nov. 7	Trinity River	At State Highway 45 at Riverside-gaging station	0		165			
6	Unnamed Creek	2.3 mi SW of Embryfield	6.0			0.5		
4	White Rock Creek	1.3 mi NW of Sebastapol	12.6			0		
4	Sulphur Creek	1.0 mi SE of Sebastapol	15.2			.1		
4	Mill Creek	1.4 mi SE of Sebastapol	15.5			.3		
6	Palmetto Creek	2.0 mi above mouth	22.0			0		
7	Trinity River	3.2 mi above Highway 190 near Onalaska	25.9		168			
4	Kickapoo Creek	At Kickapoo	26.9			0		
6	McGhee Creek	At mouth 7.0 mi N of Cold Springs	34.6			.2		
6	Wolf Creek	5.0 mi N of Cold Springs	39.7			.3		
6	Bird Creek	3.5 mi N of Cold Springs	40.5			.3		
6	Mills Creek	2.0 mi NW of Camilla	47.5			2.38		
6	Hoffman Creek	3.7 mi NW of Shepherd	61.8			1.29		
6	Long King Creek	.8 mi W of Goodrich	65.0			4.93		
7	Trinity River	.5 mi below Highway 59 near Urbana	65.7		183			
6	Copeland Creek	3.8 mi SE of Goodrich	68.3			3.83		
6	Drews Mill Creek	5.0 mi SE of Goodrich	69.3			2.13		
6	Menard Creek	4.0 mi N of Romayor	80.5			12.8		

Date 1952	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Riverside to Liberty, Tex., continued							
Nov. 6	Big Creek	3.0 mi NE of Shepherd	84.2			3.78		
6	Trinity River	At Romayor - gaging station	88.2		209			
1	Trinity River	8.7 mi above Liberty - temporary gage	133.5		229			
2	Trinity River	8.7 mi above Liberty - temporary gage	133.5		228			
8	Trinity River	8.7 mi above Liberty - temporary gage	133.5		235			

LOW-FLOW INVESTIGATIONS - BRAZOS RIVER BASIN

Leon River March 13-14, 1951

Reach: Just below Olden Lake Dam 3.7 mi southeast of Eastland to bridge on U. S. Highway 67 near Hasse, Tex.

A series of discharge measurements was made March 13, 14, 1951, on the Leon River and its tributaries, Texas, from a point just below Olden Lake Dam near Eastland, to the crossing of U. S. Highway 67 near Hasse, 45½ miles downstream, to determine the seepage gains or losses in the reach. Records of two gaging stations in the reach indicated a constant river stage for several days prior to and during the investigation. All tributaries were investigated and those having flow were measured.

As indicated in the following table, the flow of the Leon River at river mile 6.6 was 0.21 cfs, while at river mile 12.0 the streambed was dry. The streambed through this section is composed of apparently fairly deep sand. The water reappeared a short distance above river mile 15.4, consisting of a succession of shallow pools with approximately 0.01 cfs flowing between pools. About 3/4 mile below river mile 15.4, this small flow disappeared. At river mile 19.8 the streambed was dry, while at river mile 23.6 a flow of 0.32 cfs was measured, and at river mile 32.6 the flow was 0.21 cfs. From this point on downstream the flow in the river gradually increased to 4.69 cfs at river mile 45.5.

Date 1951	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Mar. 13	Leon River	Lat 32° 22', long 98°46', 300 ft below Olden Lake Dam, 3.7 mi SE of Eastland	0	56	0.46			Water sample obtained.
13	Leon River	Near Eastland (recording gage)	5.2	52	.20			150 ft below gage.
13	Leon River	Lat 32°22', long 98°42', 7.0 mi south of Ranger	6.6	52	.21			100 ft below bridge. Water sample obtained.
13	Colony Creek	Lat 32°23', long 98°40', 5.7 mi south of Ranger	9.0	54		0.01		Estimate - sample obtained.
13	Leon River	Lat 32°19', long 98°39', 7.0 mi NW of Desdemona	12.0		0			
13	Natches (Nash) Creek	Lat 32°18', long 98°40', 5.6 mi north of Gorman	14.8			0		Sand bed - sand wet.
13	Leon River	Lat 32°18', long 98°38', 5.4 mi NW of Desdemona	15.4		0			Estimate .01 cfs about ¼ mi below bridge.
13	Rough Branch Creek	Lat 32°18', long 98°37', 4.4 mi NE of Desdemona	16.0			.02		Estimate - water sample obtained.
13	Leon River	Lat 32°15', long 98°36', 3.0 mi SW of Desdemona	19.8		0			No flow in Ellison Spring Branch.
14	Leon River	Lat 32°10', long 98°32', 4.0 mi north of DeLeon	23.6	43	.32			300 ft above bridge. Water sample obtained.
14	Leon River	Lat 32°06', long 98°30', 2.0 mi east of DeLeon	32.6	48	.21			100 ft below bridge. Water sample obtained.

Date 1951	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Just below Olden Lake Dam 3.7 mi southeast of Eastland to bridge on U.S. Highway 67 near Hasse, Tex., continued								
Mar. 14	Armstrong Creek	Lat 32°06', long 98°29', 3.3 mi east of DeLeon	34.2	45		1.21		100 ft below bridge. Water sample obtained.
14	Leon River	Lat 32°03', long 98°29', 4.8 mi SE of DeLeon	35.2	49	1.73			300 ft above bridge.
14	Sabana River	Lat 32°04', long 98°32', 3.8 mi south of DeLeon	39.8	52		1.36		500 ft below bridge and below tributaries - sample obtained.
14	Leon River	Lat 31°59', long 98°28', 9.0 mi SE of DeLeon	41.0	51	3.38			100 ft below bridge.
14	Rush Creek	Lat 32°01', long 98°33', 7.3 mi SW of DeLeon	42.8	63		.81		50 ft above bridge. Water sample obtained.
14	Duncan Creek	Lat 31°58', long 98°33', 5.5 mi NE of Comanche	42.8	56		.56		50 ft below bridge. Water sample obtained.
14	Leon River	Near Hasse (recording gage)	45.5	55	4.69			2,000 ft below gage. Water sample obtained.

LOW-FLOW INVESTIGATIONS - BRAZOS RIVER BASIN

Sulphur Creek June 30, Aug. 10, 1942

Reach: Just south of Hancock Park in Lampasas, Lampasas County to a point 3.67 miles downstream and 1.5 miles downstream from Burleson Creek near Lampasas, Tex.

A series of discharge measurements was made on June 30, 1942, and another one on Aug. 10, 1942 on Sulphur Creek (tributary of Lampasas River) and tributaries, between a point in Lampasas and a point 1.5 miles downstream from Burleson Creek. The investigations were made during a constant stage and determinations represent natural conditions. Distances along the creek were measured on topographic maps prepared by the State Reclamation Department.

Date 1942	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 30	Sulphur Creek	Lat 31°03'01", long 98°11'06", just south of Hancock Park, at low-water crossing on Lampasas-Llano road	0		15.6			50 ft below crossing.
30	Sulphur Creek	Lat 31°03'21", long 98°11'13", about 100 ft upstream from city pump	.53		18.3			City pump in operation.
30	Municipal pump station	On left bank about 0.4 mi upstream from U. S. Hwy. 281	.55				1.1	Computed flow. City pumping about 500 gpm.
30	Sulphur Creek	Lat 31°03'17", long 98°11'01", about 100 ft upstream from main Hancock Spring	.77		17.9			
30	Sulphur Creek	Lat 31°03'18", long 98°10'57", about 100 ft downstream from main Hancock Spring	.87		21.0			100 ft above bridge.
30	Swimming pool spring	Lat 31°03'17", long 98°10'55", just upstream from U. S. Hwy. 281	.90			1.2		30 ft below pool.
30	Sulphur Creek	Lat 31°03'21", long 98°10'52", about 150 ft downstream from U. S. Hwy. 281	.95		25.5			Water turbulent - gravel bed.
30	Hannah Spring	Lat 31°04'06", long 98°10'34", about 200 ft upstream from Santa Fe Railroad on Hackberry Street	2.17			1.3		100 ft below spring basin.
30	Sulphur Creek	At lower crossing of Santa Fe Railroad and 1.5 miles downstream from Burleson Creek	3.67		32.2			200 ft above bridge.

Date 1942	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Just south of Hancock Park in Lampasas, Lampasas County to a point 3.67 miles downstream and 1.5 miles downstream from Burleson Creek near Lampasas, Tex., continued							
Aug. 10	Sulphur Creek	Lat 31°03'01", long 98°11'06", just south of Hancock Park, at low-water crossing on Lampasas-Llano road	0		5.0			50 ft below crossing.
10	Sulphur Creek	Lat 31°03'21", long 98°11'13", about 100 ft upstream from city pump	.53		6.8			City pump in operation.
10	Municipal pump station	On left bank about 0.4 mi upstream from U. S. Hwy. 281	.55				1.1	Computed flow. City pumping about 500 gpm.
10	Sulphur Creek	Lat 31°03'17", long 98°11'01", about 100 ft upstream from main Hancock Spring	.77		9.2			
10	Sulphur Creek	Lat 31°03'18", long 98°10'57", about 100 ft downstream from main Hancock Spring	.87		12.4			100 ft above highway bridge.
10	Swimming pool spring	Lat 31°03'17", long 98°10'55", just upstream from U.S. Hwy. 281	.90			1.0		30 ft below pool.
10	Sulphur Creek	Lat 31°03'21", long 98°10'52", about 150 ft downstream from U. S. Hwy. 281	.95		15.3			Water turbulent.
10	Hannah Spring	Lat 31°04'06", long 98°10'34", about 200 ft upstream from Santa Fe Railroad on Hackberry Street	2.17			1.5		100 ft below spring basin.
10	Sulphur Creek	At lower crossing of Santa Fe Railroad and 1.5 mi downstream from Burleson Creek	3.67		18.1			200 ft above bridge.

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Colorado River August 7-14, 1918

Reach: Colorado River, from Robert Lee to mouth near Matagorda, Tex.

An investigation of gains and losses from seepage in the Colorado River from a point at Robert Lee to the mouth was made in August 1918. The discharge was measured at various intervals along the main stream, at the mouth of each tributary, and at the point of each diversion. Gages at Bronte, Ballinger, Chadwick, Marble Falls, and Columbus are read twice daily, and at Austin a continuous recorder is maintained. Although data were insufficient to warrant a correction of discharge for time interval, these gages showed the stream to be at a practically constant stage, with no floods to interfere with the investigation. Few corrections for time intervals were necessary.

These data represent natural conditions as they were found above Columbus, but below that point the flow was practically all diverted for rice irrigation. It is therefore difficult to draw definite conclusions from the measurements made below Columbus. During the investigation the reservoir, formed by the Austin Dam, was empty, and the natural flow of the river was passing through the dam. An extremely low stage existed throughout the course of the river.

Above the mouth of San Saba River the river was dry with the exception of 0.2 cfs at the mouth of Pecan Bayou. The course of the river from Chadwick to Austin is through rough and rugged country, with most of the distance through canyons and gorges, with a few stretches of valleys. Between the Chadwick and Marble Falls gaging stations there was a slight gain. From Marble Falls to Austin dam the flow increased from 3 to 21 cfs. Between the Austin dam and Austin gaging station there was a gain of 4.1 cfs, and from the Austin gage to Platts Ferry, a distance of 11 miles, the gain was 27.4 cfs. From Platts Ferry to Columbus the flow increased from 51 to 144 cfs, or a gain of 93 cfs in 125 miles. As previously stated, the flow below Columbus was practically all diverted. Lack of sufficient data for time interval correction makes records below this point of little value. The sectional gain of 32 cfs between Austin dam and Platts Ferry, a distance of 14 miles, is due in all probability to fissure streams or springs located in the Balcones fault zone, which tend to raise the level of the water table and increase the seepage into the river.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Colorado River,	from Robert Lee to mouth near Matagorda						
Aug. 7	Colorado River	At Robert Lee	0		0			No water in river for last two weeks.
7	Liveoak Creek	At mouth	12			0		
7	Colorado River	Near Bronte (gaging station)	14		0			
7	Kickapoo Creek	At mouth	15			0		
7	Colorado River	At Maverick-Miles highway bridge	20		0			No pumps in vicinity.
7	Oak Creek	At mouth	21			0		
7	Mule Creek	At mouth	22			0		
7	Valley Creek	At mouth	36			0		
7	Colorado River	At Ballinger (gaging station)	42		0			
7	Elm Creek	At mouth	43			0		
7	Colorado River	At mouth of Concho River	61		0			
7	Concho River	At mouth	61			0		
7	Elm Creek	At mouth	70			0		
7	Mustang Creek	At mouth	74			0		
7	Colorado River	At Stacy	80		0			
7	Salt Creek	At mouth	87			0		
7	Colorado River	At Waldrip	96		0			
7	Buhl Creek	At mouth	99			0		
7	Colorado River	At Whan	110		0			
8	Home Creek	At mouth	118			0		
8	Colorado River	At Milburn	126		0			No pumping in vicinity.
8	Clear Creek	At mouth	131			0		
8	Colorado River	At Brownwood-Richland Springs crossing	134		0			No pumping.
8	Buffalo Creek	At mouth	148			0		
8	Rough Creek	At mouth	149			0		
7	J. W. Perkins ditch	1/4 mi above Regency	150				2.0	Earthen ditch.
7	S. M. Jones ditch	1 mi below Regency	151				1.6	Semi-circular flume.
7	Cottonwood Creek	At mouth	154			0		
7	Spring Creek	At mouth	157			0		
7	King Creek	At mouth	163			0		
7	Pecan Bayou	At mouth	164			0		
7	Colorado River	Below Pecan Bayou	164		0.2			Wilson pump running.
8	Oglesby-Bawson ditch	6 mi below Pecan Bayou	170				1.4	Earth canal.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
	Colorado River, from Robert Lee to mouth near Matagorda, continued							
Aug. 8	Horse Creek	At mouth	172			0		
8	E. H. Hopgood ditch	At Warrens crossing	174				0.4	
8	Prescott Creek	At mouth	174			0		
8	Bull Creek	At mouth	176			0		
8	Yarbrough ditch	11 mi northwest of San Saba	176				2.0	Semi-circular flume.
8	Nabors Creek	At mouth	180			0		
8	Edmondson ditch	1-1/2 mi above San Saba River	188				.8	Semi-circular flume.
8	Bennett ditch	1 mi above San Saba River	189				1.0	Semi-circular flume.
8	San Saba River	2 mi above mouth	190			2.9		
8	Colorado River	1/4 mi below San Saba River	190		5.2			
9	Colorado River	Near Chadwick (gaging station)	193		4.0			Constant stage.
9	Elliott Creek	At mouth	194			0		
9	Red Bluff Creek	At mouth	196			0		
9	Antelope Creek	At mouth	198			0		
9	Rough Creek	At mouth	204			.1		
9	Brazil ditch	3-1/2 mi above Bend	205				1.4	Earth canal.
9	McCourry ditch	1-1/2 mi above Bend	206				2.6	Semi-circular flume.
9	Colorado River	At Bend	208		0			
9	Cherokee Creek	At mouth	210			0		
9	Colorado River	At Tow	232		3.5			
10	Colorado River	Near Bluffton	241		3.5			At mouth of L. H. Creek.
10	Morgan Creek	At mouth	241			0		
10	Colorado River	At Bluffton-Kingsland road	248		2.6			
10	Spring Creek	At mouth	252			0		
10	Llano River	At mouth	263			.2		
10	Colorado River	Below Llano River near Kingsland	263		3.7			
10	Colorado River	1 mi above Sandy Creek	268		3.6			
10	Sandy Creek	At mouth	269			0		
10	Pecan Creek	At mouth	272			0		
10	Colorado River	3-1/2 mi above Marble Falls	276		3.0			
10	Sparerib Creek	At mouth	280			0		
10	Flatrock Creek	At mouth	281			0		
10	Little Cypress	At mouth	295			0		
9	Colorado River	Just above Pedernales River	304		9.0			
9	Pedernales River	At mouth	304			0		
9	Cow Creek	At mouth	305			0		
9	Colorado River	At Cat Hollow Ford	310		9.3			

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Colorado River,	from Robert Lee to mouth near Matagorda, continued						
Aug. 9	Bee Creek	At mouth	312			0		
9	Colorado River	At Lohmans Ford	314		7.6			
9	Williams pump	Just above Sandy Creek near Cedar Park	322				0.2	
9	Sandy Creek	At mouth	322			.1		
9	Colorado River	At Watsons Ford	323		6.6			1,000 ft below Sandy Creek.
10	Colorado River	At Cameron Ford	336		8.0			Large silt deposits.
10	Santa Monica Springs	1 mi below Cameron Ford	337			0		Silt over springs.
10	Bull Creek	At mouth	344			0		
10	Morman Springs	1/2 mi above Austin Dam	347			1.0		
10	Colorado River	Just below Austin Dam	348		20.5			
10	Colorado River	1/4 mi below Deep Eddy	349		24.2			First rapids below Deep Eddy.
10	Barton Creek	At mouth	350			14.3		
10	Austin City pump	At Austin	350½				12.0	Two pumps running.
10	Colorado River	At Austin (gaging station)	351		26.9			Constant stage.
10	Walker pump	5 mi below Austin	356				3.2	
10	Colorado River	At Platts Ferry below Austin	367		51.1			
10	Averys pump	1/2 mi below Platts Ferry	362½				1.1	
10	Shepard pump	3 mi above Onion Creek	363				1.3	
10	Colorado River	1/4 mi above Onion Creek	369		48.4			
10	Colorado River	1/4 mi above Utleys Ferry	383		63.5			
10	Big Sandy Creek	At mouth	395			0		
10	Piney Creek	At mouth	400			0		
10	Colorado River	At Bastrop	403		83.7			
11	Walnut Creek	At mouth	415			0		
11	Colorado River	At Smithville	426		101			
11	Pin Oak Creek	At mouth	437			0		
11	Colorado River	2 mi north of West Point	438		102			200 ft above S.A.P. bridge.
11	Colorado River	At LaGrange	453		123			
11	Buckners Creek	5 mi below LaGrange	458			0		
11	Williams Creek	10 mi below LaGrange	463			0		
11	Colorado River	2-1/2 mi south of Ellinger	470		132			
12	Columbine Creek	1 mi above Columbus	486			0		
12	Colorado River	At Columbus	487		144			Constant stage.
12	Lakeside pump	Near Eagle Lake	510				71.6	
12	Colorado River	1 mi below Lakeside pump	511		99.6			
12	Bunges pump	5 mi below Lakeside pump	515				5.0	

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Colorado River, from Robert Lee to mouth near Matagorda, continued							
Aug. 12	Garwood pump	At Garwood	520				70.6	
12	Colorado River	Below Garwood pump	520		30.2			900 ft below pump.
13	Colorado River	At Glen Flora about 8 mi above Wharton	541		80.2			300 ft above highway bridge.
13	Pierce estate pump	3 mi above Wharton	544				73.5	One pump operating.
13	Colorado River	At Wharton	547		21.5			
14	Southern Irrigation pump	8 mi below Wharton	555				99.3	At flume 1 mi below pump.
14	Jones Creek	At mouth	561			0		
14	Henry Miatt pump	8 mi below Jones Creek	569				6.1	
14	Carlson pump	1 mi above Blue Creek	571				1.3	
14	Colorado River	At Bay City	575		0			Upper end of raft.
14	Colorado River	4 mi above Matagorda	593		.8			

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Colorado River April 7-24, 1925

Reach: **From Robert Lee to stream-gaging station at Austin, Tex.**

An investigation of gains and losses from seepage in the Colorado River from a point at Robert Lee to the gaging station at Austin was made in April 1925. The discharge was measured at various intervals along the main stream, at the mouth of each tributary, and at the point of each diversion. Gages at Robert Lee, Ballinger, Milburn, and Marble Falls are read twice daily, and at Tow and Austin continuous recorders are maintained. Data was insufficient to warrant a correction of discharge for time interval; however, these gages showed the river to be fairly constant, with the exception of a small rise on the night of April 22, causing a small increase in discharge at the Cox Ford site. These data represent natural conditions of the river throughout the reach investigated. During the investigation the reservoir, formed by the Austin Dam, was empty, and the natural flow of the river was passing through the dam. An extremely low stage existed throughout the course of the river.

Above the mouth of the Concho River the Colorado flow was very low, and the flow began to increase appreciably below this point. An increase from 5.7 to 17.5 cfs was noted from the Concho to the Milburn gaging station. The flow from Milburn to the San Saba River was fairly constant at about 20 cfs; however, the San Saba River contributed 67 cfs, the first major source of water. The flow from this point increased gradually downstream to a maximum of 118 cfs at the gaging station near Tow, and then decreased to 76 cfs 12 mi above the Llano River. The Llano River contributed 69 cfs to increase the main flow to 196 cfs at a point 1 mile below the mouth of Llano River; however, the flow then decreased to 172 cfs at the Marble Falls gaging station. Small gains and losses then occurred in the reach from this point to Austin; the main contributer at Austin being Barton Springs, which were flowing about 23 cfs, to increase the flow at the Austin gaging station to 255 cfs.

No data was available with which to describe the geology of the river section reaches.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Robert Lee	to Austin gaging station						
Apr. 7	Colorado River	At Robert Lee	0		0			
7	Colorado River	Near Robert Lee (Gaging station)	9		0			
7	Cow Creek	At mouth	9			0		
7	Colorado River	Near Bronte (former gaging station)	16		.1			
7	Colorado River	At Maverick-Miles Highway bridge	30		0			
7	Valley Creek	At mouth	44			0		
8	Colorado River	At Ballinger (Gaging station)	50		.2			Seepage in gravel.
8	Elm Creek	At mouth	51			0		
9	Colorado River	7 mi below Ballinger	57		.5			Estimate.
9	Colorado River	9 mi below Ballinger	59		.5			Estimate.
9	Mustang Creek	At mouth	60			0		
9	Colorado River	At Nichols Crossing	63		1.6			
8	Concho River	At mouth	69			.2		Estimate.
8	Colorado River	1,000 ft below Concho River	69		5.7			
9	Colorado River	Traps Crossing - 3 mi below Concho River	72		8.2			
8	Colorado River	Above Chriswell Springs - 5 mi below Concho River	75		10.7			
8	Colorado River	¼ mi below Chriswell Springs	76		10.3			
10	Colorado River	4 mi below Stacy	84		10.1			
10	Colorado River	8 mi below Stacy	96		11.3			
10	Colorado River	At Waldrip	104		13.2			
10	Colorado River	5 mi south of Whan	118		12.8			
11	Colorado River	At Milburn gaging station	134		17.5			
11	Bollinger pump	2¼ mi north of Bowser	142				0	
11	Colorado River	2 mi north of Bowser	144		16.6			
11	McMullen and Prewitt pump	3/4 mi below Ballinger	146				0	
13	Dwyer pump	At Regency	159				0	
13	Colorado River	¼ mi below Regency	159		15.6			
13	S. M. Jones pump	1 mi below Regency	160				0	
13	Cottonwood Creek	At mouth - 3 mi below Regency	163			0		
14	Pecan Bayou	At mouth - 12 mi below Regency	173			0		
14	Colorado River	1 mi below Pecan Bayou	174		18.0			
13	Colorado River	Goldthwaite-San Saba Highway	185		22.2			

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Robert Lee to Austin gaging station, continued							
Apr. 13	Renfro pump	1 mi below Goldthwaite-San Saba Highway	186				0	
13	Taylor and Beaumont pump	3 mi below Goldthwaite-San Saba Highway	188				0	
13	Miller pump	5 mi below Goldthwaite-San Saba Highway	190				0	
13	Mausby pump	7 mi below Goldthwaite-San Saba Highway	192				0	
13	Crawford pump	10 mi below Goldthwaite-San Saba Highway	195				0	
14	Colorado River	5 mi above San Saba River	195		23.4			
15	Colorado River	2 mi above San Saba River	198		19.9			
15	Edmonson pump	1 mi above San Saba River	199				0	
15	San Saba River	½ mi above mouth	200			67.2		
15	Colorado River	At Chadwick - 2 mi below San Saba River	202		87.0			
16	Rough Creek	At mouth - 4 mi above Bend	214			1.57		
16	McCurry pump	1½ mi above Bend	216				2.0	
16	Colorado River	At Bend	218		95.0			
16	Cherokee Creek	2 mi below Bend	220				0.3	
16	Lewis and Fry pump	Just below Cherokee Creek	220				0	
16	Cagle pump	Just below Cherokee Creek	220				0	
16	Frazier pump	Just below Cherokee Creek	220				0	
16	Sulphur Springs	6 mi below Bend	224			0		
16	Gorman Creek	11 mi below Bend	229			0		
17	Falls Creek	At mouth - 3 mi above Tow	240			2.4		
17	Colorado River	At gaging station near Tow	243		102			
16	Colorado River	At gaging station near Tow	243		118			
16	Tanners pump	1 mi below gage near Tow	244				0	
16	Tow Creek	At mouth - 1 mi below Tow	244			0.2		Flow from spring ½ mi upstream.
16	Cowan Creek	At mouth - 2 mi below Tow	245			.1		
16	Beaver Creek	At mouth - 3 mi below Tow	246			.3		
16	Morgan Creek	At mouth - ¼ mi above Bluffton	251			.1		
17	Colorado River	At Llano-Burnet Highway	251		107			
17	S. W. Graphite pump	¼ mi below Llano-Burnet Highway	252				0.8	

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Robert Lee	to Austin gaging station, continued						
Apr. 17	Lion Creek	1 mi below Llano-Burnet Highway	252			0		
17	Campground Creek	5 mi below Llano-Burnet Highway	256			0		
17	Redrock Creek	7 mi below Llano-Burnet Highway	258			0		
17	Colorado River	12 mi above Llano River	262		76.3			
17	Clear Creek	12 mi above Llano River	262			0		
17	Spring Creek	11 mi above Llano River	263			0		
17	Peter Creek	Hoover Valley	265			0		
17	Powdermill Creek	5 mi above Llano River	269			0		
17	Llano River	At mouth - Kingsland	274			69.0		
18	Colorado River	1 mi below Llano River	275		196			No change in stage - overnight.
18	Sandy Creek	At mouth - 6 mi below Llano River	280			0		
18	Colorado River	1,000 ft below Sandy Creek	280		179			
20	Pecan Creek	At mouth - 8 mi above Marble Falls	282			.2		
20	Slickrock Creek	At mouth - 6 mi above Marble Falls	284			0		
20	Colorado River	4 mi above Marble Falls	285		163			
20	Tiger Creek	At mouth - 2 mi above Marble Falls	288			0		
20	Meeks pump	5/8 mi above Marble Falls	289				0	
20	Phelps pump	1/2 mi above Dam at Marble Falls	290				0	Pumps intermittently.
20	Stamford pump	3/8 mi above Dam at Marble Falls	290				0	Pumps intermittently.
20	Wagner pump	1/4 mi above Dam at Marble Falls	290				0	Pumps intermittently.
20	Sparerib Creek	At mouth - at Marble Falls	290			0		All flow is in sand beds.
20	City pump	At Marble Falls City pump at Falls	290				.3	Pumping 200,000 gallons per day.
20	Colorado River	At gaging station at Marble Falls	290		172			
21	Flatrock Creek	At mouth - near Marble Falls	291			0		
21	Hamilton Creek	At mouth - 5 mi below Marble Falls	295			.2		
21	Sycamore Creek	At mouth - 5 mi below Marble Falls	295			0		
21	Doublehorn Creek	At mouth - 8 mi below Marble Falls	298			.5		
21	Postoak Branch	At mouth - 13 mi below Marble Falls	303			0		
21	Spanish Oak Creek	At mouth - 14 mi below Marble Falls	304			0		
21	Little Cypress Creek	At mouth - 9 mi above Pedernales River	307			.2		
22	Colorado River	100 ft above mouth of Pedernales River	316		226			

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Robert Lee to Austin gaging station, continued							
Apr. 22	Pedernales River	1 mi above mouth - above backwater	316			3.2		Backwater extends 1 mi.
21	Cow Creek	At mouth - 1 mi below Pedernales River	317			.1		
22	Cedar Knob Springs	4 mi below Pedernales River	320			.1		
22	Colorado River	At Cox Ford - 6 mi below Pedernales River	322		202			
23	Colorado River	At Cox Ford - 6 mi below Pedernales River	322		216			Small rise on river.
22	Bee Creek	At mouth - 8 mi below Pedernales River	324			.2		
23	Colorado River	At Lohmans Ford - 9 mi below Pedernales River	325		228			Small rise on river.
23	Sandy Creek	At mouth - ½ mi above Watson Ford	334			.1		
23	Colorado River	At Watson Ford - 18 mi below Pedernales River	334		238			
23	Cypress Creek	At mouth - 1 mi below Watson Ford	335			.2		Water comes from springs.
23	Bull Creek	Near Austin - 8 mi above Austin gage	357			0		
24	Barton Creek	At Austin	364			23.2		
24	City pump	At City Water Works	364				10.8	Pumping 7,000,000 gals. per day.
24	Shoal Creek	At mouth - at Austin	364			3.5		Estimate.
24	Lone Star Ice Company	At Austin	364				.1	Pumping 200 gals. per min.
25	Colorado River	At gaging station at Austin	365		255			Constant stage.

South Concho River June 18, 1953

Reach: South Concho River, from a point about 2 miles above stream-gaging station at Christoval, Tex. to a point 12 miles downstream.

A series of discharge measurements was made on June 18, 1953, on South Concho River from a point about 2.0 miles upstream from gaging station at Christoval, Tex., to a point 12 miles downstream and above backwater from Lake Nasworthy. These measurements were made to determine seepage gains or losses in the reach. The gaging stations on South Concho River at Christoval and on South Concho Irrigation Company's Canal at Christoval indicated that there had been no appreciable change in stage for several days prior to the investigation. Just prior to the investigation the reach was inspected by airplane and no inflow from tributaries or diversions other than South Concho Irrigation Company's Canal were observed.

Date 1953	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 18	South Concho R	2.1 mi south of Christoval	0	79	4.98			
18	South Concho Irrig. Co. Canal	At Christoval - gaging station	1.9				0.34	Computed by weir formula.
18	South Concho R	At Christoval - gaging station	2.0	82	3.12			Gravel bed.
18	South Concho R	1.9 mi north of Christoval	4.8	83	3.39			Rock bed.
18	South Concho R	5.9 mi, north of Christoval	9.0	83	1.92			Gravel bed.
18	South Concho R	10 mi south of San Angelo	12.0		0			

Concho River **March 1918**

Reaches: South Concho River, from Christoval to confluence with North Concho River at San Angelo, Tex.
Middle Concho River, from San Angelo-Mertzon road crossing to the mouth
Spring Creek, from a point just above Seven Springs to the mouth
North Concho River, from Sterling City to confluence with South Concho River
Concho River, from confluence of North and South Concho Rivers to mouth

Seepage investigation on Concho River, including Spring Creek and North and South Concho Rivers, was made March 27 and 28, 1918. With the exception of the Middle Concho, numerous pumping plants are situated along each of the above streams and during the investigation there was a large amount of irrigating. This is the only factor that would affect results. Data were insufficient to warrant a correction of discharge for time interval, but in all the streams there was a constant stage previous to and at the time of the investigation so that correction for time interval was in most cases not necessary.

In Spring Creek there was a gain of 10 cfs in a distance of 27 miles. Above Spring Creek the Middle Concho was dry, but from the mouth of Spring Creek to the confluence with South Concho River there was a gain of 2 cfs in 2 miles. The North Concho from Sterling City to Water Valley showed a gain of 1.0 cfs, but from Water Valley to the mouth there was a loss of 2.0 cfs. In the South Concho from Christoval to the confluence with the North Concho there was a gain of 12 cfs in 20 miles. In the main Concho there was a gain of 5 cfs, but throughout the lower half of the river's course the measurements show there was a seepage loss. From the gaging station near San Angelo to the Paint Rock gage there are 10 dams and reservoirs which affect the accuracy of a seepage investigation. Interpretations of the measurements on the main Concho are therefore somewhat doubtful.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	South Concho River, from Christoval to confluence with North Concho River							
Mar. 27	Christoval Canal	At Christoval	0				9.7	
27	South Concho R	300 ft below Christoval Canal	0		3.4			
27	Pecan Creek	At mouth	9			0		
28	South Concho R	Just above Middle Concho R	11.8		6.0			
28	Middle Concho R	At mouth	12			3.9		
28	South Concho R	1/2 mi below Middle Concho R	12.5		20.5			
28	Hank pump	At Metcalfe Lake 1/2 mi above diversion	15				2.7	Computed from pump capacity.
28	Metcalfe Canal	3-1/2 mi below Middle Concho R	15.5				12.0	At headgate.
28	South Concho R	Just below Metcalfe diversion dam	15.5		0			
28	South Concho R	At Christoval road crossing	16.5		.4			

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	South Concho River, from Christoval to confluence with North Concho River, continued							
Mar. 28	Lovelace pump	1/4 mi below Christoval road crossing	16.8				.9	
28	San Angelo L&P pump	1/2 mi above mouth of So. Concho	19.3				1.2	Computed from pump capacity.
28	South Concho R	Just below San Angelo L&P Co. dam	19.3		1.0			Estimate.
28	South Concho R	At mouth	19.8		3.8			Springs contribute flow.
	Check data on South Concho River in April 1918							
Apr. 27	South Concho R	Just above Middle Concho R	11.8		2.0			
27	Middle Concho R	At mouth	12			1.8		
27	South Concho R	3/4 mi below Middle Concho R	12.8		6.0			
27	Metcalfe Canal	3-1/2 mi below Middle Concho R	15.5				5.2	
	Middle Concho River, from San Angelo-Mertzon road crossing to the mouth							
Mar. 27	Middle Concho R	At San Angelo-Mertzon road crossing	0		0			
28	Middle Concho R	At mouth	22		3.9			
	Spring Creek, from a point just above Seven Springs to the mouth							
Mar. 27	Spring Creek	Just above Seven Springs	0		1.9			
27	Spring Creek	Just below Seven Springs	0		9.9			
27	Mertzon Canal	At Mertzon	3				9.3	
27	Spring Creek	100 ft below Mertzon Canal	3		0			
27	Return flow from Mertzon Canal	1500 ft below Mertzon Canal	3.4			.2		Estimate.
27	Spring Creek	1500 ft below Mertzon Canal	3.4		.2			Estimate.
27	Spring Creek	1/4 mi north of Sherwood	7		.5			Estimate - no pumping above.
27	Spring Creek	At Sherwood - Tankersly road crossing	11		1.6			No flow in Lopez Creek.
27	Hager pump	1-1/2 mi south of Tankersly	16				.8	Estimate.
27	Spring Creek	Just below Hager pump	16		1.9			
27	Spring Creek	Just above Dove Creek	20		2.1			
27	Dove Creek	At mouth	20			4.2		
27	Mottel Canal	2 mi above mouth of Spring Creek	25				5.9	
27	Spring Creek	Just below Mottel Canal	25		.8			Estimate.
27	Spring Creek	At mouth	27		.8			Estimate.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	North Concho River, from Sterling City to confluence with South Concho River							
Mar. 27	North Concho R	At Sterling City	0		0.6			
27	Sterling Creek	3 mi below Sterling City - at mouth	3.0			0.5		Estimate.
27	North Concho R	300 ft below Sterling Creek	3.0		1.0			Estimate.
27	North Concho R	At Broome - 9 mi below Sterling City	9.0		0			
27	North Concho R	At Water Valley	20.0		1.3			Estimate.
27	Two pumps	1 mi below Water Valley	21.0				0	Not pumping.
27	North Concho R	At Carlsbad	27.0		2.0			Estimate.
27	North Concho R	3 mi below Carlsbad	30.0		0			
27	North Concho R	At mouth	48.0		0			
	Concho River, from confluence of North and South Concho Rivers to mouth							
Mar. 27	Concho R	At confluence of N and S Concho R	0		3.8			Measurement - good.
27	Concho R	At gaging station 1/4 mi below confluence	.2		5.1			Measurement - good.
28	Newton pump	Northeast of San Angelo	8.8				2.2	Computed from pump capacity.
28	Red Bank Creek	At mouth	9.2			0		
28	Pumping plant	Southwest of Miles	12.8				2.0	Computed from pump capacity.
28	Crownest Creek	At mouth	14			0		
28	Pumping plant	4-1/2 mi southwest of Miles	16				2.0	Computed from pump capacity.
28	Concho R	South of Miles	17		0			
28	Pumping plant	South of Miles	17.1				2.2	Computed from pump capacity.
28	Concho R	4 mi south of Miles	18		1.5			Estimated.
28	Lipan Creek	At mouth	26.5			0		
28	Kickapoo Creek	At mouth	31.5			0		
28	Concho R	At gaging station 2 mi west of Paint Rock	32		.7			Estimated.
28	Concho R	At mouth	51.5		0			

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Concho River — February 28 to March 20, 1925

Reaches: South Concho River, from a point just below main springs, 5 miles above Christoval, Tex. to the mouth.
Middle Concho River, from Kiowa Creek to mouth.
Spring Creek, from Seven Springs above Mertzon to mouth.
Dove Creek, from a point about 9 miles above Knickerbocker to mouth.
North Concho River, from a point above Sterling City to confluence with South Concho River.
Concho River, from confluence of North and South Concho Rivers to mouth.

The purpose of this investigation was to determine gains and losses of flow in the river reaches listed above in the Concho River watershed. The area covered is the same as that investigated in 1918; however, the river miles distance at some of the sites are revised in this report. During this investigation the stream flow was practically constant and time interval was neglected.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	South Concho River, from a point just below main springs, 5 miles above Christoval, Tex. to the mouth							
Mar. 12	South Concho R	At Main Springs - 5 mi above Christoval	0		10.7			No flow above springs.
12	Mill Spring	1 mi above Christoval	4			2.4		
12	Christoval Canal	At Christoval - 5 mi below Main Springs	5				8.0	
12	South Concho R	At Christoval - below Christoval Dam	5		21.6			
13	Return flow from Christoval Dam	4 mi below Christoval	9.1			1.8		
13	Pecan Creek	At mouth - just above Broome Dam	14.4			0		
13	Diversion at Broome Dam	500 ft below Pecan Creek	14.4				19.6	
13	South Concho R	Just below Broome Dam	14.4		8.4			
13	Return flow from Broome Dam	2 mi below Pecan Creek	16.4			7.1		
13	Return flow from Broome Dam	2.3 mi below Pecan Creek	16.7			5.4		
14	South Concho R	At new City Dam - 4 mi above mouth	20.8		19.6			
16	South Concho R	At new City Dam - 4 mi above mouth	20.8		22.3			Less diversions upstream.
16	South Concho R	At mouth	24.8		19.4			

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Discharge, in cfs: Tributary	Discharge, in cfs: Diversion	Remarks
	Middle Concho River, from Kiowa Creek to mouth							
Mar. 10	Middle Concho R	Mouth of Kiowa Creek	0		0.1			Kiowa Creek dry.
10	Middle Concho R	Mouth of Liveoak Draw	6.8		0			Liveoak Creek dry.
10	Middle Concho R	7.8 mi below Kiowa Creek	7.8		0			
10	Middle Concho R	8.5 mi below Kiowa Creek	8.5		.3			Estimate.
10	Middle Concho R	11.6 mi below Kiowa Creek	11.6		0			
10	Middle Concho R	13.1 mi below Kiowa Creek	13.1		.9			
10	Middle Concho R	Near Arden - 2 mi above San Angelo-Mertzon road crossing	23.7		1.0			No flow in Dry Creek.
11	West Rocky Cr	At mouth	26.8			0.7		
11	Middle Concho R	Just above East Rocky Creek	29.7		1.2			
11	Middle Concho R	At Baucum Dam	36.5		.1			No diversions.
11	Middle Concho R	At 12 Mile Bridge	38.2		0			No diversions.
11	Middle Concho R	½ mi above Spring Creek	45.2		2.1			Gravel bed - seepage.
11	Middle Concho R	Just below Spring Creek	45.7		7.3			
11	Middle Concho R	At mouth	47.7		0			Gates at Dam ½ mi upstream had just been closed.
	Spring Creek, from Seven Springs above Mertzon to mouth							
Mar. 6	Spring Creek	Just above Seven Springs	0		.7			Estimate.
6	Spring Creek	Just below Seven Springs	.1		12.2			
6	Mertzon Canal	At Mertzon	3				7.8	
6	Spring Creek	At Mertzon - below Mertzon Canal	3		5.4			
6	Middle Ditch Diversion	1½ mi below Mertzon	4.5				2.7	
7	Spring Creek	3.7 mi below Mertzon	6.7		7.5			At Lee's Dam.
7	Spring Creek	At Sherwood-Tankersley crossing	10.6		8.0			
7	Spring Creek	2.2 mi above Tankersley	14.3		4.4			
7	Spring Creek	1.2 mi above Russell Dam	16.5		4.8			
7	Spring Creek	Just below Russell Dam	17.7		0			Gates at Dam closed.
9	Spring Creek	.1 mi above Dove Creek	18.7		.8			
9	Elliott Pump	.2 mi below Dove Creek	19.0				3.1	
9	White Pump	.8 mi below Dove Creek	19.6				1.9	
9	Mottel Canal	1 mi below Dove Creek - at Dam	19.8				6.2	Old Lackey Dam.
9	Spring Creek	Just below Mottel Dam	19.9		.2			
9	Spring Creek	3.9 mi below Dove Creek	22.7		2.4			
9	Spring Creek	At mouth	26.5		4.6			
11	Spring Creek	500 ft above mouth	26.5		4.2			Check measurement.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Dove Creek, from a point about 9 miles above Knickerbocker to mouth.							
Mar. 4	Dove Creek	Just below spring source	0		13.0			
4	Diversion Canal	Just above Stillson Dam	.9				11.7	
4	Dove Creek	Just below Stillson Dam	1.1		.7			
4	Diversion Canal	Just above San Jose Dam	3.9				4.1	
4	Dove Creek	½ mi below San Jose Dam	4.4		8.6			
5	Dove Creek	½ mi below San Jose Dam	4.4		7.6			
5	Diversion Canal	Just above Baze Dam	8.5				4.5	
5	Dove Creek	At Knickerbocker	8.7		8.9			
5	Dove Creek	Just above mouth	11.8		8.4			
	North Concho River, from a point above Sterling City to confluence with South Concho River							
Feb. 28	North Concho R	2 mi above McIntyres Dam	0		0			
28	North Concho R	At McIntyres Dam	2		.2			Estimate.
28	McIntyres Pump	1½ mi below Dam	3.5				0	Not pumping.
28	North Concho R	At McIntyres Pump	3.5		1.2			
28	North Concho R	½ mi above Sterling City	11.6		1.4			
28	North Concho R	At Sterling City - below Santa Fe Pump	12.1		1.2			Pump in operation.
28	North Concho R	8.4 mi above Water Valley	23.5		1.0			
Mar. 2	North Concho R	5.0 mi above Water Valley	26.9		1.9			
2	North Concho R	.6 mi above Water Valley	31.3		3.2			
3	North Concho R	Near Carlsbad - gaging station	37.0		3.9			Constant stage.
3	North Concho R	8.8 mi above San Angelo	45.6		3.1			Gravel beds.
17	North Concho R	*At San Angelo - gaging station	54.4		*2.5			Constant stage.
17	North Concho R	½ mi above mouth	55.3		2.3			
	*Discharge	Mar. 3 - 2.5 cfs						
	Concho River, from confluence of North and South Concho Rivers to mouth							
Mar. 17	Concho River	At gaging station near San Angelo	0		22.3			
17	Boyd Pump	1 mi below confluence	1.0				1.5	
17	Kaisers Pump	7.2 mi below confluence	7.2				3.1	
17	McDonald Pump	7.4 mi below confluence	7.4				1.0	
17	Concho River	8.0 mi below confluence	8.0		16.4			
18	Hart Pump	13 mi below confluence	13				1.2	
18	Lackey Pump	13 mi below confluence	13				2.1	
18	Concho River	14 mi below confluence - at Mullins crossing	14		10.0			

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
	Concho River, from confluence of North and South Concho Rivers to mouth, continued							
Mar. 18	Richard Pump	.4 mi below Mullins crossing	14.4				1.0	
18	Ollie May Pump	1.0 mi below Mullins crossing	15.0				2.2	
18	Davis No. 1 Pump	1.5 mi below Mullins crossing	15.5				2.2	
18	Davis No. 2 Pump	1.6 mi below Mullins crossing	15.6				1.8	
18	Rackett Pump	1.6 mi below Mullins crossing	15.6				1.6	
18	Concho River	2.0 mi below Mullins crossing at Rackett Dam	16.0		1.5			Estimate.
18	Concho River	3 mi below Mullins crossing south of Miles	17.0		4.4			
19	Concho River	3 mi below Mullins crossing south of Miles	17.0		11.1			
19	Allen No. 1 Pump	17.1 mi below confluence	17.1				1.9	
19	Kenedy Pump	17.1 mi below confluence	17.1				1.8	
19	Balcom Pump	17.6 mi below confluence	17.6				1.0	
19	Allen No. 2 Pump	17.6 mi below confluence	17.6				1.5	
19	Reed Pump	17.8 mi below confluence	17.8				3.4	
19	Concho River	18.0 mi below confluence	18.0		1.5			Estimate.
19	Concho River	18.5 mi below confluence	18.5		0			
19	Concho River	20.4 mi below confluence	20.4		0			
19	Concho River	25 mi below confluence at Rowena-Merata crossing	25.7		0			
20	Lipan Creek	28.4 mi below confluence	28.4			0		
20	Concho River	34.0 mi below confluence at Simm Dam	34.0		.2			Estimate.
20	Concho River	At gaging station near Paint Rock	37.0		.7			Estimate - constant stage.
20	Concho River	At mouth	54.5		1.6			Estimate.

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

North Concho River May 25-26, 1918

Reach: From a point 13 miles above Sterling City to confluence with South Concho River at San Angelo, Tex.

During the investigation the river was at a constant stage and discharge represents the natural conditions.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
May 25	North Concho R	At McIntyres Dam - 13 mi above Sterling City	0		0.2			Estimate - 300 ft below dam.
25	North Concho R	0.75 mi below McIntyres Dam	0.75		1.2			
25	McIntyres ditch	Near pumping plant	1.0				2.3	8" pump - 25' lift.
25	North Concho R	11 mi above Sterling City	3.0		.3			
25	North Concho R	0.5 mi above Slaton Dam	4.0		.1			
25	Slaton ditch	Near pumping plant	4.0				.2	
25	North Concho R	Below Slaton Dam	4.5		.2			Estimate. Seepage under dam.
25	North Concho R	1 mi above Byers Dam	6.5		.0			
25	Byers ditch	At flume	7.0				1.8	West pump only.
25	North Concho R	Below Byers Dam	7.5		.1			Estimate. Seepage under dam.
25	James Dailey ditch		9.0				.0	Not pumping.
25	North Concho R	Below James Dailey pump	9.0		.3			Measurement, fair.
25	H. K. Ray ditch	At flume	9.2				.4	
25	Allen ditch		9.5				.3	
25	A. C. Pierson ditch		9.5				.0	Not pumping.
25	North Concho R	Below Allen and Pierson pumps	9.5		.2			Estimate.
25	Ray and Johnson pumps		11.0				.0	Not pumping.
25	North Concho R	Just above Johnson pump	11.0		.2			Estimate.
25	Henry Bode pump		13.0				.0	Not pumping.
25	North Concho R	At Henry Bode pump	13.0		.1			Estimate.
25	North Concho R	At Sterling City	14.0		.0			
25	North Concho R	6 mi below Sterling City	20.0		.0			
25	North Concho R	9 mi below Sterling City	23.0		.0			
25	North Concho R	10 mi below Sterling City	24.0		.3			Estimate.
25	North Concho R	18 mi below Sterling City	32.0		.0			
25	North Concho R	25 mi below Sterling City	39.0		.0			
25	North Concho R	1.5 mi above Water Valley	44.0		.9			Measurement rated, good.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 13 miles above Sterling City to confluence with South Concho River at San Angelo, continued							
May 26	North Concho R	At Water Valley	45.0		1.8			
26	North Concho R	0.5 mi below Water Valley	45.5		2.7			
26	Trodden and Nell pumps	1.5 mi below Water Valley	46.5				0.0	Not pumping.
26	North Concho R	Road crossing - 7½ mi below Water Valley	51.5		1.7			
26	Carlsbad Sanitarium	At Carlsbad	56				.1	
26	North Concho R	At Carlsbad	56		1.5			Below Sanitarium Dam
26	North Concho R	0.5 mi below Carlsbad	56.5		1.5			Below 2nd pump.
26	North Concho R	4.5 mi below Carlsbad	60.5		1.3			
26	North Concho R	9 mi below Carlsbad	65		.0			
26	North Concho R	11 mi above San Angelo	66		.2			Estimate.
26	North Concho R	6 mi above San Angelo	71		.1			Estimate.
26	North Concho R	At San Angelo gaging station	77		.2			
26	North Concho R	At mouth	78		.2			Estimate.

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

San Saba River March 29-31, 1918

Reach: From Fort McKavett Springs near Fort McKavett, Tex. to mouth.

The low-flow investigation on San Saba River was carried on from March 29 to 31. From McKavett Springs to the Rector Dam and Canal at San Saba, natural conditions were found. Owing to lack of sufficient data, results below the Rector Dam are doubtful.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Mar. 29	San Saba River	1 mi below Fort McKavett Springs	0		8.6			
29	Rocky Creek	At mouth	10			0.5		Estimate.
29	Clear Creek	At mouth	13			11.9		
29	San Saba River	.8 mi below Clear Creek	13.8		26.7			
29	Ellis pump	1 mi below Clear Creek	14				5.2	
29	Russell pump	2½ mi above Menard	18.5				2.6	
29	Las Moras Creek	At mouth	20.5			.8		Estimate.
29	San Saba River	At Menard - gaging station	21		21.7			
30	Kitchen Canal	5 mi below Menard	26				4.4	
30	McWilliams Canal	10 mi below Menard	31				2.4	
30	San Saba River	At Hext-Brady crossing	41		30.9			
30	San Saba River	At Brady-Camp San Saba crossing	56		28.0			
30	San Saba River	Just above mouth of Brady Creek	76		34.9			
30	Brady Creek	At mouth	76			1.7		
30	San Saba River	At Dorans Ranch 5 mi below Brady Creek	81		34.0			
30	Sloans Springs	At mouth 7 mi below Brady Creek	83			4.7		
30	Jobs Creek	At mouth	87			0		
30	Wallace Creek	At mouth	90			0		
30	Harkey pump	½ mi above railroad bridge west of San Saba	91				3.4	
30	Gunter pump	½ mi below railroad bridge west of San Saba	92				2.2	
30	Richland Creek	At mouth	92.1			0		
30	Young Pierce pump	1 mi above gaging station near San Saba	94				1.1	

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Fort McKavett Springs near Fort McKavett, Tex. to mouth, continued.							
Mar. 30	San Saba River	Near San Saba - gaging station	95		33.0			
30	Rector Canal	½ mi above Mill Creek	97.5				2.5	
31	San Saba River	Just below Rector Dam	97.6		32.5			
30	Mill Creek	At mouth	98			22.9		Computed from differences.
30	San Saba River	3/4 mi below Mill Creek	98.8		55.4			
30	Becker pump	1 mi below Mill Creek	99				1.8	
31	San Saba River	At mouth	105		23.0			

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

San Saba River July 27-29, 1933

Reach: From a point just above Fort McKavett, Tex. to Brady Creek.

During the investigations the river was at a constant stage, and measurements represent natural conditions.

Date 1933	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
July 27	San Saba River	¼ mi above Fort McKavett	0		9.7			
27	Government Spring	At mouth near Fort McKavett	.5			2.0		
27	San Saba River	At first Fort McKavett-Menard crossing	1.0		14.2			
27	Mears Pump	4 mi below Fort McKavett	4.0				1.7	
27	McKnight Pump	6 mi below Fort McKavett	6.0				1.9	
27	San Saba River	8 mi below Fort McKavett	8.0		11.1			
27	Rocky Creek	At mouth	10.0			.2		Estimate.
27	Clear Creek	At mouth	13.0			14.1		
27	San Saba River	½ mi below Clear Creek	13.5		25.1			
27	San Saba River	Just above Noyes Canal	17.0		24.4			
28	Noyes Canal	At Menard	17.0				0	
28	Waddell Pump	Below Noyes Canal head gate	17.8				0	
28	Placker Pump	2 mi above Menard	19.0				2.1	
28	San Saba River	At Menard - gaging station	21.0		20.7			
28	San Saba River	At 5 mi crossing on Menard-Mason road	26.0		21.8			
28	Kitchen Canal	5½ mi below Menard	26.5				9.9	Pumping 27th and 28th.
28	San Saba River	At second Menard-Mason crossing	31.0		7.9			Pump upstream not pumping.
28	San Saba River	At Mathews Tract	35.0		5.3			No pumps operating.
28	San Saba River	At Brady-Hext crossing	41.0		2.2			
28	San Saba River	9 mi below Brady-Hext crossing	50.0		1.4			
28	Calf Creek	At mouth 10 mi below Brady-Hext road	51.0			0		
29	San Saba River	Near Camp San Saba	60.0		1.5			
29	San Saba River	¼ mi above Voca	64.0		2.1			
29	San Saba River	¼ mi above Lost Creek	69.0		2.0			
29	Lost Creek	At mouth	69.3			.2		Estimate.
29	San Saba River	At Campbell crossing 4 mi below Lost Creek	72.0		1.3			
29	Deer Creek	At mouth	73.0			0		
29	San Saba River	At Deer Creek	73.0		0			
29	Deep Creek	At mouth	78.5			0		River starts flowing 3 mi above Brady Creek.

Date 1933	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point just above Fort McKavett to Brady Creek, Continued							
July 29	San Saba River	Just above Brady Creek	80.0		18.3			
29	Brady Creek	Just above mouth	80.0			4.5		
29	San Saba River	Just below Brady Creek	80.1		22.8			Obtained by addition.

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

San Saba River — February 20-21, 1940

Reach: From a point below Fort McKavett, Tex. to stream-gaging station at Menard, Tex.

A series of discharge measurements was made during the period February 20-21, 1940, on the San Saba River and its tributaries and diversions, Tex., between a point 1 mile northeast of Fort McKavett and the gaging station at Menard, 20.9 miles downstream, to determine the seepage gains or losses. The investigation was made during a period of constant stage of the river. All flowing tributaries were measured. Determination of gain or loss represent normal conditions except the apparent gain of 4.4 second-feet from above Noyes Canal to the Menard gaging station. The discharge of Noyes Canal at the gaging station on the Canal at Menard on this date was 22.7 second-feet, or 4.1 second-feet less than at the headgates. This loss of 4.1 second-feet from the Canal presumably returns to the river above the river gage at Menard and essentially accounts for this apparent gain of 4.4 second-feet.

Date 1940	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Discharge, in cfs: Tributary	Discharge, in cfs: Diversion	Remarks
Feb. 20	San Saba River	At first McKavett-Menard crossing	1		23.8			Gravel beds.
20	San Saba River	At third McKavett-Menard crossing	6.7		20.8			Rock channel - no pumping.
20	Rocky Creek	At road crossing about 1 mi above mouth	10.0			1.3		Estimate.
20	Clear Creek	150 ft above mouth	12.5			18.2		
20	San Saba River	¼ mi below Clear Creek	12.7		44.9			Rock channel.
20	Dry Creek	600 ft above mouth	12.8			0		
21	San Saba River	At dam-site 6½ mi above Menard	15.4		44.7			Gravel and rock channel.
21	San Saba River	At 4-mi crossing ½ mi above Noyes Canal	17.0		42.9			Earth channel.
21	Noyes Canal	At headgate - 4 mi above Menard	17.9				26.8	
21	Coglin Creek	At mouth	18.1			1.2		
21	Las Moras Creek	At road crossing 1 mi above Menard	21.3			.2		Estimate.
21	Celery Creek	1,000 ft above mouth	21.7			1.4		Estimate.
21	San Saba River	At Menard- gaging station	21.9		23.3			Constant stage.

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

San Saba River November 17-18, 1921

Reach: From damsite near Dorans Ranch to gaging station near San Saba, Tex.

During the investigation the river was at a constant stage and discharges represent the natural conditions. No flow of consequence was found in tributaries not shown in the table of measurements.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
1921					Main Stream	Tributary	Diversion	
Nov. 17	San Saba River	At damsite at Dorans Ranch 20 mi above San Saba	0		25.0			
18	Fleming Spring	At Fleming Ranch near San Saba	1			3.0		Estimate.
18	Sloan Spring	At road crossing near San Saba	2			5.3		
18	Wallace Creek	At road crossing near San Saba	9			2.1		
18	Richland Creek	At mouth	11			0		
18	San Saba River	Near San Saba - gaging station	14		34.5			

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Brady Creek March 29, 1918

Reach: From Brady, Tex. to mouth

During the investigation the creek was at a constant stage and discharges represent the natural conditions.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
1918					Main Stream	Tributary	Diversion	
Mar. 29	Brady Creek	At Brady	0		0			
29	Brady Creek	8 mi south of Rochelle	13		1.0			
29	Brady Creek	At mouth	28		1.7			

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Llano River — March 31 to April 3, 1918

Reaches: South Llano River, from a point above Telegraph, Tex. to confluence with North Llano River.
Llano River, from Junction, Tex. to the mouth.

The low-flow investigation in the Llano River basin included the South Llano River and the Llano River from Junction to the mouth. From the mouth of Big Paint Creek to the confluence with the North Llano River there was practically no gain or loss in the South Llano River. On the Llano River in the reach from the gaging station near Junction to Beaver Creek there was a loss of 10 cfs; from Beaver Creek to Little Llano River there was a gain of 28 cfs; and a loss of 7 cfs from Little Llano River to the mouth, with a net gain of 11 cfs from the junction of North and South Llano Rivers to the mouth of the Llano River, a distance of 105 miles.

Data were insufficient to warrant a correction of discharge for time interval, but prior to and during the period of each investigation the stage was practically permanent so that a correction for time interval was generally not necessary.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	South Llano River, from a point above Telegraph to confluence with North Llano							
Apr. 1	Big Paint Creek	At mouth about 3 mi below 700 Springs	0			23.1		
1	South Llano R	½ mi below Paint Creek	.5		34.8			
1	Theo Hunger Pump	2 mi below Telegraph	4.0				1.9	
1	Llano Land & Irrigation Co. Pump	6 mi above Junction	13.0				7.0	
1	Cedar Creek	At mouth	18.5			1.0		Estimate.
1	South Llano R	At mouth just above North Llano R	19.0		29.2			
	Llano River, from Junction to the mouth							
Apr. 1	South Llano R	Just above North Llano River	0		29.2			
1	North Llano R	At mouth	0			1.8		
1	Llano River	3 mi below Junction - gaging station	3		42.6			
2	Neal Pump	3/4 mi above Johnson Fork	6.2				.5	Estimate.
2	Westervelt Pump	1/2 mi above Johnson Fork	6.5				.8	Estimate.
2	Johnson Fork	At mouth - 7 mi below Junction	7.0			7.5		

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Llano River, from Junction to the mouth, continued							
Apr. 2	Llano River	Just below Johnson Fork	7.0		47.9			
2	J. W. White Pump	At Damtown	19.5				1.8	
2	Llano River	Due south of London - at Damtown	20		42.5			
2	Llano River	3 mi SE of Streeter	35		40.2			
3	James River	At mouth	43			0.5		
3	Llano River	Just below James River	43		42.3			
3	Comanche Creek	At mouth	51			0		
3	Llano River	½ mi above Beaver Creek	54		37.4			
3	Beaver Creek	At mouth	54.5			.5		
3	Willow Creek	At mouth	55.5			0		
3	Llano River	At Castell	64		45.3			
3	Hickory Creek	At mouth	72.5			0		
3	Llano River	9 mi above Llano	73.5		50.8			
Mar. 31	Llano River	3/4 mi above Llano Dam	82		56.4			
31	Llano River	1/4 mi below Llano Dam (Temporary gage)	83		65.7			
Apr. 1	Little Llano R	At mouth	90.5			0		
1	Llano River	Just above Miller Creek near Lone Grove	92		65.7			
1	Miller Creek	At mouth	92			.1		
1	Honey Creek	At mouth	102			0		
1	Llano River	At mouth near Kingsland	106		58.8			

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Llano River　　　　February 6-21, 1925

Reaches: North Llano River, from a point 10.2 miles above Roosevelt to Junction, Tex.
South Llano River, from a point just below confluence of West and South Forks to the mouth.
Johnson Fork Llano River, from headwater springs 8.3 miles above Segovia to mouth.
Llano River, from confluence of North and South Forks to the mouth.

During these investigations the rivers were at a constant stage and discharge represents the natural conditions.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	North Llano River, from a point 10.2 miles above Roosevelt to Junction, Tex.							
Feb. 7	North Llano R	At road crossing 10.2 mi above Roosevelt	0		0			
7	North Llano R	8.1 mi above Roosevelt	2.1		12.7			Rock channel.
8	North Llano R	At Roosevelt	10.2		15.5			
8	Menard Creek	At mouth 1.6 mi below Roosevelt	11.8			3.7		
8	North Llano R	1.9 mi below Roosevelt	12.1		19.0			
8	Copperas Creek	5.0 mi below Roosevelt at road crossing	15.2			2.8		
9	North Llano R	At Copperas School 5.8 mi below Roosevelt	16.0		22.0			
9	Bois D'Arc Creek	At mouth .7 mi below Copperas School	16.7			.2		Gravel channel.
9	North Llano R	Just below Bois D'Arc Creek	16.7		21.9			
9	North Llano R	At road crossing 10.8 mi below Roosevelt	21.0		21.9			Gravel channel.
9	North Llano R	At road crossing 6.8 mi above Junction	25.0		22.8			
10	Bear Creek	At mouth 5.6 mi above Junction	26.2			3.3		
10	North Llano R	Near Junction - gaging station	27.3		25.6			
14	North Llano R	At mouth near Junction	31.8		16.9			
	South Llano River, from a point just below confluence of West and South Forks to the mouth							
Feb. 10	South Llano R	Just below confluence of West and South Forks	0		.5			Estimate.
10	South Llano R	24.2 mi above Junction	1.7		2.0			Estimate.
11	Unnamed Spring	23.2 mi above Junction	2.7			8.9		

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	South Llano River, from a point just below confluence of West and South Forks to the mouth, continued							
Feb. 11	South Llano R	23.2 mi above Junction and 1.1 mi above 700 Springs	2.7		15.7			Rock channel.
11	South Llano R	.2 mi below 700 Springs	3.8		32.6			
12	South Llano R	Just above Paint Creek	6.7		32.7			No pumping above.
12	Big Paint Creek	At mouth 19.2 mi above Junction	6.7			36.5		
12	South Llano R	.3 mi below Big Paint Creek	7.0		67.8			
12	South Llano R	At Telegraph	8.6		66.4			
13	South Llano R	Just below Chalk Creek	16.4		72.3			
13	Cedar Creek	½ mi above mouth at Junction	25.4			2.2		
14	South Llano R	At mouth at Junction	25.9		74.8			
	Johnson Fork Llano River, from headwater springs 8.3 miles above Segovia to mouth							
Feb. 6	Johnson Fork Llano	At springs 8.3 mi above Segovia	0		1.9			800 ft below springs.
6	Johnson Fork Llano	7.4 mi above Segovia	.9		8.9			
6	Joy Branch	4.4 mi above Segovia	3.9			1.4		Estimate.
6	Johnson Fork Llano	Just below mouth of Joy Branch	4.0		13.8			Springs in channel above.
6	Johnson Fork Llano	At road crossing 3 mi above Segovia	5.3		14.6			
7	Johnson Fork Llano	At road crossing 1.6 mi above Segovia	6.7		14.8			Gravel bed.
7	Johnson Fork Llano	At road crossing 1.7 mi below Segovia	10.0		13.8			No diversions above.
7	Johnson Fork Llano	At road crossing 3.8 mi below Segovia	12.1		13.0			Gravel bed.
15	Johnson Fork Llano	.3 mi above mouth and 8.5 mi below Segovia	16.8		12.2			Water goes into gravel beds below this point.
	Llano River, from confluence of North and South Forks to the mouth							
Feb. 14	Llano River	At junction of North and South Forks	0		97.7			Gravel beds.
14	Llano River	1,000 ft below junction	.2		101			
14	Llano River	3 mi below junction - gaging station	3.0		101			
15	Johnson Fork	6.8 mi below junction	6.8			12.2		Seepage through gravel beds.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
	Llano River, from confluence of North and South Forks to the mouth, continued							
Feb. 15	Llano River	6.8 mi below junction	6.8		111			
15	Llano River	At Yates-London road crossing	15.0		107			
16	Bluff Creek	Southeast of Streeter	35.5			0.7		
16	Llano River	$1\frac{1}{2}$ mi below Bluff Creek	37.0		114			Rock channel.
16	James River	Near mouth and 9 mi SE of Mason	43.6			3.8		
17	Llano River	0.4 mi below James River	44.0		114			
17	Llano River	3/4 mi above Beaver Creek	54.2		118			Gravel channel.
17	Beaver Creek	About 0.3 mi aboye mouth	55.0			.7		
18	Llano River	At Castell-Mason road crossing	64.9		118			Gravel channel.
18	Llano River	At Castell - gaging station	69.7		122			Gravel channel.
19	Llano River	About 8 mi above Llano	74.7		114			
19	Llano River	3/4 mi above Llano	82.3		119			
20	Llano River	Just below dam at Llano	83.0		118			Sand and rock channel.
20	Little Llano R	At mouth	90.0			1.1		Estimate.
20	Llano River	3 mi below Little Llano River	93.0		116			Sand channel.
20	Miller Creek	At mouth	93.2			.1		Estimate.
21	Llano River	At old Llano-Kingsland road crossing	94.2		121			Sand channel.
21	Llano River	At Llano-Kingsland road crossing	98.7		120			
21	Llano River	At Kingsland - just above mouth	105		122			Sand channel.

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Llano River — September 3, 4, 1952

Reach: From gaging station near Junction to gaging station at Llano, Tex.

A series of discharge measurements was made during the period September 3, 4, 1952, on the Llano River and its major tributaries beginning at the gaging station near Junction, Tex., and continuing downstream to the gaging station at Llano, Tex., to determine and locate the seepage gains or losses. The investigation was made during a period of relatively constant stage of the river, and no diversions were observed in this section of the river.

Date 1952	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Sept. 3	Llano River	Near Junction - gaging station	0		16.8			
3	Johnson Fork	At road crossing 3.3 mi east of Junction	4			2.03		
3	Llano River	At road crossing 2.3 mi SE of Teacup	10		15.8			
4	Llano River	At Ranch Road 385, 3.8 mi NE of Teacup	16		13.6			
3	Llano River	At road crossing 10 mi SW of Mason	35		5.67			
3	James River	10 mi S of Mason, ½ mi above mouth	38			0		
3	Llano River	At road crossing 8.5 mi S of Mason	39		2.57			
4	Llano River	At U. S. Highway 87 crossing .5mi S of Hedwig	47		.73			
4	Llano River	At road crossing at Castell	59		.01			
4	Llano River	At road crossing 13.9 mi W of Llano	64		0			
4	Llano River	At road crossing 1.6 mi W of Llano	76		0			
4	Llano River	At Llano - gaging station	79		0			

LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Pedernales River   January 9-17, 1956

Reach: From a point 2 miles downstream from Harper, Gillespie County, to stream-gaging station near Johnson City, Blanco County, Tex.

Objective: For several years, a comprehensive hydrologic study of the interrelationships of surface and ground waters in various river basins in central and south Texas has been conducted by the U. S. Geological Survey, in cooperation with the State Board of Water Engineers. The objective of this investigation is to extend these studies into the Pedernales River basin and to evaluate the interchange of surface and ground waters in that basin.

This report shows the results of an intensive investigation of the low-flow characteristics of the Pedernales River during a drought period from a point near Harper, Gillespie County, to the U. S. Geological Survey-State Board of Water Engineers gaging station, 1.2 miles northeast of Johnson City, Blanco County.

SURFACE WATER INVESTIGATIONS

Conclusions: The Pedernales River system derives its low or base flow from the following:

1. Headwater springs issuing from the base of the Edwards limestone near Harper on the main stem and on most of the tributaries entering from the south.

2. Contributions from extensive areas of the Hensell sand member of Barnes (1948) enter the river principally from the north through tributaries and seepage to the large beds of alluvium along the river valley. Potentially, Barnes' Hensell sand member is the best aquifer in the Pedernales basin.

3. Springs and seeps originating in areas of faulting, jointing, and solution channeling in the Ordovician rocks (Palo Alto Creek to Blumenthal) and in the Pedernales dolomite member (at and below Stonewall),.

4. Springs that issue from the Tanyard formation in the North Grape Creek area.

This series of measurements indicate that the Pedernales River system loses only small amounts of water here and there throughout the 70 miles investigated and that these losses are principally due to evaporation, transpiration, and to irrigation pumpage. No area was found where losses of consequence could be attributed to seepage into the groundwater reservoirs.

Summary: During this investigation the flow of the Pedernales River was wholly from ground-water sources and no flood water was encountered at any time. Prior to the investigation on Dec. 1, 1955, a small rise occurred with a maximum discharge of 16 cfs (cubic feet per second) at the gaging station at Johnson City. The discharge had dropped to 5.3 cfs by December 11 and averaged about 5 cfs for the remainder of the month. During the first half of January 1956 the flow at Johnson City dropped from 4.8 to 3.3 cfs with a 1.0 cfs decline in flow during the period of this investigation. From January 9 to 16 the weather was dry with cold nights and warm sunny days. On January 17 the weather changed to cloudy with north winds and intermittent drizzle, and during the night of January 17-18 rain and sleet fell, amounting to more than an inch of precipitation over most of the watershed. A small amount of surface runoff resulted which caused the river discharge to rise from 3.3 to 11.0 cfs at Johnson City. The investigation was discontinued at this time due to the presence of an indeterminate amount of surface runoff in addition to a probable increase in base flow of the river.

At the time of this investigation, the farthest upstream flow of the Pedernales River system issued from springs near the base of the Edwards limestone. On the main stem of the river these springs are located a short distance downstream from Harper, Gillespie County, and were flowing at a rate of 0.3 cfs. The Edwards limestone, which caps the major drainage divides of the upper reaches of the Pedernales, contains many joints, fissures, and solution channels. Much of the rain which falls on the Edwards outcrop penetrates to the water table and eventually appears as surface flow through springs and seeps.

The flood plain of the Pedernales River contains large deposits of alluvium (gravel, sand and silt) which can absorb and store considerable water. The initial flow from the springs near Harper and the inflow from Scott Branch, about 0.15 cfs, is soon lost in the alluvial deposits as it progresses downstream, completely disappearing about 13 miles below Harper.

The Cap Mountain limestone member of the Riley formation crops out in the river channel at a point about 2 miles above Morris Ranch, and about 4 miles below the point where the initial flow disappeared. This outcrop forms a heavy rock ledge across the channel which acts as a dam across the beds of alluvium. No water was flowing over the rock outcrop at this point indicating that the alluvium beds were not full of water at this time. Numerous wells take water from the gravels, and transpiration losses occur through the trees and other vegetation that grows on the alluvium terraces.

All the tributaries entering from the south probably have headwater springs issuing near the base of the Edwards limestone, but Scott Branch was the only one having flow at its mouth. Wolf Creek has spring flow on both branches above State Highway 16 but was dry at its mouth. The combined flow in Wolf Creek amounted to 0.46 cfs (206 gallons per minute) and was all lost to pumping, evaporation, and transpiration before reaching the Pedernales. Four irrigation pumps were located on Wolf Creek with a combined capacity of about 1,600 gallons per minute with two of them pumping a total estimated 1,000 gallons per minute. These two pumps were taking water from a single large natural pool although one of the pump owners has four small dams on the creek. Wolf Creek was selected for complete investigation as an example of a typical tributary. The scope of the study did not include investigating all tributaries to source.

A short distance below the outcrop of the Cap Mountain limestone member the river starts to flow on the surface again.

From Morris Ranch to Palo Alto Creek the river flows through the southern edge of a large area of the Hensell sand member of Barnes (1948). This is the basal member of the Shingle Hills formation (Barnes, 1948), which forms the best and most extensive aquifer in the area, capturing a relatively high percentage of the rain which falls upon its surface. The peach orchards and peanuts cultivated in Gillespie County are grown on the pink and red Hensell sand member of Barnes (1948).

At the county road crossing south of Morris Ranch a flow of 0.1 cfs was found and 1 mile downstream it had increased to 0.4 cfs (180 gallons per minute). About 0.1 mile above State Highway 16, at the foot of a 3/4-mile long pool, only 0.1 cfs was found flowing. On the south bank and about 500 feet upstream from the foot of the pool, an irrigation pump was pumping an estimated 500 gallons per minute from the river. According to a local resident, this pool has never pumped dry and is reputed to have underground recharge. Very likely it is directly connected to the large beds of alluvium along the river valley and the reservoir is much more extensive than appears on the surface. Throughout this reach the gravel beds along the flood plain are large, with a number of gravel pits which invariably fill with water to river level when excavated below that elevation.

The flow gradually increases as it progresses downstream, to 0.6 cfs one mile above Live Oak Creek which was flowing 0.56 cfs at its mouth. About 1,000 feet below Live Oak Creek 1.10 cfs was measured in the river. Bear Creek, which enters from the south about 3.5 miles upstream from Live Oak Creek, was dry at its mouth but several small seeps were found along the north bank between Bear and Live Oak Creeks.

River flow measurements indicate very little fluctuation in discharge from Live Oak to Palo Alto Creeks with only small inflow from tributaries. Muesebach Creek was dry at its mouth and Barons Creek was flowing 0.05 cfs where it entered the river. Barons Creek has some flow through the town of Fredericksburg and had an estimated flow of 0.2 cfs at U. S. Highway 290. An irrigation pump was taking an estimated 400 gallons per minute from a pool behind a temporary dirt dam on Barons Creek about 3/4 mile below U. S. Highway 290. Another irrigation pump (4" intake) was located on the north bank of the river just upstream from Muesebach Creek. It pumps from a large gravel pit, but was not operating when observed. The pit is located about 200 feet from the river bank and its water surface appeared to be the same as that in the river. A 4-foot rock dam has been built across the river a few feet upstream from Palo Alto Creek. This dam forms a large pool on which are located two irrigation pumps. A 6" pump on the north bank was pumping an estimated 500 gallons per minute to irrigate a large field of winter grain. A 4" pump on the south bank was not pumping but had a pipe line to a surface storage pond (capacity about 10 acre-feet) from which a very large field (100 acres more or less) had been irrigated. A 2" electric pump was pumping (estimated 100 gallons per minute) from a shallow well into the surface tank. The well probably takes water from the large beds of river alluvium. Palo Alto Creek was contributing 0.02 cfs to the river. This was the total surface flow but very probably much more water is carried by underflow below the surface of the wide sand creek bed.

From Palo Alto Creek to Blumenthal the heavy beds of gravel in the river channel give way to Ordovician rocks from which rise a series of springs and seeps along faults and joints. The river discharge measured 1.36 cfs 1.6 miles above Palo Alto Creek, 1.98 cfs 0.5 mile below Palo Alto Creek, and 3.14 cfs 1.5 miles below Palo Alto Creek and near Blumenthal. Numerous seeps and small springs were observed along the channel below Palo Alto Creek and along the fault line just above Blumenthal.

From Blumenthal to Stonewall the river again crosses the alluvium beds associated with the Hensell sand member of Barnes (1948) and shows little variation in discharge through this reach. South Grape Creek had no surface flow at its mouth although there was a small flow just above the bridge on U. S. Highway 290. Some water may have been entering the river through the sand below the surface of the creek bed.

At Stonewall, where the Pedernales dolomite member of the Wilberns formation appears in the river channel, river flow increases to 3.95 cfs. This increase is associated with an area of intensive jointing and solution channeling in the dolomite which yields water to wells and springs in the Pedernales area. About 1.2 miles below Stonewall the river discharge decreased to 3.09 cfs, but it increased to 3.49 at a point 3.4 miles below Stonewall. About 3/4 mile below Stonewall the river crosses an area of faulted rock which may take some water from the river. Also, measuring conditions in this area are not good, and some of the apparent gain and loss may be due to inaccuracy of flow measurements.

A 3-mile stretch below Stonewall is the most heavily pumped area encountered along the Pedernales River. Four pumps, with an estimated total capacity of 2,000 gallons per minute, were located and 2 other pump sites were found where the pumps had been removed. Two pumps on the north bank were pumping from a small lake (formed by a concrete dam about 5 feet high). One was irrigating winter grain and the other was pumping into a small concrete-lined earthen tank about 500 feet from the river. Another pump (about 2") was pumping into this same tank from a shallow well about 300 feet from the river. The well had an open concrete-walled sump about 25 feet deep with the electric motor and pump at the bottom of this sump. The other two pumps take water from a second small lake (formed by a concrete dam about 4 feet high) about 1/2 mile below the 5-foot dam. The two pump sites, where the pumps had been removed, are located upstream from both of the small lakes.

From Stonewall to McDougals crossing the stream flows directly upon rock surfaces of the Riley and Wilberns formations and on the Oatman Creek granite of Stenzel (1932), in places partially disappearing into solution channels and sinks but reappearing and maintaining its quantity of flow downstream. About 3/4 mile above McDougals crossing (FM 1320) a flow of 3.37 cfs was measured. Fault-line springs and seeps were contributing minor amounts of water in the vicinity of McDougals crossing. From Stonewall to Johnson City, a distance of about 21 miles, the streambed falls about 380 feet, or an average of about 18 feet to the mile. Within this reach, the fall approaches 25 feet to the mile between Hye and North Grape Creek, a distance of about 10 miles.

Below McDougals crossing the streambed is of rock and some small losses probably occur in the zone of fracturing above and below the mouth of Rocky Creek. River-flow measurements indicate minor losses. A flow of 2.97 cfs was measured half a mile below Rocky Creek. This flow decreased to 2.65 cfs and 2.62 cfs at points 3 miles and 1 mile, respectively, above North Grape Creek. Rocky Creek contributed 0.05 cfs at its mouth.

The surface flow of North Grape Creek amounted to 0.53 cfs. Probably the total contribution of the creek is somewhat greater because of flow through the deep beds of sand at the mouth of the creek. North Grape Creek contributes the only inflow of consequence from Stonewall to Johnson City and derives its flow from headwater springs which issue from joints and solution channels in the Tanyard formation. River flow was measured at 3.66 cfs about 700 feet below North Grape Creek.

The discharge measurement below North Grape Creek was made late in the afternoon of January 17. Rain began a few hours after that measurement was completed. This rain caused sufficient surface runoff to make further measurements useless; therefore, the investigation was discontinued. The river flow of 3.3 cfs, as indicated at the gaging station near Johnson City, was determined from the continuous recorder record and is not the result of an actual discharge measurement.

Method of Investigation: The field work was done by a party of three, an engineer from the State Board of Water Engineers and a geologist and an engineer from the U. S. Geological Survey, during the period Jan. 9-17, 1956. The geologic maps of Gillespie and part of Blanco Counties, prepared by the Bureau of Economic Geology, University of Texas, were used as a guide to locating tributaries, road crossing, geologic formations, etc.

Measurements of streamflow were made at approximately 2-mile intervals on the main stream, and inflow from all tributaries was measured. Measurement sites were selected on impermeable material wherever possible to prevent underflow bypassing the measuring section. Unfortunately, such sites are scarce and, therefore, many measurements necessarily were made on gravel beds. The river was observed at many points where measurements were not made in order for the geologist to observe and study the geology. Geologic features were considered in the selection of measuring sites as well as channel conditions and the 2-mile interval. The scope of the study precluded investigating all tributaries upstream to their sources. Therefore, Wolf Creek was selected as a typical tributary to be completely studied.

Wherever pumps or pump sites were observed, the size of the pump was determined and a few pump owners were interviewed by the engineer from the State Board of Water Engineers. The pumps were mostly portable, being either trailer or tractor mounted. A few sites were found where the pumps had been removed for the winter. All irrigation systems observed were of the sprinkler type using aluminum pipe to transport the water, and some were operating to irrigate winter grain crops. Pumps and pump sites are shown in tables, but it is certain that there are others that were not observed. Therefore, those shown do not represent the total number pumping during the irrigation season.

In order to illustrate that variations in base flow were negligible during the period of study, a discharge hydrograph for the Johnson City gaging station is included as figure 1.

Streamflow measurements in this investigation range in accuracy from good (probably less than 5% in error) to poor (possible error may exceed 8%). This accuracy rating is estimated from the physical conditions of the measuring section. The better sections are on gravel or sand and the poorer ones on rock. In tables where rock is indicated in the measuring section, probably all the flow is represented, but where gravel is shown there is a possibility of an indeterminate amount of flow below the surface of the gravel deposit. Measurements were made on rock wherever possible, but rock channels do not ordinarily lend themselves to good or even fair (probable error less than 8%) measuring conditions and are particularly poor for measurement of small discharges.

GEOLOGY

General Setting: The Pedernales River system has been developed on a marginal portion of the Edwards Plateau where much of the original plateau surface has been removed by erosion. Along the main river channel are outcrops of rocks ranging in age from Precambrian to Recent. These rocks grade from coarse, poorly indurated sands and gravel through silt and clay to dense limestones and crystalline dolomites. The upper reaches of the channel are characterized by poorly indurated sand, gravel, silt, and clay of Cretaceous age. Denser rocks of Paleozoic age crop out at Morris Ranch, near Palo Alto Creek, and form most of the streambed from Stonewall to Johnson City. Alluvium is noticeably concentrated along portions of the stream where Cretaceous rocks crop out, whereas the streambed is generally scoured to bedrock where the channel cuts rocks of Paleozoic age.

Formations and their Water-Bearing Properties

Precambrian rocks: Rocks of Precambrian age are represented in the Pedernales area by the Oatman Creek granite of Stenzel (1932). According to Barnes (1952d), Stenzel's Oatman Creek granite consists of medium to coarsely crystalline pink to red aplogranite. The formation is relatively impermeable except, of course, where it might be fractured or weathered.

Cambrian rocks: The Cambrian rocks of the Pedernales River area have been divided into two formations, the Riley formation and the Wilberns formation. The lower or Riley formation has been divided into three members, in ascending order the Hickory sandstone member, the Cap Mountain limestone member, and the Lion Mountain sandstone member. The Hickory sandstone member consists of massive, crossbedded coarse-grained sandstone which grades upward into fine sandstone and shale. Cementation is generally poor. The Hickory does not crop out in the area, however, is relatively permeable

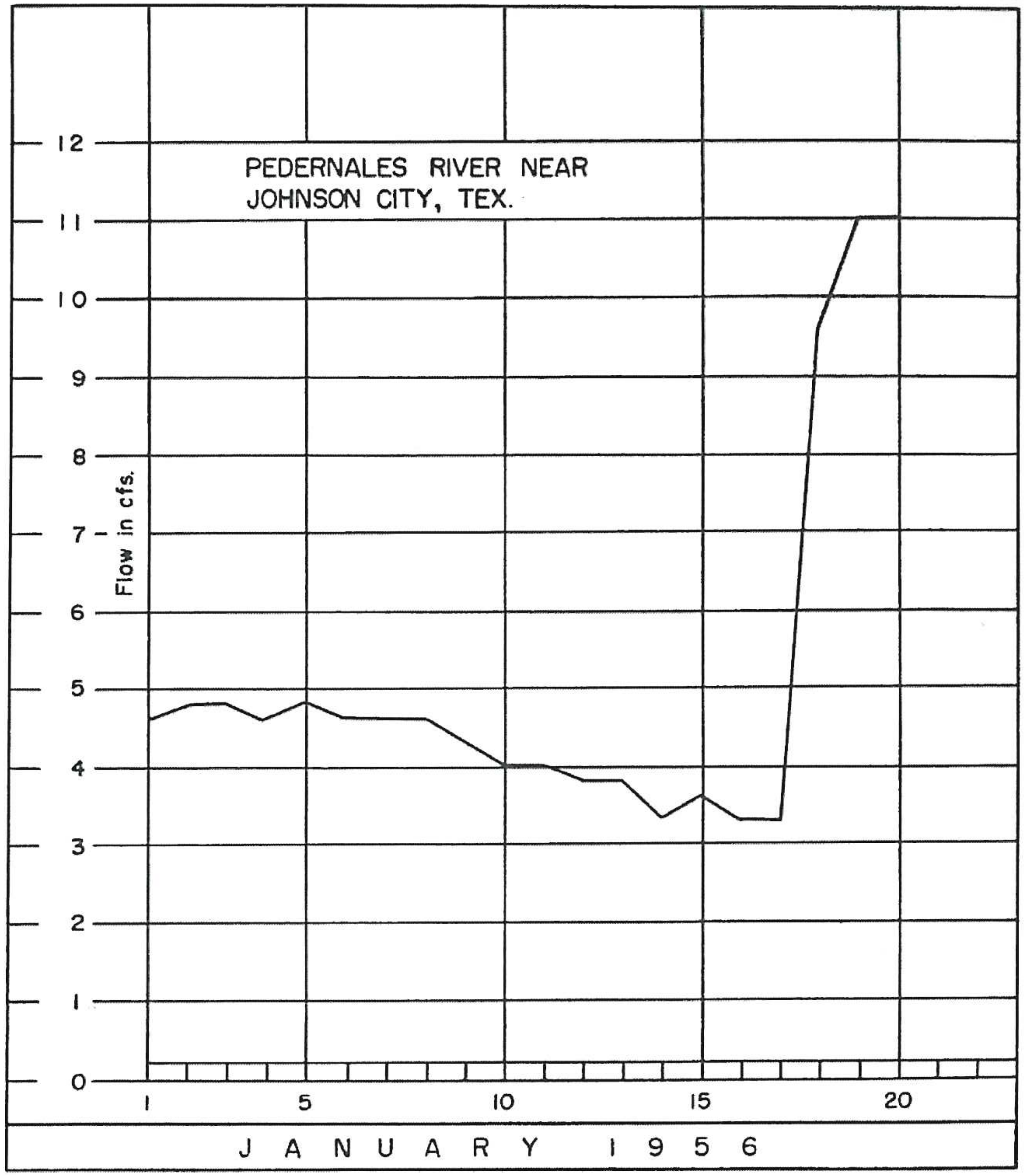

FIGURE 1.- DISCHARGE HYDROGRAPH, PEDERNALES RIVER NEAR JOHNSON CITY, TEX.

and yields water to wells in many places in the Pedernales River area and elsewhere in central Texas. The Cap Mountain limestone member consists of tightly cemented sandstones which grade upward into massive, solution-jointed limestones. Persistent silty zones are present near the top of the member. Water is obtained locally from joints and solution channels in this member. The Lion Mountain sandstone member of the Riley formation consists of highly glauconitic grey to brown sandstone. Its water-bearing properties are not known.

The Wilberns formation lies disconformably upon older rocks and is divided into five members. The basal or Welge sandstone member consists of poorly indurated light-brown nonglauconitic sand which during wet seasons becomes saturated. The Welge grades upward into the Morgan Creek limestone member which consists of relatively impermeable coarse to fine-grained greenish-gray limestone. The Point Peak shale member overlies the Morgan Creek member and consists of thin-bedded argillaceous limestone, fissile shale, and massive stromatolitic bioherms. It is relatively impermeable. The San Saba limestone member overlies the Point Peak and consists of thick-bedded hard limestone which grades laterally into the top member of the Wilberns formation, the Pedernales dolomite member. The Pedernales consists of coarse to fine-grained dolomite and contains stromatolitic bioherms. The upper surface of the Pedernales member is in disconformable contact with overlying beds, and is noticeably jointed by solution and fracturing. The member yields water to wells and springs in the Pedernales area.

Ordovician rocks: Ordovician rocks in the area consist largely of limestones and dolomites which have been divided into the Tanyard formation below and the Gorman formation above (Cloud and Barnes, 1946). Springs in the North Grape Creek area issue from joints and solution channels in the Tanyard formation.

Cretaceous rocks: The Cretaceous rocks of the Pedernales area are represented by the Shingle Hills formation of Barnes (1948) and the Fredericksburg group. Barnes has divided his Shingle Hills formation into a sandy member, the Hensell, and an upper sequence of thin-bedded limestones, dolomites, and clays, the Glen Rose member. The coarse materials of Barne's basal Hensell form the best and most extensive aquifer in the area, capturing a relatively high percentage of the rain which falls upon its surface. The Glen Rose member of Barnes is relatively impermeable.

The Fredericksburg group in the Pedernales area includes the Walnut clay, Comanche Peak limestone, and Edwards limestone, in ascending order. The Walnut clay grades upward into the Comanche Peak limestone, which is highly argillaceous and fossiliferous. Neither formation may be considered an aquifer. The Edwards limestone caps the major drainage divides of the upper reaches of the Pedernales area and consists of hard limestone, dolomite, and chert. The limestone contains many joints, fissures, and solution channels, and much of the rain that falls on the outcrop of the Edwards penetrates to the water table and is transmitted just above the contact between the Edwards and Comanche Peak.

Alluvium: Deposits of alluvium of Recent age occur in many places along the Pedernales River. The alluvium consists largely of thin disconnected beds of gravel, sand and silt. The material in most places is coarser near the bottom.

Conclusions: Two distinct types of lithology are responsible for the storage, transmission, and discharge of water of the Pedernales River system. The coarse sands and gravels of the Cretaceous readily absorb rainfall, and transmit it to discharge points in wells and springs. Because of their extensive outcrop area the sands of Cretaceous age form the best aquifer in the Pedernales basin. Limestones of the Fredericksburg group and those of Paleozoic age may collect and transmit water wherever fracturing and solution channeling have created zones of permeability. The sandstones of Paleozoic age may serve as aquifers, but because of greater induration and limited surface outcrop, they are less prolific than the sands of Cretaceous age.

Date 1956	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 2 miles downstream from Harper, Gillespie County, to stream-gaging station near Johnson City, Blanco County, Tex.							
Jan. 9	Pedernales R	2 mi downstream from Harper	0		0			Rock streambed.
9	Pedernales R	0.5 mi downstream from Head Spring	0.5		.3			Est. Rock streambed.
9	Pedernales R	100 ft below Pecan Creek	2.3		.3			Est. Gravel streambed.
9	Pedernales R	At county crossing	4.0		.3			Est. Rock streambed.
9	Pedernales R	Just above Scott Branch	5.7		.25			Est. Gravel streambed.
9	Scott Branch	At mouth	5.7			0.15		Est. Gravel streambed.
9	Flag Creek	At mouth	7.3			0		Gravel streambed.
9	Pedernales R	1.0 mi below Flag Creek	8.3		0			Gravel streambed.
9	Pedernales R	At county crossing	9.2		.2			Est. Rock streambed.
9	Pedernales R	0.5 mi above ranch crossing	11.4		.1			Est. Gravel streambed.
10	Pedernales R	1.5 mi above White Oak Creek	13.3		0			Est. Gravel streambed.
10	Pedernales R	500 ft above White Oak Creek	14.7		0			Rock streambed.
10	White Oak Cr	At mouth	14.8			0		Gravel streambed.
10	Pedernales R	At county crossing - natural rock	16.5		0			Rock streambed.
10	Pedernales R	At county crossing	18.0		.05			Est. Gravel streambed.
10	Spring Creek	At mouth	19.2			0		Est. Gravel streambed.
10	Pump site	On right bank	19.2				-	Pump removed.
10	Pedernales R	At county crossing	19.5		.1			Est. Gravel streambed.
10	Pedernales R	1.0 mi above State Highway 16	20.6		.4			Est. Gravel streambed.
10	5" pump	On right bank	21.3				1.0	Est. Irrigating winter grain.
10	Pedernales R	0.1 mi above State Highway 16	21.4		.1			Est. Gravel streambed.
16	Wolf Creek	12.1 mi above mouth	-		0			Rock streambed.
16	Spring Area	10.6 to 12.1 mi above mouth of Wolf Creek	-			-		Could not measure flow.
16	3" pump	On right bank; 11.0 mi above mouth of Wolf Creek	-				-	Not pumping.
16	Wolf Creek	9.8 mi above mouth	-	50°	.37			Rock streambed.
16	Tributary	From right; 9.0 mi above mouth of Wolf Creek	-			.1		Est. Rock streambed.
16	Wolf Creek	8.3 mi above mouth	-	50°	.46			Gravel streambed.
16	6" & 5" pump	4.3 mi above mouth of Wolf Creek	-				2	Est. From large pool.
16	Wolf Creek	3.6 mi above mouth	-		.1			Est. Rock streambed.
16	4" pump	On right bank; 1.9 mi above mouth of Wolf Creek	-				-	Not pumping.
16	Wolf Creek	At mouth	21.5		0			Gravel streambed.

Date 1956	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Jan. 10	Pedernales R	0.3 mi above Bear Creek	23.5		0.2			Est. Gravel streambed.
10	Bear Creek	At mouth	23.8			0		Est. Gravel streambed.
10	Tributary	From left bank	25.0			.02		Est. Sand streambed.
10	Pedernales R	2.0 mi above Live Oak Creek	25.1		.3			Est. Gravel streambed.
10	Tributary	From left bank	25.2			.01		Est. Sand streambed.
10	Pedernales R	1.0 mi above Live Oak Creek	26.0		.6			Gravel streambed.
10	Live Oak Creek	At mouth	27.0	52°		.56		Sand streambed.
10	Pedernales R	500 ft below Live Oak Creek	27.1	53°	1.10			Gravel streambed.
10	Pump site	--	27.8				-	Pump removed.
10	Pedernales R	0.4 mi above U.S. Highway 87	28.8	51°	1.24			Sand and gravel streambed.
11	Pedernales R	0.2 mi above Muesebach Creek	31.0		1.0			Est. Gravel streambed.
11	4" pump	0.2 mi above Muesebach Creek; on left bank	31.0				-	Not pumping.
11	Muesebach Cr	At mouth	31.2			0		Gravel streambed.
11	4" pump	On Barons Creek; 1 mi above mouth	-				1	Est. From pool behind temporary dirt dam.
11	Barons Creek	At mouth	32.0			.05		Est. Sand streambed.
11	Pedernales R	0.3 mi below Barons Creek	32.3	45°	.96			Gravel streambed.
11	Pedernales R	200 ft above U.S. Highway 290	34.4	52°	.90			Gravel streambed.
11	Pedernales R	--	36.6	52°	1.31			Gravel streambed.
11	Pedernales R	2 mi north of Rocky Hill School	38.4	50°	1.36			Rock streambed.
12	4" pump	On right bank; 0.5 mi above Palo Alto Creek	38.9				-	Not pumping.
12	6" pump	On left bank; 0.3 mi above Palo Alto Creek	39.1				1	Est. From pool behind 4 ft dam.
12	Palo Alto Cr	At mouth	39.4			.02		Est. Sand streambed.
12	Pedernales R	0.6 mi below Palo Alto Creek	40.0	50°	1.98			Rock streambed.
12	Pedernales R	150 ft above county crossing	41.5	54°	3.14			Sand over rock streambed.
12	South Grape Cr	At mouth	43.2			0		Sand streambed.
12	Pedernales R	1.4 mi below South Grape Creek	44.6	48°	3.09			Sand and gravel streambed.
12	Cave Creek	At mouth	45.4			0		Sand streambed.
12	Pump site	0.2 mi below Cave Creek	45.6				-	Pump removed.
12	Pedernales R	0.2 mi above Three Mile Creek	46.7	50°	2.82			Gravel streambed.
12	Three Mile Cr	At mouth	46.9			0		Sand streambed.
12	Pedernales R	2,000 ft below concrete crossing	48.8	51°	3.95			Rock streambed.
13	Pump site	0.6 mi below Stonewall; on right bank.	49.2				-	Pump removed.
13	Pump site	1.0 mi below Stonewall; on right bank	49.6				-	Pump removed.

Date 1956	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Jan. 13	Pedernales R	1,000 ft below concrete crossing	50.0	43°	3.09			Gravel streambed.
16	5" pump	In shallow pit; on left bank	50.5				1	Pumping into concrete-lined earth tank.
14	6" pump	On left bank	50.9				1	Pumping from small lake with 5 ft channel dam.
13	6" pump	On left bank	51.1				-	Not pumping.
13	6" pump	On left bank	51.7				-	Not pumping. Takes water from small reservoir with 4 ft channel dam.
13	Pedernales R	60 ft below concrete bridge	52.2	54°	3.49			Gravel streambed.
13	Iron Rock Cr	At mouth	54.9			0		Rock streambed.
13	Pedernales R	0.7 mi above F.M. 1320	56.5	53°	3.37			Rock streambed.
17	Pedernales R	0.7 mi above F.M. 1320	56.5	44°	3.34			Rock streambed.
17	Rocky Creek	At mouth	57.6			.05		Est. Rock streambed.
17	Pedernales R	0.5 mi below Rocky Creek	58.2	44°	2.97			Rock streambed.
17	Pedernales R	--	59.8	46°	2.65			Rock streambed.
17	Pedernales R	About 1.0 mi above North Grape Creek	62.0	44°	2.62			Rock streambed.
17	North Grape Cr	At mouth	63.1	46°		.53		Sand streambed.
17	Pedernales R	700 ft below North Grape Creek	63.3	45°	3.66			Sand streambed.
17	Pedernales R	At gaging station near Johnson City	70.0		3.3			Not measured. From continuous recorder record.

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LOW-FLOW INVESTIGATIONS - COLORADO RIVER BASIN

Onion Creek April 23-24, 1958

Reach: From FM Road 12 in Hays County to State Highway 71 in Travis County, Tex.

Problem: To determine gains and losses in streamflow in the section of Onion Creek from Farm Road 12, two miles south of Dripping Springs, Hays County, to State Highway 71, five miles east of Austin, Travis County, Texas; with particular attention paid to losses into the Edwards limestone.

Results: Data obtained in this set of stream-flow measurements are as follows:

1. The flow gradually increased from 10 cfs to about 57 cfs in the first 14 miles of channel investigated. This reach is on the Glen Rose limestone with the streambed composed mainly of smooth rock. Flow was found in each of the tributaries inspected.

2. About 10 cfs was lost in the 10 mile (approximate) reach that is on the Edwards limestone. This reach extends from about mile 16 to the fault line and the falls at mile 26, about 3 miles upstream from Buda.

3. Below Buda the flow increased 31 cfs, from 50 to 81 cfs, in 26 miles; of the increased flow, about three cfs can be attributed to measurable tributary inflow. The remainder of this increase in flow probably comes from the alluvium in the creek valley.

Discussion: Current-meter measurements were made at seven points on the main stream through the 59 mile reach; four of these measurements were made to determine losses into the Edwards limestone. Tributary inflows were estimated only at points accessible to highways and county roads. The channel was investigated only at such points as indicated by discharge measurements or field estimates. No attempt was made to pace the measurements with the rate of change in flow as the investigation progressed downstream. The flow was probably decreasing 2% to 5% per day, as in comparable streams crossing the Balcones fault zone; no check was made of this condition. All measurements and estimates were of base flow, there having been no recent surface runoff. Stream-flow measurements at mile 14 and 25.6 were made as near the contacts of the Edwards limestone as practicable. The pickup in flow found at mile 20 probably comes from the short stretch of Glen Rose limestone downstream from mile 14, a pickup in flow being unlikely after the stream crosses onto the Edwards limestone. The three cfs loss indicated between mile 25.6 and mile 29 is probably absorbed at or near the downstream contact of the Edwards limestone, a fault line and falls about 600 ft below the measuring section. Although several small lakes with channel dams were found, no irrigation equipment was seen; nevertheless, it is likely that a considerable quantity of water is used for irrigation during the growing season.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From FM Road 12 in Hays County to State Highway 71 in Travis County							
Apr. 23	Onion Creek	At FM 12	0		10			Estimate. Gravel and rock streambed.
23	South Onion Cr	At FM 12, 1.4 mi above mouth	1.4			7		Estimate. Broken rock streambed.
23	Tributary	From right; 3.8 mi above mouth	3.7			3		Estimate. Rock streambed.
23	Onion Creek	At abandoned county concrete crossing	10.0	71°	53.0			Gravel streambed.
23	Tributary	From right; at mouth	10.3			.1		Estimate. Rock streambed.
23	Tributary	From right; 0.6 mi above mouth	12.9			2		Estimate. Rock streambed.
23	Onion Creek	400 ft below lower crossing of FM 150	14.0	73°	57.3			Smooth rock streambed.
23	Tributary	From right; 1.8 mi above mouth	18.8			0		Gravel streambed.
23	Onion Creek	At abandoned crossing on Kuykendal ranch	20.0	78°	60.2			Rough rock.
23	Onion Creek	At abandoned crossing 600 ft above falls	25.6	81°	53.5			Rough rock.
23	Onion Creek	At Buda; 100 ft above FM 967	29.0	82°	50.5			Rock and gravel streambed.
24	Bear Creek	At mouth	34.5			1		Estimated. Rock streambed.
24	Rinard Creek	1.0 mi above mouth	39.2			.3		Estimate. Rock streambed.
24	Slaughter Cr	1.7 mi above mouth	40.0			.2		Estimate. Rock streambed.
24	Onion Creek	200 ft below county crossing at Bluff Springs	41.1	75°	65.6			Gravel streambed.
24	Boggy Creek	1.0 mi above mouth	41.9			.4		Estimate. Rock streambed.
24	Marble Creek	0.9 mi above mouth	45.5			.1		Estimate. Gravel streambed.
24	Williamson Cr	2.8 mi above mouth	47.1			.8		Estimate. White rock streambed.
24	Cotton Mouth Cr	4.4 mi above mouth	50.1			0		Gravel streambed.
24	Onion Creek	600 ft above State Highway 71	55.1	74°	81.4			Gravel streambed.
24	Onion Creek	At mouth	59.2		-			Backwater from Colorado River.

LOW-FLOW INVESTIGATIONS - LAVACA RIVER BASIN

Lavaca River — Nov. 4, 1947; Aug. 5, 6, 1948

Reach: From Dr. Lee pumping plant to Koop Brother's pump near Edna, Tex.

A series of discharge measurements was made Nov. 4, 1947, and Aug. 5, 1948, on Lavaca River between Dr. R. E. Lee's pump, about 3½ miles northwest of Edna, and Koop Brother's pump, about 6½ miles southeast of Edna. Discharge measurements were made of Lavaca River at upper and lower ends of river reach, and at three intervening points. In addition, the quantity of water being diverted from river by each of three pumps was measured. These were all of the known diversions from this reach of the river at the time the investigation was made. There was no inflow into the reach. The investigations were made during periods of constant stage of river as indicated at gaging station near Edna which is within the reach. The determination of gain or loss represent normal conditions.

Measurements in November were made when no pumps were operating and none had been operated during the preceding week. Measurements in August were made while all pumps were operating at a constant rate of speed and had been for several days preceding the measurements.

Date 1947	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Nov. 4	Lavaca R	Just above Dr. Lee pump near Edna	0		15.6			
4	Dr.Lee's pump	3½ mi NW of Edna	0				0	
4	Lavaca R	At U.S.Hwy 59 - gaging station	3.0		17.6			
4	Lavaca R	Just above Babb's pump 3 mi SW Edna	4.1		17.4			
4	Babb's pump	3 mi SW of Edna	4.1				0	
4	Lavaca R	Just below old county bridge 4 mi SW	6.5		19.4			
4	Lavaca R	Just above Koop Bro's. pump 6½ mi S Edna	9.5		21.3			
4	Koop Bro's. pump	6½ mi S of Edna	9.5				0	

Date 1948	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Dr. Lee pumping plant to Koop Brother's pump near Edna, Tex., continued							
Aug. 5	Lavaca R	Just above Dr. Lee pump	0		17.7			
5	Dr. Lee pump	3½ mi NW of Edna	0				6.48	
5	Lavaca R	At U.S.Hwy. 59 - gaging station	3.0		12.7			
5	Lavaca R	Just above Babb pump	4.1		13.1			
5	Babb pump	3 mi SW of Edna	4.1				10.5	
5	Lavaca R	Just below old county bridge 4 mi SW	6.5		4.34			
6	Lavaca R	Just above Koop Bro's. pump	9.5		5.20			
5	Koop Bro's. pump	6½ mi S of Edna	9.5				6.49	

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Guadalupe River — January 16-19, 1928

Reach: From Comfort to New Braunfels, Tex.

During the investigation the river was at a constant stage and measurements represent the natural conditions.

Date 1928	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Jan. 16	Guadalupe River	2 mi above Comfort - Gaging station	0		52.0			
16	Cypress Creek	$\frac{1}{4}$ mi above mouth at Comfort	3.0			1.5		
16	Holliday Creek	600 ft above mouth near Comfort	4.8			.3		
16	Guadalupe River	At Railroad bridge below Comfort	6.4		58.6			
16	Guadalupe River	At Highway crossing at Waring	12.2		58.7			
17	Joshua Creek	2 mi above mouth near Waring	16.0			1.6		
17	Sister Creek	$\frac{1}{2}$ mi above mouth near Sisterdale	19.7			.4		
17	Guadalupe River	Just below Sister Creek near Sisterdale	19.7		65.4			
17	Wasp Creek	At mouth 6 mi below Sisterdale	29.5			.2		
17	Sabino Creek	At mouth 8 mi NE of Boerne	31.2			.5		
17	Guadalupe River	Just below Sabino Creek at Ammans crossing	31.2		70.9			
17	Guadalupe River	At Schillers crossing 4 mi N of Bergheim	45.6		68.3			
18	Currys Creek	$\frac{1}{2}$ mi above mouth	55.8			2.6		
18	Guadalupe River	At Specks crossing 2.5 mi SW of Spring Branch	57.5		71.9			
18	Spring Branch	$1\frac{1}{2}$ mi above mouth near Spring Branch	59.0			1.5		
18	Guadalupe River	Near Spring Branch - Gaging station	61.7		73.5			
18	Big Spring	At Cranes Mill	78.5			3.9		
18	Guadalupe River	At road crossing at Cranes Mill	78.5		72.3			
18	Guadalupe River	At road crossing 2 mi NE of Sattler	92.7		88.9			
19	Jacobs Creek	At mouth 2 mi below Sattler	95.9			0		
19	Guadalupe River	4 mi below Sattler	97.4		83.2			
19	Isaacs Creek	At mouth $5\frac{1}{2}$ mi above New Braunfels	103.5			0		
19	Guadalupe River	$\frac{1}{4}$ mi above Elm Creek 5 mi above New Braunfels	103.9		81.6			

Date 1928	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Comfort to New Braunfels, Tex. - Continued							
Jan. 19	Elm Creek	At mouth near New Braunfels	104.3			0		
19	Guadalupe River	1 mi above Comal River - Gaging station	108.7		77.7			

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Guadalupe River February 18-22, 1929

Reach: From Comfort to New Braunfels, Tex.

During the investigation the river was at a constant stage and discharge measurements represent the natural conditions.

Date 1929	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
Feb. 18	Guadalupe River	2 mi above Comfort - gaging station	0		41.1			
18	Cypress Creek	¼ mi above mouth at Comfort	3.0			0.2		
18	Holliday Creek	600 ft above mouth near Comfort	4.8			0		
18	Guadalupe River	At Railroad bridge below Comfort	6.4		42.5			
18	Guadalupe River	At Highway crossing at Waring	12.2		36.4			
19	Joshua Creek	2 mi above mouth near Waring	16.0			.7		
19	Sister Creek	½ mi above mouth near Sisterdale	19.7			.2		
19	Guadalupe River	Just below Sister Creek near Sisterdale	19.7		45.2			
19	Wasp Creek	At mouth 6 mi below Sisterdale	29.5			0		
19	Guadalupe River	Just above Sabino Creek at Ammans crossing	31.2		40.7			
19	Sabino Creek	At mouth 8 mi NE of Boerne	31.2			.3		
19	Guadalupe River	At crossing 4 mi above Oberley crossing	34.2		38.2			
19	Guadalupe River	At Schillers crossing 4 mi N of Bergheim	45.6		43.0			
20	Curry Creek	½ mi above mouth	55.8			1.0		
20	Guadalupe River	At Specks crossing 2.5 mi SW of Spring Branch	57.5		47.7			
20	Spring Branch	1½ mi above mouth near Spring Branch	59.0			.9		
20	Guadalupe River	Near Spring Branch - Gaging station	61.7		47.4			
21	Guadalupe River	In Demijohn Bend E of Spring Branch	73.3		34.3			
21	Big Springs	At Cranes Mill	78.5			2.9		
21	Guadalupe River	Below Big Spring at Cranes Mill	78.5		39.2			
21	Guadalupe River	5 mi NW of Sattlers Store	86.2		48.8			
22	Guadalupe River	2 mi NE of Sattlers Store	94.0		48.2			
22	Jacobs Creek	At mouth 2 mi below Sattlers	95.9			.1		
22	Guadalupe River	4 mi below Sattlers	97.4		53.1			

Date 1929	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Comfort to New Braunfels, Tex. - Continued							
Feb. 22	Isaacs Creek	At mouth $5\frac{1}{2}$ mi above New Braunfels	103.5			0		
22	Godes Canal	At Highway bridge $\frac{1}{2}$ mi above Elm Creek	103.9				9.3	Gates closed prior to measurement
22	Guadalupe River	Just below Godes Canal	104.1		53.0			Includes flow of Canal
22	Elm Creek	At mouth	104.3			0		
22	Guadalupe River	Above Comal River - Gaging station	108.7		49.0			Average discharge for day

Guadalupe River   January to May 1955

Reach: From county road crossing above U. S. Highway 281 near Spring Branch to New Braunfels, Tex.

Conclusions and Summary: A casual study of the discharge tables might lead to the belief that substantial amounts of water are lost in the reach of the Guadalupe River under study. Also, an algebraic summation of the actual gains and losses, as indicated by discharge measurements of the river and measurements of inflow from springs, would show a considerable loss. However, as explained later, the actual losses to the ground-water reservoir are small. Ben M. Petitt, Jr., and W. O. George, geologists of the Ground Water Branch of the U. S. Geological Survey, in their report on San Antonio area have this to say:

"The Guadalupe River, in contrast to most of the other streams crossing the Balcones fault zone, apparently does not lose significant quantities of water to the Edwards limestone . . . Investigations to determine seepage losses have failed to disclose losses greater than those that might be expected from evapotranspiration. However, there are minor losses and gains in various reaches of the river . . .

. . . Between Spring Branch and New Braunfels . . . stream losses and gains are insignificant."

These losses and gains are evident in the variation in discharge shown in the tables. The largest loss and gain occurred between sites 6 and 13 in the vicinity of Demijohn Bend. This bend is located at the end of a high ridge of rock that holds the river to a northeasterly course for several miles before it turns sharply in a southerly direction to meander down the opposite side of the rocky ridge. The river distance from the site of measurement 6 to Wolle Springs is 15 miles, and the drop in elevation is about 85 feet. This gives an average fall of about 6 feet to the mile. The airline distance is 3.5 miles, which gives an average fall of 24 feet to the mile. It is reasonable to assume that, with such a steep slope, water would find its way through this short stretch of cavernous limestone rock. The Wolle Springs have a history of flowing muddy or murky water prior to an upriver rise. This condition was observed by Pat H. Holland of the U. S. Geological Survey and R. L. Lowry, consulting engineer, on May 10-11, 1955. Cranes Mill Spring is also reported to flow muddy or murky water prior to upriver rise or during periods of heavy local or upriver rain.

The average temperature of the river water from measurement sites 6 to 11 was about 50°, while the average temperature of Wolle Springs was 56°. The temperature of river water responds readily to changes in air temperature, and water flowing underground will eventually assume the temperature of the surrounding formation. The springs measured in this study increase in temperature in a downstream order: Wolle Springs, 56°, Cranes Mill Spring, 65°, and Sorrel Creek Spring, 70.5°. This indicates that Wolle Springs are near the source of water supply and that Sorrel Creek Spring is the farthest away. Comal Springs, located at New Braunfels about 28 miles downstream from Sorrel Creek, have a mean temperature of about 74°.

The chemical analyses of 39 samples taken in January 1955, 32 from the river and 7 from springs, indicate that all the water was very similar in chemical content. (See table of chemical analyses.)

Table of chemical analyses gives in downstream order the analyses of samples collected in the Guadalupe River low-flow investigation during the period Jan. 24-31, 1955. Water from Spring Branch Creek was somewhat higher in bicarbonate and distinctly lower in chloride than the run of the river water. Water from the Sorrel Creek Spring was higher in hardness and bicarbonate and lower in chloride than the river water. Water from the various Wolle Springs and Cranes Mill Springs was very similar to the river water. The analyses suggest that gains in streamflow in some stretches of the Guadalupe River probably represent recoveries of water lost in other reaches upstream and not new water from distant sources.

The series of low-flow measurements started on Jan. 17, 1955, on the Guadalupe River was interrupted by rain and a subsequent increase in flow.

During the period January 24-31, discharge measurements were made at 32 locations in the 57 mile reach from a point 2-1/2 miles upstream from Spring Branch Creek to the gaging station at New Braunfels. All tributary flow of consequence was measured, including springs when measurable. Water samples were collected and water temperatures determined at all measuring sites and at all springs, whether measured or not. Physiography of river channel was obtained at all measuring sites and springs.

After a study was made of the January 24-31 series of measurements, thirteen points for re-measurement were selected. From February 28 to March 2 these thirteen re-measurements were made. Water temperatures were determined at each point but no water samples were collected.

Additional series of eight selected measurements were made on March 14-15, 29-30, April 12-13, 26-27, and May 10-11. Rainfall early in May caused small rises on the river and prevented further low-flow studies during that month.

Site No.	Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	JAN.	From county road crossing above U. S. Highway 281 near Spring Branch to New Braunfels, Tex.							
1	17	Guadalupe River	At county road crossing above U. S. Highway 281	0	54°	38.4			Small gravel streambed.
2	17	Guadalupe River	500 ft above Spring Branch Creek	2.4	54°	34.1			Large gravel streambed.
2-A	17	Spring Branch Creek	At mouth	2.5	52°		1.0		Estimate. Rock and clay streambed
3	17	Guadalupe River	About 1 mi above U. S. Highway 281	3.3	57°	34.5			Small gravel streambed.
4	17	Guadalupe River	About 1 mi below U. S. Highway 281	4.7	55°	29.8			Small gravel streambed.
5	17	Guadalupe River	At gaging station near Spring Branch	5.7		32			From rating curve.
9	17	Guadalupe River	At Wunderlich ranch	15.1		0			Local information.
		The investigation was interrupted by rain.							
	Jan.								
1	24	Guadalupe River	At county road crossing above U. S. Highway 281	0	46°	51.5			Streambed of small gravel.
2	24	Guadalupe River	500 ft above Spring Branch Creek	2.4	48°	49.0			Streambed of large gravel.
2-A	24	Spring Branch Creek	At mouth	2.5	52°		1.0		Estimate. Rock and clay streambed
3	24	Guadalupe River	About 1 mi above U. S. Highway 281	3.3	49°	46.1			Streambed of small gravel.
4	24	Guadalupe River	About 1 mi below U. S. Highway 281	4.7	48°	44.5			Streambed of small gravel.
5	24	Guadalupe River	At gaging station near Spring Branch	5.7		49			From rating curve.
6	24	Guadalupe River	1.5 mi below gaging station	7.0	50°	44.3			Streambed of boulders and gravel.
7	25	Guadalupe River	At Smithson Valley county road	10.0	46°	28.0			Streambed of medium gravel.
8	25	Guadalupe River	2.5 mi below county road	12.5	54°	22.0			Streambed of small gravel.
9	25	Guadalupe River	At Wunderlich ranch	15.1	49°	13.2			Streambed of small gravel.
10	25	Guadalupe River	100 ft below Rebecca Creek	16.4	49°	11.4			Streambed of small gravel.
11	26	Guadalupe River	At lower end of Demijohn Bend	18.0	48°	9.2			Streambed of small gravel.
12	26	Guadalupe River	At Ben Wolle's upper pasture	20.5	50°	11.1			Streambed of medium gravel.
12-A	26	Wolle Spring 1	At Ben Wolle's upper pasture	21.0	56°		2.0		Estimate.
12-B	26	Wolle Spring 2	At Ben Wolle's upper pasture	21.2	55°		3.0		Estimate.
12-C	26	Wolle Spring 3	At Ben Wolle's lower pasture	22.0	56°		6.9		Between outlet and river.
12-D	26	Wolle Spring 4-5	At Ben Wolle's lower pasture	22.0	57°		10.0		Estimate.
13	26	Guadalupe River	At lower end of Wolle ranch	22.3	54°	27.1			Streambed of medium gravel.

Site No.	Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Jan.								
14	27	Guadalupe River	800 ft above Cranes Mill Spring	24.5	53°	24.9			Boulders and gravel.
14-A	27	Cranes Mill Spring	--	24.6	65°		8.1		Difference of measurements 14 and 15.
15	27	Guadalupe River	400 ft below Cranes Mill Spring	24.7	53°	33.0			Streambed of smooth rock.
16	27	Guadalupe River	2.5 mi below Cranes Mill Spring	27.2	57°	31.9			Streambed of rough rock.
17	27	Guadalupe River	1.5 mi above Tom Creek	29.0	55°	35.8			Gravel over rock.
17-A	27	Sorrel Creek Spring	--	29.4	70.5°		-		Not measurable.
18	27	Guadalupe River	200 ft above Tom Creek	30.4	55°	39.1			Streambed of smooth rock.
19	28	Guadalupe River	2 mi below Tom Creek	32.3	50°	41.9			Streambed of rough rock.
20	28	Guadalupe River	2.5 mi below Tom Creek	32.9	54°	37.8			Streambed of smooth rock.
21	28	Guadalupe River	Krause ranch - 2 mi above Canyon dam site	34.3	56°	41.8			Streambed of smooth rock.
22	28	Guadalupe River	3/4 mi below Canyon dam site	37.3	55°	40.8			Streambed of smooth rock.
23	29	Guadalupe River	1.5 mi below Canyon dam site	38.1	50°	37.9			Gravel over rock.
24	29	Guadalupe River	500 ft above Sattler Creek	39.9	53°	40.8			Rock streambed.
25	29	Guadalupe River	1 mi above 1st crossing below Sattler	41.7	51°	38.1			Rock streambed.
26	29	Guadalupe River	2 mi below Sattler	42.8	54°	35.4			Streambed of rough rock.
27	29	Guadalupe River	About 3 mi below Sattler	43.7	53°	43.0			Measurement poor - gravel.
28	30	Guadalupe River	About 7 mi above Hueco Springs	45.5	50°	41.6			Streambed of smooth rock.
29	30	Guadalupe River	About 4.5 mi above Hueco Springs	48.0	50°	40.7			Streambed of small gravel.
30	30	Guadalupe River	About 1.0 mi above Hueco Springs	51.5	50°	35.7			Gravel and rock.
30-A	30	Hueco Springs	--	52.6	-		0		
31	30	Guadalupe River	3/4 mi below Hueco Springs	53.3	52°	39.4			Fairly uniform rock streambed.
32	31	Guadalupe River	3/4 mi above Gruene	55.1	53°	35.9			Uniform rock streambed.
33	31	Guadalupe River	3/4 mi above gaging station at New Braunfels	57.0	55°	38.8			Streambed of gravel.
	Feb.								
1	28	Guadalupe River	At county road above U. S. Highway 281	0	60°	33.1			Streambed of small gravel.
5	28	Guadalupe River	At gaging station near Spring Branch	5.7	63°	31.5			Streambed of uniform rock.
11	28	Guadalupe River	At lower end of Demijohn Bend	18.0	64°	6.96			Streambed of small gravel.
14	28	Guadalupe River	800 ft above Cranes Mill Spring	24.5	65°	22.2			Boulders and gravel.
14-A	28	Cranes Mill Spring	--	24.6			5.3		Difference of meas. 14 and 15.
15	28	Guadalupe River	400 ft below Cranes Mill Spring	24.7	66°	27.5			Streambed of smooth rock.

Site No.	Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Mar.								
17	1	Guadalupe River	1.5 mi above Tom Creek	29.0	66°	30.4			Gravel over rock.
19	1	Guadalupe River	2.0 mi below Tom Creek	32.3	68°	38.2			Streambed of rough rock.
22	1	Guadalupe River	3/4 mi below Canyon dam site	37.3	68°	36.0			Streambed of smooth rock.
26	1	Guadalupe River	2 mi below Sattler	42.8	71°	37.0			Streambed of rough rock.
27	1	Guadalupe River	About 3 mi below Sattler	43.7	69°	35.2			On gravel - measurement poor.
29	1	Guadalupe River	About 4.5 mi above Hueco Springs	48.0	69°	39.3			Streambed of small gravel.
30	1	Guadalupe River	About 1.0 mi above Hueco Springs	51.5	72°	38.5			Gravel and rock.
30-A	1	Hueco Springs	--	52.6			0		
33	2	Guadalupe River	3/4 mi above gaging station at New Braunfels	57.0	67°	37.4			Streambed of gravel.
	Mar.								
1	14	Guadalupe River	At county road above U. S. Highway 281	0	69°	28.4			Small gravel.
5	14	Guadalupe River	At gaging station near Spring Branch	5.7	70°	25.7			Uniform rock.
11	14	Guadalupe River	At lower end of Demijohn Bend	18.0	72°	3.54			Small gravel.
15	14	Guadalupe River	400 ft below Cranes Mill Spring	24.7	71°	27.2			Smooth rock. Spring flowing.
19	14	Guadalupe River	2 mi below Tom Creek	32.3	74°	35.7			Rough rock.
29	14	Guadalupe River	About 4.5 mi above Hueco Springs	48.0	74°	38.7			Small gravel.
30	15	Guadalupe River	About 1.0 mi above Hueco Springs	51.5	71°	35.5			Gravel and rock.
30-A	15	Hueco Springs	--	52.6			0		
33	15	Guadalupe River	3/4 mi above gaging station at New Braunfels	57.0	71°	39.4			Gravel.
	Mar.								
0	29	Guadalupe River	300 ft below Bergheim-Kendalia road	-10.3	55°	28.4			Gravel.
1	29	Guadalupe River	At county road above U. S. Highway 281	0	55°	31.0			Small gravel.
5	29	Guadalupe River	At gaging station near Spring Branch	5.7	60°	27.6			Gravel over rock.
11	29	Guadalupe River	At lower end of Demijohn Bend	18.0	60°	1.0			Estimate. 300 ft upstream all flow is below gravel. 300-500 ft downstream springs trickle from bluff on right.
15	29	Guadalupe River	400 ft below Cranes Mill Spring	24.7	60°	19.6			Smooth rock. Spring flowing.
19	30	Guadalupe River	2 mi below Tom Creek	32.3	57°	27.0			Rock and gravel.
29	30	Guadalupe River	About 4.5 mi above Hueco Springs	48.0	56°	26.9			Small gravel.

Site No.	Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Mar.								
30	30	Guadalupe River	About 1.0 mi above Hueco Springs	51.5	62°	24.8			Gravel and rock.
30-A	30	Hueco Springs	--	52.6			0		
33	30	Guadalupe River	3/4 mi above gaging station at New Braunfels	57.0	59°	27.0			Gravel.
	Apr.								
1	12	Guadalupe River	At county road above U. S. Highway 281	0	71°	23.4			Gravel.
5	12	Guadalupe River	At gaging station near Spring Branch	5.7	74°	19.9			Gravel over rock.
11	12	Guadalupe River	At lower end of Demijohn Bend	18.0	76°	0.2			Estimate. Gravel.
15	12	Guadalupe River	400 ft below Cranes Mill Spring	24.7	75°	15.5			Smooth rock. Spring flowing.
19	12	Guadalupe River	2 mi below Tom Creek	32.3	80°	22.3			Rock and gravel.
29	12	Guadalupe River	About 4.5 mi above Hueco Springs	48.0	74°	22.6			Gravel.
30	13	Guadalupe River	About 1.0 mi above Hueco Springs	51.5	68°	22.2			Gravel and rock.
30-A	13	Hueco Springs	--	52.6			0		
33	13	Guadalupe River	3/4 mi above gaging station at New Braunfels	57.0	70°	23.1			Gravel.
	Apr.								
1	26	Guadalupe River	At county road above U. S. Highway 281	0	75°	10.1			Gravel.
5	26	Guadalupe River	At gaging station near Spring Branch	5.7	81°	8.20			Gravel over rock.
11	26	Guadalupe River	At lower end of Demijohn Bend	18.0		0.0			
15	26	Guadalupe River	400 ft below Cranes Mill Spring	24.7	78°	6.29			Smooth rock. Spring flowing.
19	26	Guadalupe River	2 mi below Tom Creek	32.3	78°	12.2			Rock and gravel.
29	26	Guadalupe River	About 4.5 mi above Hueco Springs	48.0	78°	12.8			Gravel.
30	27	Guadalupe River	About 1.0 mi above Hueco Springs	51.5	73°	12.0			Gravel and rock.
30-A	27	Hueco Springs	--	52.6			0		
33	27	Guadalupe River	3/4 mi above gaging station at New Braunfels	57.0	75°	10.9			Gravel.
	May								
5	9	Guadalupe River	At gaging station near Spring Branch	5.7		500			A peak of about 500 cfs.occurred at 1:00 a.m.
5	10	Guadalupe River	At gaging station near Spring Branch	5.7	75°	119			Rock streambed. Water muddy.
7	10	Guadalupe River	At Smithson Valley county road	10.0		75			Estimate. Water murky.
11	10	Guadalupe River	At lower end of Demijohn Bend	18.0		35-50			Estimate. Water clear.
12-C	10	Wolle Spring 3	Ben Wolle's lower pasture	22.0			Trickle		Water muddy. River clear.
12-D	10	Wolle Spring 4-5	Ben Wolle's lower pasture	22.0			6		Estimate. Water muddy. River clear.

Site No.	Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
						Main Stream	Tributary	Diversion	
30-A	May 10	Hueco Springs	--	52.6			0		
33	10	Guadalupe River	3/4 mi above gaging station at New Braunfels	57.0	79°	6.96			Gravel. Water clear. Rise has not reached this point.
6-A	May 11	Guadalupe River	At cave about 2-1/2 mi below gaging station	8.2		-			Cave opening above water. Could not estimate flow. Water very muddy.
7	11	Guadalupe River	At Smithson Valley county road	10.0		60			Estimate. Water murky.
12-A	11	Wolle Spring 1	Ben Wolle's upper pasture	21.0			0.5		Estimate. Water clear from spring and in river.
12-D	11	Wolle Spring 5	Ben Wolle's lower pasture	22.0			4		Estimate. Water muddy. River clear. Springs 3 and 4 dry.
14-A	11	Cranes Mill Spring		24.6			6-8		
15	11	Guadalupe River	400 ft below Cranes Mill Spring	24.7		75			Estimate. Water clear.

Chemical Analyses, Guadalupe River, January 24-31, 1955

Site No.	Date 1955 Jan.	Stream	Location	Disch. (cfs)	Bicarbonate (ppm)	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)	Specific conductance (micromhos at 25° C)	pH
1	24	Guadalupe River	At county road crossing above U. S. Highway 281	51.5	268	24	240	516	8.2
2	24	Guadalupe River	500 ft above Spring Branch Creek	49.0	271	24	246	516	8.0
2-A	24	Spring Branch Creek	At mouth	1.0	285	15	244	489	8.1
3	24	Guadalupe River	About 1 mi above U. S. Highway 281	46.1	272	25	247	516	8.1
4	24	Guadalupe River	About 1 mi below U. S. Highway 281	44.5	276	25	251	526	8.1
5	24	Guadalupe River	At gaging station near Spring Branch	-	278	26	252	527	8.2
6	24	Guadalupe River	1.5 mi below gaging station	44.3	278	26	252	532	8.2
7	25	Guadalupe River	At Smithson Valley county road	28.0	279	26	251	528	8.2
8	25	Guadalupe River	2.5 mi below county road	22.0	274	26	245	517	8.1
9	25	Guadalupe River	At Wunderlich ranch	13.2	275	26	248	525	8.0
10	25	Guadalupe River	100 ft below Rebecca Creek	11.4	274	26	248	517	8.2
11	26	Guadalupe River	At lower end of Demijohn Bend	9.2	274	26	256	525	8.1
12	26	Guadalupe River	At Ben Wolle's upper pasture	11.1	274	26	252	528	8.0
12-A	26	Wolle Spring 1	At Ben Wolle's upper pasture	2.0	272	26	244	511	8.1
12-B	26	Wolle Spring 2	At Ben Wolle's upper pasture	3.0	271	26	246	526	7.9
12-C	26	Wolle Spring 3	At Ben Wolle's lower pasture	6.9	278	26	252	535	7.8
12-D	26	Wolle Spring 4-5	At Ben Wolle's lower pasture	-	277	26	252	535	7.8
13	26	Guadalupe River	At lower end of Wolle ranch	27.1	275	26	254	532	8.0
14	27	Guadalupe River	800 ft above Cranes Mill Spring	24.9	274	26	250	528	8.1

Chemical Analyses, Guadalupe River, January 24-31, 1955

Site No.	Date 1955 Jan.	Stream	Location	Disch. (cfs)	Bicar-bonate (ppm)	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)	Specific conductance (micromhos at 25° C)	pH
14-A	27	Cranes Mill Spring	-	8.1	292	23	268	559	7.6
16	27	Guadalupe River	2.5 mi below Cranes Mill Spring	31.9	277	24	254	531	7.9
17	27	Guadalupe River	1.5 mi above Tom Creek	35.8	280	24	258	529	8.1
17-A	27	Sorrel Creek Spring	-	-	333	14	290	673	7.5
18	27	Guadalupe River	200 ft above Tom Creek	39.1	279	24	254	526	8.0
19	28	Guadalupe River	2 mi below Tom Creek	41.9	282	24	260	527	8.0
20	28	Guadalupe River	2.5 mi below Tom Creek	37.8	280	24	254	525	8.0
21	28	Guadalupe River	Krause ranch - 2 mi above Canyon dam site	41.8	276	24	248	520	8.0
22	28	Guadalupe River	3/4 mi below Canyon dam site	40.8	267	24	240	513	8.0
23	29	Guadalupe River	1.5 mi below Canyon dam site	37.9	267	24	240	513	8.1
24	29	Guadalupe River	500 ft above Sattler Creek	40.8	269	24	246	513	8.1
25	29	Guadalupe River	1 mi above 1st crossing below Sattler	38.1	265	25	242	510	8.1
26	29	Guadalupe River	2 mi below Sattler	35.4	265	25	240	512	8.1
27	29	Guadalupe River	About 3 mi below Sattler	43.0	262	24	236	507	8.1
28	30	Guadalupe River	About 7 mi above Hueco Springs	41.6	262	24	238	498	8.1
29	30	Guadalupe River	About 4.5 mi above Hueco Springs	40.7	260	24	238	501	8.1
30	30	Guadalupe River	About 1.0 mi above Hueco Springs	35.7	253	24	230	492	8.1
31	30	Guadalupe River	3/4 mi below Hueco Springs	39.4	253	24	230	491	8.1
32	31	Guadalupe River	3/4 mi above Gruene	35.9	252	23	230	494	8.1
33	31	Guadalupe River	3/4 mi above gaging station at New Braunfels	38.8	259	23	232	495	8.1

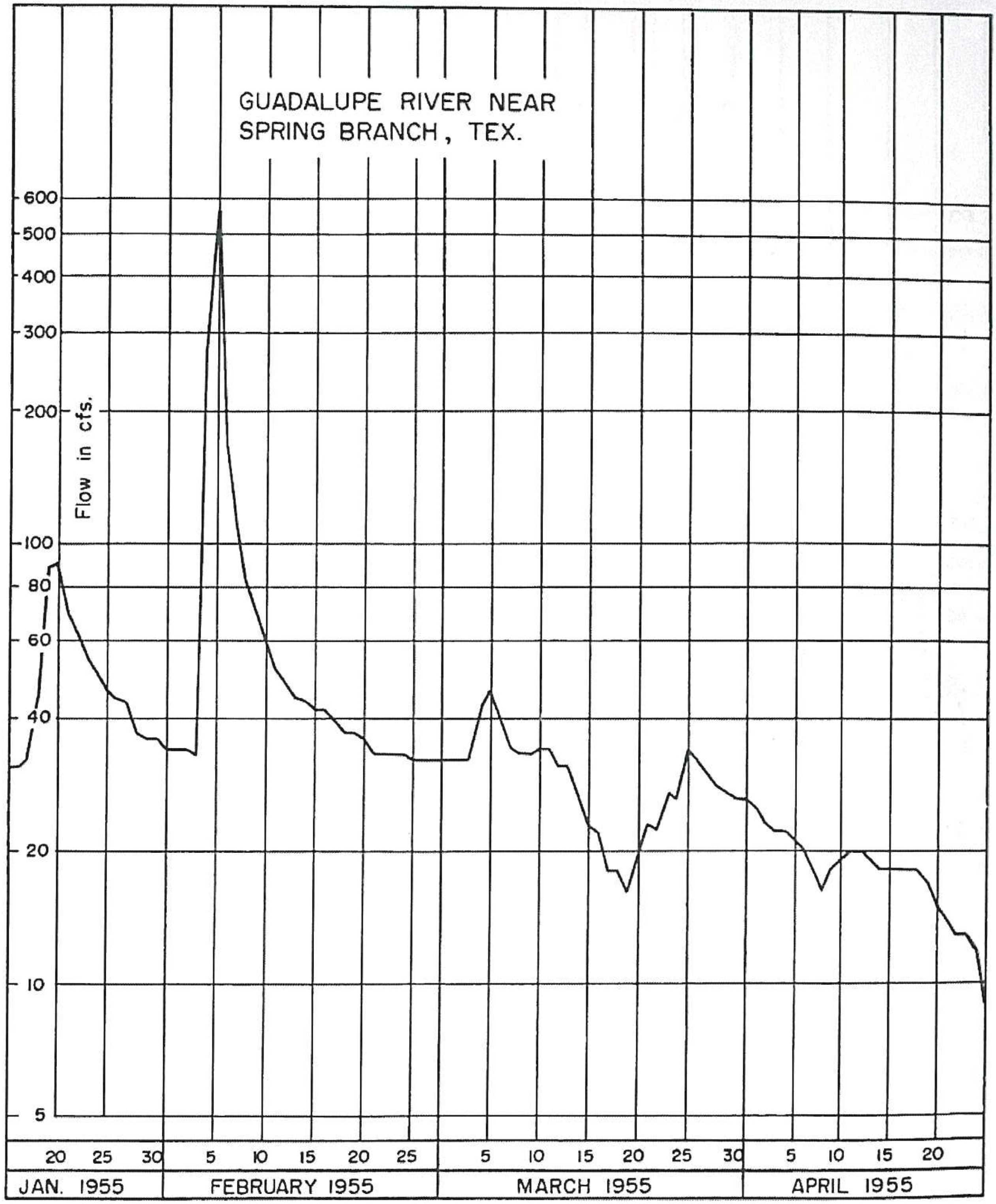

FIGURE 2.- DISCHARGE HYDROGRAPH, GUADALUPE RIVER NEAR SPRING BRANCH, TEX.

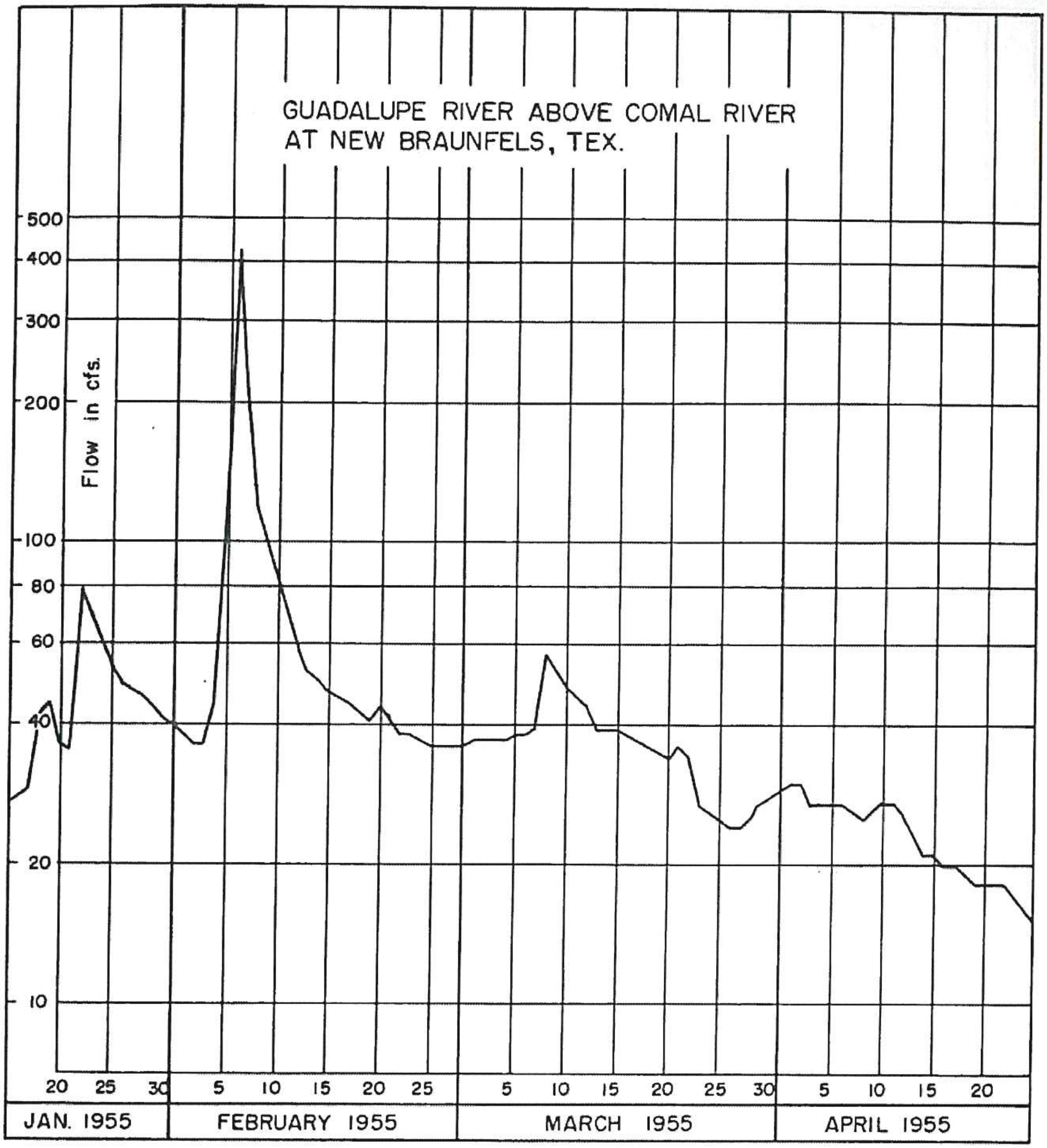

FIGURE 3.- DISCHARGE HYDROGRAPH, GUADALUPE RIVER ABOVE COMAL RIVER AT NEW BRAUNFELS, TEX.

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

San Marcos Springs March 2 to June 1, 1955

Location: San Marcos Springs are located at San Marcos, Hays County, Tex.

Conclusions and Summary: Discharge measurements and daily discharge record of San Marcos Springs show that the springs respond readily to rainfall and decrease in flow more slowly than other large springs in this region. Several showers fell in the vicinity of San Marcos from May 16 to 19 which caused small rises on the San Marcos River. The spring discharge increased from 78 to 106 cfs during this period and decreased only 12 cfs by July 21. During this same time, Comal Springs increased from 80 to 110 cfs and decreased to 68 cfs by June 30. (See hydrograph of daily discharges.)

Available quality-of-water data indicate that the immediate sources of water for Comal and San Marcos Springs are different. The analyses suggest that the Blanco River might be a source of part or all of the flow of San Marcos Springs. It does not appear from that data that the flow of Comal Springs is derived from the usual flow of the Guadalupe River.

During the period March 2 to June 1, 1955, weekly discharge measurements were made of the flow of San Marcos Springs at San Marcos, Tex. On April 6 a temporary recording gage was installed on the San Marcos River about 1-1/2 miles downstream from the springs. This gage was operated until June 1 and daily discharges were computed for the period. Weekly water samples were obtained from the springs during the investigation period.

A discharge hydrograph for the period of daily record was prepared and extended to fill out the period of investigation on basis of weekly discharge measurements; and as a basis for comparison a discharge hydrograph for Comal River at New Braunfels was plotted.

The fluctuations of flow of the San Marcos Springs is partially due to the operation of the dam at the springs area. The springs flow from the base of a rock cliff into a small lake that covers several acres. The lake contains a rank growth of water plants which are cut from time to time with a power mower. These cuttings float to the dam and lodge on the spillway and gate openings. The operator allows this debris to collect until the rise in lake level becomes objectionable at which time the debris is cleared away. As soon as it is removed the excess storage starts draining and results in a small rise on the river below the dam. This is the cause of the small sharp peaks.

Concurrently with the low-flow investigations in the Guadalupe and Blanco Rivers, a series of water samples were collected from the San Marcos Springs in Hays County, and the Comal Springs in Comal County. Results of the analyses are given in the tables.

The determination of nitrate was added to the tests run on the spring samples because nitrate concentrations have been observed to vary considerably in various springs along the Balcones fault zone and because sudden changes in nitrate might indicate inflow of local surface runoff.

Analyses of the weekly samples collected from San Marcos Springs between March 9 and June 1, 1955, showed that the chemical composition of the spring water changed very little during the period of sampling. The spring water had the same chloride concentration as the Blanco River at mile 38.6 of the Jan. 24-28, 1955 low-flow investigation; just above the reach where the Blanco River flow disappeared underground. The San Marcos Springs water was harder and higher in bicarbonate and conductivity and lower in pH than the Blanco River water. If, after disappearing underground, the water of the Blanco River were to become charged with carbon dioxide, it would attack the limestone through which it flowed and its bicarbonate, hardness, and conductivity would increase. The analyses suggest that the Blanco River could be a source of part or all of the San Marcos Springs water.

Analyses of five samples collected from the Comal Springs from March 23 to May 10, 1955, showed that the chemical composition of the Comal Springs water was nearly constant and the water was consistently less concentrated than the San Marcos Springs water. The Comal Springs water had about the same bicarbonate content and hardness and about half the chloride concentration that was found in the Guadalupe River water. Hence, it did not appear that water flowing from Comal Springs came from the usual flow of the Guadalupe River.

Analyses of water samples collected from Comal Springs over a period of many years are given in table of chemical analyses. Examination of the table shows considerable variation in the concentration of some constituents. Apparent changes from time to time in the hardness and concentrations of calcium and bicarbonate may be as much due to differences in length of time between collection and analysis as to changes in the quality of the spring water. The rather large fluctuations in the amount of sodium reported may not represent real changes in quality of water. Sodium was computed generally by difference and not determined; hence, the sodium variation may be due in part to the difference in cation-anion balance. The nearly constant chloride and sulfate concentrations suggest that the quality of water in the Springs changed little from year to year.

Three complete analyses of samples collected from San Marcos Springs between 1937 and 1955 are given in table of chemical analyses. They suggest that the water of San Marcos Springs is much more variable in chemical content than water from Comal Springs. Unfortunately, not enough samples of water from San Marcos Springs have been analyzed in the past to make certain that this is the case.

Chemical Analyses, San Marcos Springs

Date of Collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°)	pH
	in parts per million														
Oct. 4, 1937			90	15	17		268	22	51			335	284		
May 16, 1947	11	0.05	90	20	7.1	5.4	334	19	22	0.8	3.0	349	306	602	7.2
Mar. 9, 1955							331		15		5.2		284	559	7.3
Mar. 16, 1955							312		16		5.5		284	556	7.3
Mar. 23, 1955	13		82	21	5.2	0.5	309	17	16	1.0	4.6	334	291	556	7.4
Mar. 30, 1955							311		16		4.5		280	562	7.4
Apr. 6, 1955							310		16		6.6		280	556	7.4
Apr. 13, 1955							311		16		6.0		282	571	7.4
Apr. 20, 1955							314		16		5.4		278	556	7.5
Apr. 27, 1955							314		16		5.1		284	562	7.5
May 4, 1955							313		16		5.8		284	561	7.3
May 11, 1955							307		16		5.8		280	563	7.2
May 18, 1955							310		16		5.9		278	559	7.2
May 25, 1955							308		16		5.8		278	562	7.2
June 1, 1955							308		16		5.9		280	560	7.1

Chemical Analyses, Comal Springs

Date of Collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°)	pH
	in parts per million														
May 25, 1934							268	30	12				264		
Oct. 27, 1936			56	19	15		244	26	17			253	219		
Apr. 10, 1938			75	17	3.3		266	23	13	0.0	5.0	267	257		
June 24, 1941			63	17	18		272	23	12		3.7	271	227		
Aug. 13, 1941							272	23	11						
Sept. 16, 1941	12	0.01	73	17	4.8		264	24	12	0.1	4.4	280	252		
Apr. 2, 1942	11	0.01	70	17	11		274	22	12	0.1	4.0	288	244		
Jan. 10, 1944			78	17	5.5		280	23	13		5.5	280	264		
Jan. 22, 1944	11	0.02	74	16	6.2	3.0	270	23	12	0.4	5.5	287	250		7.6
Mar. 23, 1944							270	24	12						
Oct. 9, 1945			76	18	2.8		274	20	14		5.6	292	264		
Feb. 1, 1947			80	20	2.1		286	28	14		4.0	289	282	506	7.4
Aug. 7, 1951	13	0.21	74	17	7.2	0.4	274	22	12	0.0	4.5	292	254	507	7.5
Mar. 23, 1955							275		14				258	501	7.4
Mar. 30, 1955							277		12		4.7		258	496	7.5
Apr. 13, 1955							278		14		4.5		256	507	7.5
Apr. 27, 1955							277		13		4.8		252	504	7.3
May 10, 1955							270		13		4.5		248	506	7.3

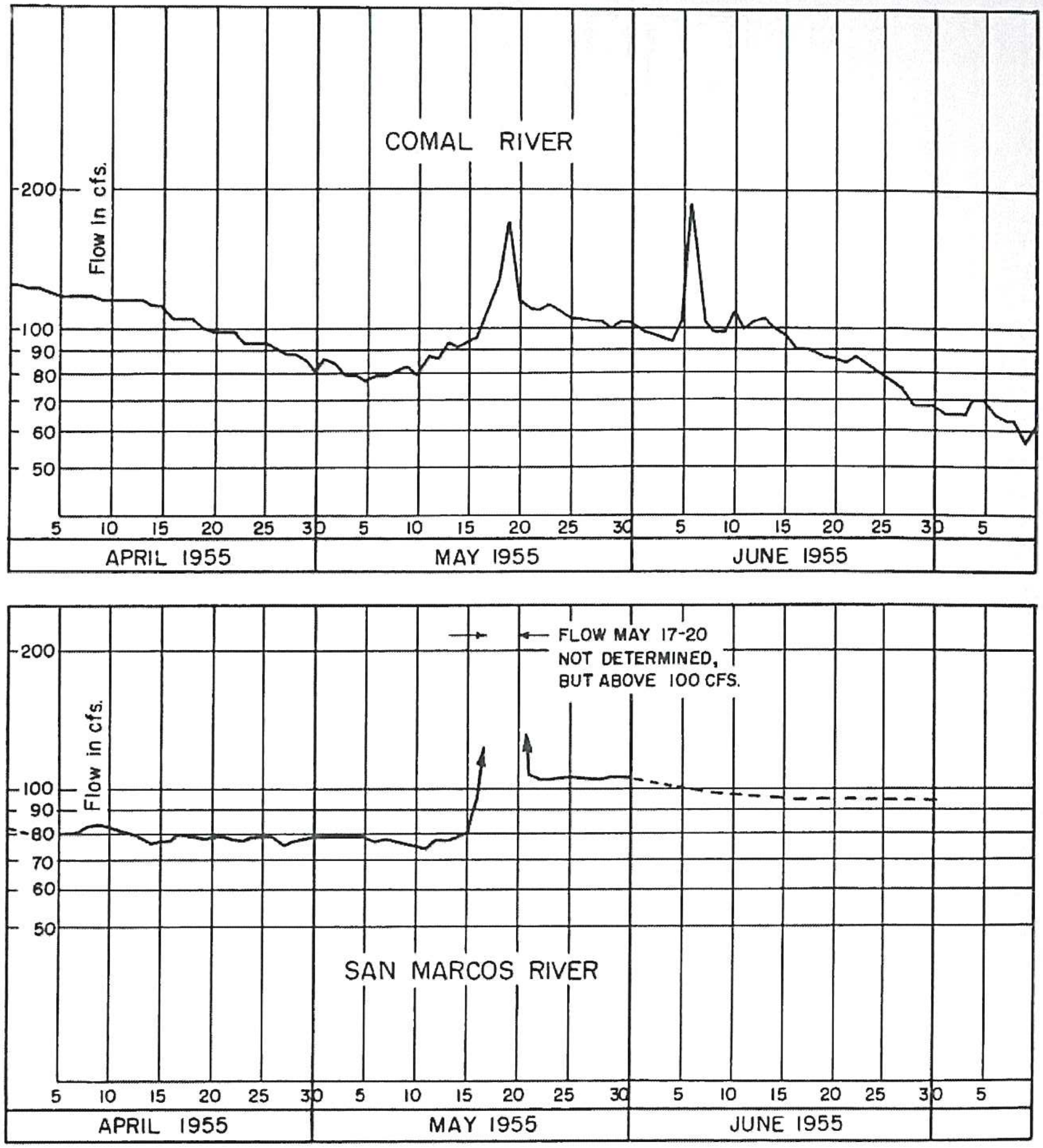

FIGURE 4.-DISCHARGE HYDROGRAPHS, COMAL RIVER AT NEW BRAUNFELS, TEX., AND SAN MARCOS RIVER AT SAN MARCOS, TEX.

Blanco River — January 24-28, 1955; March 15-16, 1955

Reach: From a point 9.6 miles upstream from Little Blanco River to U. S. Highway 81 about 3 miles northeast of San Marcos, Tex.

Conclusions and Summary: A study of the two series of measurements on the Blanco River (table of discharge measurements) shows that the two principal sources of ground water that make up the base flow of the river are the springs about 11 miles above Wimberley, and spring-fed Cypress Creek. The base flow of Cypress Creek comes from Jacobs Well, a large spring a few miles above Wimberley. There was little or no loss of water from the Blanco River until it reached the mouth of Halifax Creek, where it disappeared completely in the outcrop of the Edwards limestone. Measurements indicate that flow was practically constant during the investigation.

The table of chemical analyses gives in downstream order the analyses of samples collected in the Blanco River low-flow investigation during the period Jan. 24-28, 1955. Results of these analyses, when considered by groups, clearly show changes due to aeration and loss of carbon dioxide. Thus the analyses of samples collected from mile 4.7-14.3, 16.3-25.3, and 27.6-38.6 showed decreases in bicarbonate, hardness, and specific conductance from point to point downstream, although the chloride concentrations increased slightly. Precipitation of calcium carbonate apparently occurred slowly downstream and no admixture of new water was indicated.

During the period Jan. 24-28, 1955, discharge measurements were made at 30 locations in a 49.6 mile reach of the Blanco River, from a point 9.6 miles upstream from Little Blanco River to U. S. Highway 81 about 3 miles northeast of San Marcos, Tex. All tributary flow was measured and water samples and water temperatures obtained at each measuring section.

On March 15-16 further discharge measurements were made at the critical points in the reach. Water temperatures were obtained but no additional water samples were taken.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
	From a point 9.6 miles upstream from Little Blanco River to U. S. Highway 81 about 3 miles northeast of San Marcos, Tex.							
Jan. 24	Blanco River	At east crossing of Chimney Valley road	0		0			
24	Blanco River	--	4.8		0			
24	Blanco River	--	8.1		0			
24	Blanco River	--	9.0		0			
24	Blanco River	--	9.5		0			
24	Little Blanco River	At mouth	9.6			0.1		
24	Blanco River	700 ft below Little Blanco	9.7		0			
25	Blanco River	3 mi below Little Blanco	12.5		0			
25	Blanco River	1,000 ft above crossing on Burnet ranch	13.6		0			
25	Blanco River	30 ft above crossing on Burnet ranch	13.7	67°	2.68			Gravel.
25	Blanco River	1,000 ft below crossing on Burnet ranch	13.9		.36			
25	Blanco River	2,000 ft below crossing on Burnet ranch	14.1		.02			
25	Blanco River	300 ft below 2-story rock house	14.3		.11			
25	Blanco River	1/2 mi below rock house	14.9		0			
25	Blanco River	At concrete crossing on Fishers store road	16.3	58°	7.50			Gravel.
26	Blanco River	On G. W. Haschke ranch	18.2	50°	7.25			Gravel.
26	Blanco River	0.7 mi above hunting lodge at pool	20.4	51°	7.30			Gravel.
26	Blanco River	400 ft below gravel road crossing	23.2	52°	7.13			Gravel.
26	Blanco River	On J. S. Leach ranch opposite Samson house	25.3	53°	7.84			Gravel.
26	Cypress Creek	3/4 mi above mouth at State Highway 12	26.9	54°		2.55		Gravel.
27	Blanco River	At gaging station at Wimberley	27.6	49°	10.5			Gravel.
27	Blanco River	700 ft above concrete bridge crossing	30.1	55°	11.0			Rock channel.
27	Blanco River	20 ft above concrete bridge crossing	32.7	55°	11.1			Gravel channel.
27	Blanco River	1/2 mi below creek on left bank	34.9	60°	10.6			Rock channel.
28	Blanco River	1.0 mi above Halifax Creek	38.6	47°	10.6			Gravel channel.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Jan. 28	Halifax Creek	At mouth	39.5			0		
28	Blanco River	400 ft below draw on left bank	39.9	55°	1.36			Rock channel.
28	Blanco River	1/2 mi below previous measurement	40.4	48°	0.14			Rock channel.
28	Blanco River	1/2 mi below previous measurement	40.9		0			Rock channel.
28	Blanco River	--	41.9		0			
28	Blanco River	--	45.9		0			
28	Blanco River	--	47.6		0			
28	Blanco River	At U. S. Highway 81 crossing	49.6		0			
Mar. 15	Blanco River	At Fishers store road crossing	16.3	70°	7.70			Gravel on rock.
15	Cypress Creek	3/4 mi above mouth at State Highway 12	26.9	69°		2.60		Gravel.
15	Blanco River	At gaging station at Wimberley	27.6	73°	10.1			Gravel.
16	Blanco River	1.0 mi above Halifax Creek	38.6	68°	10.4			Rock.
16	Blanco River	About 1 mi below Halifax Creek	40.4		.3			Rock.
16	Blanco River	100 ft below previous measurement	40.4		0			Rock. End of flow.
16	Blanco River	At U. S. Highway 81	49.6		0			

Chemical Analyses, Blanco River, January 24-28, 1955

Date 1955 Jan.	Stream	Location	Disch. (cfs)	Bicarbonate (ppm)	Chloride (ppm)	Hardness as $CaCO_3$ (ppm)	Specific conductance (micromhos at 25° C)	pH
24	Little Blanco River	About 3 miles above mouth	0.2	344	13	296	549	8.0
24	Little Blanco River	At mouth	.1	291	13	262	523	7.8
25	Blanco River	30 ft above crossing on Burnet ranch	2.68	314	14	310	615	7.7
25	Blanco River	1,000 ft below crossing on Burnet ranch	.36	298	15	302	584	8.0
25	Blanco River	300 ft below 2-story rock house	.11	244	15	253	499	8.1
25	Blanco River	At concrete crossing on Fishers store road	7.50	302	14	296	572	8.0
26	Blanco River	On G. W. Haschke ranch	7.25	283	15	280	545	8.1
26	Blanco River	0.7 mi above hunting lodge at pool	7.30	260	15	274	509	8.1
26	Blanco River	400 ft below gravel road crossing	7.13	238	15	250	479	8.1
26	Blanco River	On J. S. Leach ranch opposite Samson house	7.84	236	15	245	479	8.2
26	Cypress Creek	3/4 mi above mouth at State Highway 12	2.55	282	14	247	488	8.1
26	Cypress Creek	At bridge below Jacob's Well	2.39	326	14	294	563	8.0
27	Blanco River	At gaging station at Wimberley	10.5	241	14	247	476	8.2
27	Blanco River	700 ft above concrete bridge crossing	11.0	225	16	231	450	8.2
27	Blanco River	20 ft above concrete bridge crossing	11.1	222	14	222	445	8.2
27	Blanco River	1/2 mi below creek on left bank	10.6	216	16	216	436	8.2
28	Blanco River	1.0 mi above Halifax Creek	10.6	217	16	219	440	8.2
28	Blanco River	400 ft below draw on left bank	1.36	205	16	212	420	8.2
28	Blanco River	1/2 mi below previous measurement	0.14	203	14	204	420	8.2

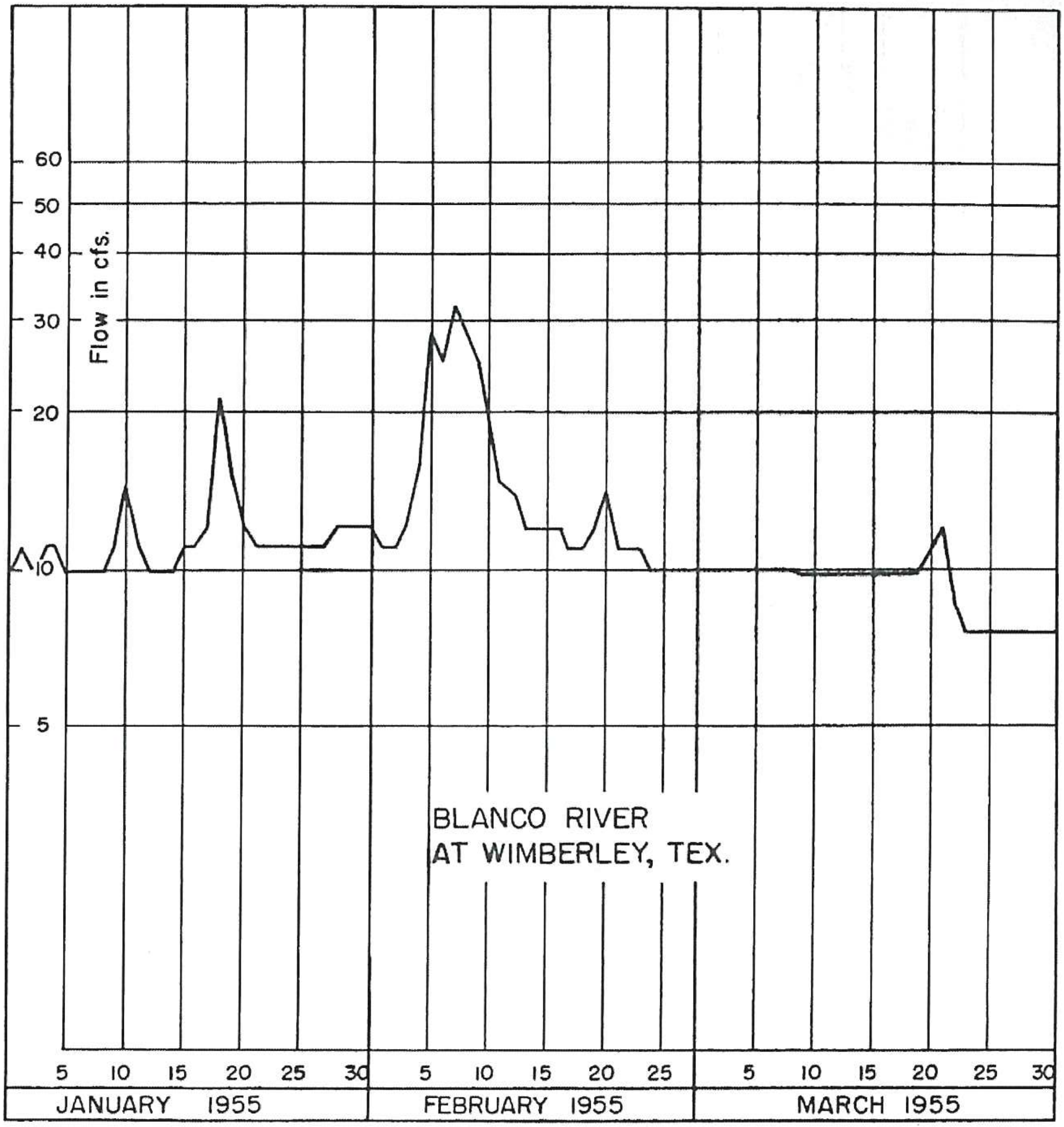

FIGURE 5.- DISCHARGE HYDROGRAPH, BLANCO RIVER AT WIMBERLEY, TEX.

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Blanco River June-July 1924

Reach: From a point at San Marcos-Wimberly crossing to International-Great Northern Railroad bridge near Kyle, Tex.

During these investigations the river was at a constant stage, and the measurements represent the natural conditions. There was no surface inflow or diversion.

Date 1924	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 12	Blanco River	At road crossing at Wimberly	0		202			Rock channel
12	Blanco River	At Falls about 1 mi above Halifax Creek	11.4		231			
12	Blanco River	At I.& G.N. Railroad bridge SW of Kyle	19.4		216			
July 16	Blanco River	At road crossing at Wimberly	0		64.7			
16	Blanco River	At Nance Ranch below Wimberly	3.7		63.2			
15	Blanco River	At Falls about 1 mi above Halifax Creek	11.4		67.7			
15	Blanco River	At I.& G.N. Railroad bridge SW of Kyle	19.4		51.9			
July 22	Blanco River	At Falls about 1 mi above Halifax Creek	11.4		58.4			
22	Blanco River	3/4 mi below Halifax Creek	13.4		53.8			
22	Blanco River	3/4 mi below Old Mill near Kyle	15.6		45.3			

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Blanco River July 10-11, 1957

Reach: From Cypress Creek at Wimberley to gaging station near Kyle, Tex.

Problem: To determine gains and losses in streamflow in the reach of Blanco River from the gaging station at Wimberley to the gaging station near Kyle, Hays County, Tex.

Results: The streamflow increased from 62.4 cfs at gaging station at Wimberley to 69.0 cfs at a point 5.2 miles downstream. Of the 62.4 cfs discharge at Wimberley gaging station, 12.1 cfs came from Cypress Creek which enters the Blanco River about one-fourth mile above the gaging station. At a point 11.1 miles downstream from the Wimberley station and 1 mile upstream from Halifax Creek, the Blanco River streamflow had dropped to 64.1 cfs; Halifax Creek was not flowing. From this measuring section one mile upstream from Halifax Creek to the gaging station near Kyle, a distance of 5.1 miles, the discharge dropped to 48.5 cfs.

Discussion: Current-meter measurements were started at Cypress Creek at 10:30 a.m. July 10 and completed at the Kyle gaging station at 4:30 p.m. July 11. Each measurement was made at a good section, either on rock or rock covered by gravel. No attempt was made to pace the measurements with the rate of change in streamflow and no time interval corrections were made. The rate of change in discharge was determined at each gaging station and was found to be fairly uniform throughout the reach. At the Wimberley station the discharge dropped 10.4 cfs in 4 days (4.2% per day) and at the Kyle station 7.5 cfs in 4 days (3.9% per day).

In the reach investigated, the Blanco River streambed is principally rock with small falls, steep rock riffles and some gravel deposits on the rock. There are many large pools, with shallow flows between: the resulting water surface exposure is large in proportion to the amount of streamflow involved, and evaporation and transpiration losses are high during the summer months when water temperatures range from 90° to 100° Fahrenheit. The gain and loss above Halifax Creek can be considered normal for the season. The loss below a point one mile above Halifax Creek, 15.6 cfs in 5 miles, is excessive for normal evaporation and transpiration losses; this water apparently is lost in a series of large pools where it seeps into the cracks and crevices in the porous streambed.

Date 1957	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Cypress Creek at Wimberley to gaging station near Kyle, Tex.							
July 10	Cypress Creek	At FM 12 crossing	0	79°		12.1		Rock.
10	Blanco River	At gaging station at Wimberley	0.5	89°	62.4			Rock and gravel.
14	Blanco River	At gaging station at Wimberley	0.5	-	52.0			Not measured. Determined from recorder record.
10	Blanco River	Above concrete bridge	3.1	95°	67.4			Rock.
10	Blanco River	Just above concrete crossing	5.7	93°	69.0			Gravel.
11	Blanco River	Morton ranch	7.9	97°	68.9			Rock and gravel.
11	Blanco River	1.0 mi above Halifax Creek	11.6	89°	64.1			Rock.
11	Halifax Creek	At mouth	12.5			0		Rock.
11	Blanco River	0.5 mi below Halifax Creek	12.9	87°	57.4			Rock and gravel.
11	Blanco River	At gaging station near Kyle	16.7	90°	48.5			Rock and gravel.
15	Blanco River	At gaging station near Kyle	16.7	-	41.0			Not measured. Determined from recorder record.

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

San Antonio River July 17, 1957

Reach: From Hildebrand Ave. to mouth of San Pedro Creek in San Antonio, Tex.

Problem: To determine gains and losses in streamflow in the section of San Antonio River within the city of San Antonio from Hildebrand Ave. just above the spring area in Brackenridge Park to the mouth of San Pedro Creek. (See accompanying sketch.)

Results: The flow increased from zero just above the spring area in Brackenridge Park to about 9 cfs at the stream-gaging station at South Alamo Street. Data are insufficient to determine gains or losses from South Alamo Street to the mouth of San Pedro Creek. San Pedro Creek was contributing 3.53 cfs at a point about 1,200 ft above its mouth. No point of diversion or loss was located.

Discussion: Current-meter measurements were made at points of critical interest or wherever significant amount of flow was found. Ponded conditions caused by small dams prevented current-meter measurements of the flow between 7th Street and South Alamo Street. Flow conditions were probably stable or near stable above the Pioneer Flour Mill.

The unregulated instantaneous flow at South Alamo Street is difficult to determine when Pioneer Flour Mill is in operation. This mill is located about 1,000 feet upstream from the South Alamo Street stream-gaging station and regulates the flow by operation of gates on a small channel reservoir. As a result, the measured discharge (12 cfs) does not represent the natural condition. Flow of about 9 cfs was estimated at this point on basis of mean discharge for the month (9.7 cfs) as determined at the gaging station. The effect of regulation extends downstream, and current-meter measurements below South Alamo Street likewise do not represent the natural condition.

The flow measured in the 8 mile reach above South Alamo Street comes partly from wells in Brackenridge Park and partly from water emptied into the river from industrial wells; it is impossible to recognize or identify the many small contributions that come into the river in this highly developed reach.

Date 1957	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
July 17	San Antonio R	200 ft above Hildebrand Ave.	0		0			
17	Pump	In channel under Hildebrand Ave.	0			0.8		Estimate.
17	Zoo well	Combined flow from canal	.8			1.5		Estimate.
17	San Antonio R	In Brackenridge Park 125 ft below dam	.9	82°	3.81			Gravel channel.
17	San Antonio R	In Brackenridge Park 300 ft above mill race	2.0	84°	4.27			40 ft above foot bridge.
17	Mill race	In Brackenridge Park 100 ft above mouth	2.1			.02		No flow at upper end.

Date 1957	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
July 17	San Antonio R	At Josephine St.	2.3	84°	5.73			Claybed.
17	Storm sewers	25 ft below Josephine St.	2.3			.05		From left bank - estimate.
17	San Antonio R	150 ft below Jones St.	3.0	84°	6.09			Gravel channel.
17	San Antonio R	At 7th St.	3.7	85°	6.62			
Ponded conditions prevented measuring discharge between 7th St. and S. Alamo St. Part of increased flow at S. Alamo St. is released water from Pioneer Flour Mill reservoir.								
17	San Antonio R	At gaging station at S. Alamo St.	5.8	86°	12.0			Gravel channel.
17	San Antonio R	75 ft above Simpson St.	6.7	87°	12.0			Flow regulated by flour mill.
17	San Antonio R	500 ft below service company plant	7.2	89°	14.2			Flow regulated by flour mill.
17	San Antonio R	200 ft above San Pedro Creek	8.0	90°	14.5			Flow regulated by flour mill.
17	San Pedro Creek	1/4 mi above mouth	8.1	93°		3.53		600 ft below Mitchell St.

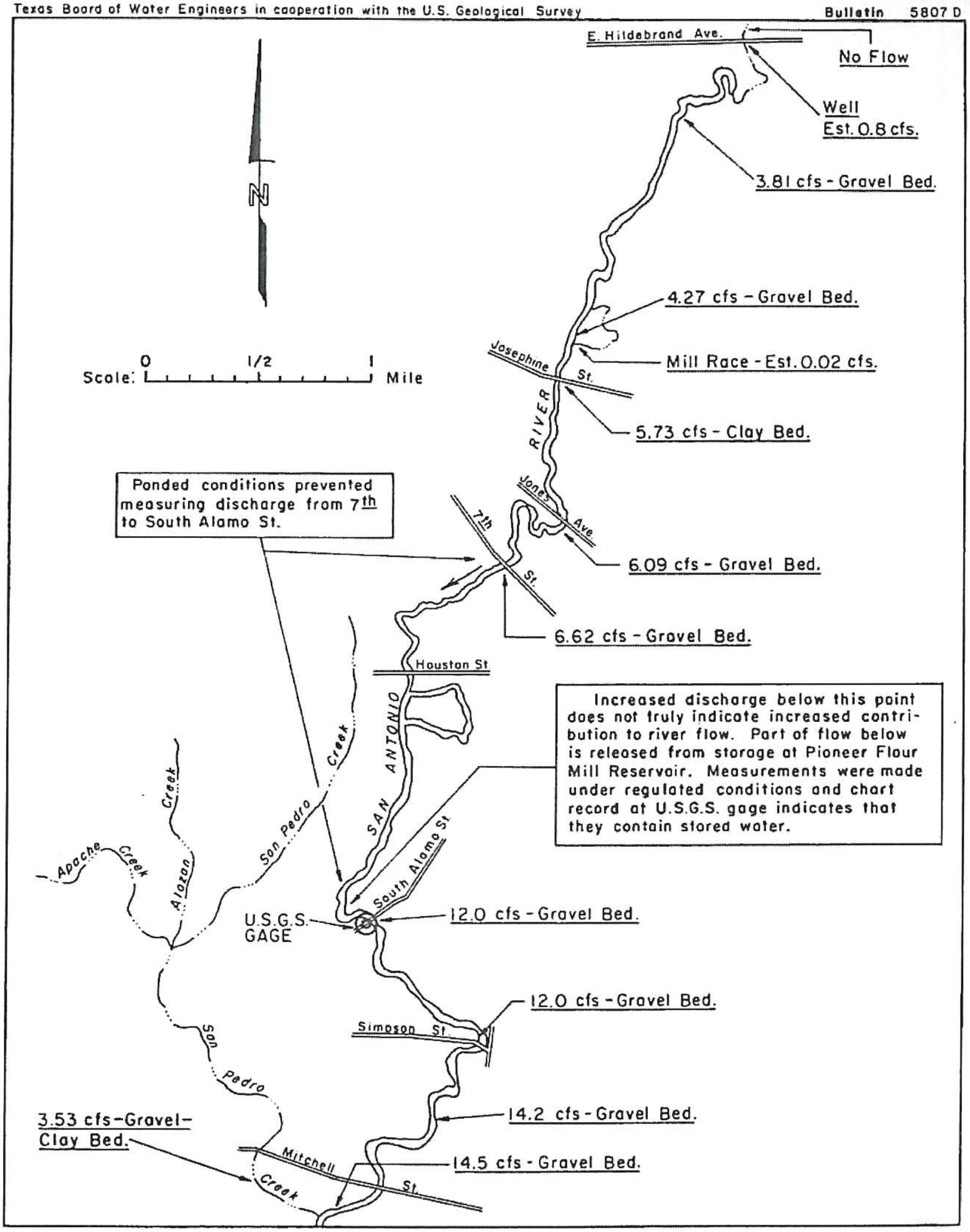

FIGURE 6 – LOW FLOW IN INVESTIGATION OF THE SAN ANTONIO RIVER AT SAN ANTONIO, TEXAS

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Medina River　　　　June 3-5, 1925

Reach: From a point 5 miles above Lima to 4 miles below Pipe Creek, Tex.

During these measurements the river was at a constant stage.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 3	Medina River	5.3 mi NW of Lima	0		1.0			
3	Medina River	3.5 mi NW of Lima	2.0		3.4			
3	Onion Creek	3.5 mi NW of Lima	2.1			1.0		
3	Medina River	1.4 mi NW of Lima	4.5		6.4			
3	Brewington Creek	.8 mi NW of Lima	6.3			.2		
3	Medina River	3.4 mi SE of Lima	11.1		4.6			
3	Chalk Creek	4.9 mi SE of Lima	12.8			.2		
3	Medina River	5.0 mi SE of Lima	12.9		3.6			
3	Medina River	1.0 mi NW of Medina	16.1		8.4			
3	S Prong Medina	At Medina	17.7			1.5		
3	Medina River	3.3 mi SE of Medina	22.8		10.5			
4	Medina River	3.3 mi SE of Medina	22.8		10.1			
4	Weinans Creek	3.5 mi NW of Bandera	25.6			.2		
4	Medina River	4.7 mi NW of Bandera	25.9		12.0			
4	Medina River	At Bandera	34.2		10.9			
4	Myrtle Creek	1.4 mi NE of Bandera	36.2			.1		
4	Medina River	4.1 mi SE of Bandera	38.6		10.5			
5	Cold Springs	3.0 mi SW of Pipe Creek	41.7			5.0		
5	Medina River	3.0 mi SW of Pipe Creek - gaging station	41.7		13.4			
5	Medina River	4.2 mi SW of Pipe Creek	43.8		11.4			

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Medina River — January 3-7, February 17-18, September 6-7, 1955

Reaches: From a point 8.3 miles above Medina to a point 1.5 miles below Bandera - Medina county line, Tex.
From Bandera to Turks Head Mountain in Medina Lake, Tex.
From Wallace Creek, 5.8 miles above Medina to Turks Head Mountain in Medina Lake, Tex.

Problem: To determine gains and losses in streamflow in the section of Medina River from Bandera to Medina Lake, Tex.

Results: Data obtained in the three sets of measurement indicate that two sections of the channel lose small amounts of base flow. The upper losing section is about 8 miles long and extends from Bandera to the spring area 1.6 miles above the stream-gaging station near Pipe Creek; in February 1955 this reach absorbed about 9 cfs of flow. The second losing reach, extent not known, is located in the vicinity of the fault that crosses the river 4.5 miles below the gaging station near Pipe Creek; in February and in September 1955, this reach absorbed about 3.5 cfs of flow. The only source of inflow of consequence is Cold Spring, which enters the river about 1.6 miles upstream from the stream-gaging station near Pipe Creek, at the site of a former stream-gaging station (1923-34). Although the scope of these investigations did not include any portion of the stream above Bandera, a few estimates were made in the 28 mile reach above that point. The estimates indicate that probably most of the base flow developed by this stream comes from the watershed above Bandera; and that some water may be absorbed in the channel between Medina and Bandera.

Discussion: Current-meter measurements were made at all points where there were appreciable amounts of flow; many small flows were estimated. The channel was investigated throughout the reach and the discharge measurements were made as rapidly and as thoroughly as possible. No attempt was made to pace the measurements with the rate of change in flow as the investigation progressed downstream. The rate of change in flow was determined at the Pipe Creek stream-gaging station. Flow was practically constant during the January and February periods; and was decreasing during the September investigation, recorder record showing a decrease in flow from 5.01 to 3.80 cfs between September 7 and 11. No lakes with channel dams were found and no irrigation equipment was seen; however, it is likely that a considerable quantity of water is used to irrigate small acreages in the river valley above Bandera.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 8.3 miles above Medina to a point 1.5 miles below Bandera - Medina county line							
Jan. 3	Medina River	0.5 mi below Rocky Creek	0		0			Gravel channel.
3	Medina River	Just below Wallace Creek	2.5		0			Gravel channel.
3	Medina River	At Medina	8.3		1.5			Estimate. Gravel channel.
3	Medina River	State Highway 16, above Indian Cr	22.5		.15			Estimate. Gravel channel.
3	Medina River	FM 689, at Bandera	27.8		.01			Estimate. Gravel channel.
3	Bandera Creek	At mouth	29.5			0		Rock streambed.
3	Medina River	Just below Bandera Creek	29.5		0			Rock streambed.
4	Medina River	3 mi below Bandera Creek	32.4		0			Rock streambed.
4	Medina River	Just above Privilege Creek	33.9		0			Gravel channel.
4	Privilege Creek	At mouth	33.9			0		Gravel channel.
4	Artesian well	Left bank, just below creek	33.9			.01		Estimate.
4	Medina River	--	35.7		0			Channel of gravel and boulders.
4	Medina River	--	36.6		0			Channel of gravel and boulders.
4	Big Spring	1,500 ft above Cold Spring	36.9			.2		Estimate. On left bank in edge of river.
4	Seep Spring	1,000 ft above Cold Spring	37.0			.1		Estimate. Beginning of rock streambed. Flow at top of rock on right bank.
4	Artesian well	Right bank	37.1			.01		Estimate. 50 ft from river.
4	Cold Spring	At site of discontinued gaging station on Medina River	37.2			.35		Estimate. On right bank.
4	Medina River	Just below discontinued gaging station	37.3	68°	.9			Gravel over rock.
4	Medina River	At gaging station near Pipe Cr	39.0	61°	1.0			Rock streambed.
6	Medina River	At gaging station near Pipe Cr	39.0		.9			Not measured. From continuous recorder record.
5	Red Bluff Cr	At mouth	39.8			0		Rock.
5	Medina River	Just below Red Bluff Creek	39.8		1.0			Estimate. Rock streambed.
6	Medina River	0.5 mi above tributary from left	43.0		.7			Estimate. Gravel channel.
6	Tributary	From left	43.5			0		Estimate. Gravel channel.
6	Medina River	100 ft below tributary	43.5		0			Flow disappears in bar of large loose gravel.
6	Medina River	--	44.1		0			Rock streambed.
7	Medina River	--	44.8		0			Gravel channel.
7	Medina River	0.5 mi below Bandera-Medina county line	46.1		0			Gravel channel.
7	Medina River	--	47.1		0			Road crossing on natural rock streambed.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Bandera to Turks Head Mountain in Medina Lake							
Feb. 17	Medina River	FM 689, at Bandera	27.8	62°	10.4			Gravel over rock channel.
17	Privilege Cr	At mouth	33.9			0		Gravel channel.
17	Medina River	500 ft below Privilege Creek	34.0	65°	4.06			Gravel over rock channel.
18	Medina River	Above springs	36.6		1.0			Estimate. Channel of gravel and boulders.
18	Big Spring	1,500 ft above Cold Spring	36.9			.2		Estimate. On left bank in edge of river.
18	Seep Spring	1,000 ft above Cold Spring	37.0			.1		Estimate. Beginning of rock streambed. Flow at top of rock on right bank.
18	Artesian well	Right bank	37.1			0.05		Estimate. 50 ft from river.
18	Cold Spring	At site of discontinued gaging station on Medina River	37.2			9.0		Estimate. On right bank.
18	Medina River	At gaging station near Pipe Creek	39.0	63°	10.1			Rock streambed.
23	Medina River	At gaging station near Pipe Creek	39.0		10			Not measured. From continuous recorder record.
18	Medina River	0.5 mi below Bandera-Medina county line	46.1	65°	6.52			Gravel channel.
18	Cypress Creek	At mouth, from right bank	48.2			0		Gravel channel.
18	Medina River	At Turks Head Mountain	48.2		6.13			Gravel channel.
	From Wallace Creek, 5.8 miles above Medina to Turks Head Mountain in Medina Lake							
Sept. 6	Wallace Creek	At mouth	2.5			0		Gravel channel.
6	Medina River	Just below Wallace Creek	2.5		.3			Estimate. Gravel channel.
6	Medina River	At Medina	8.3		5.0			Estimate. Gravel channel.
6	Medina River	State Highway 16, above Indian Creek	22.5		3.0			Estimate. Gravel channel.
6	Medina River	FM 689, at Bandera	27.8	78°	2.80			Gravel over rock channel.
6	Medina River	100 ft above Bandera Creek	29.4	80°	2.56			Gravel.
6	Bandera Creek	At mouth	29.5			0		Rock channel.
6	Medina River	--	31.1		1.0			Broken rock channel.
6	Medina River	--	31.2		.4			Broken rock and gravel channel.
6	Medina River	3 mi below Bandera Creek	32.4		.1			Estimate. Rock streambed.
7	Medina River	Just above Privilege Creek	33.9		0			Gravel channel.
7	Privilege Creek	At mouth	33.9			0		Gravel channel.
7	Artesian well	Left bank, just below creek	33.9			.01		Estimate.
7	Medina River	--	35.7		0			Streambed of gravel and boulders.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
From Wallace Creek, 5.8 miles above Medina to Turks Head Mountain in Medina Lake, continued								
Sept. 7	Artesian well	--	35.7			.01		Estimate. In overflow channel.
7	Medina River	—	36.6		0			Streambed of gravel and boulders.
7	Big Spring	1,500 ft above Cold Spring	36.9			.1		Estimate. On left bank in edge of river.
7	Seep Spring	1,000 ft above Cold Spring	37.0			.02		Estimate. Beginning of rock streambed. Flow at top of rock on right bank.
7	Artesian well	Right bank	37.1			.02		Estimate. 50 ft from river.
7	Cold Spring	At site of discontinued gaging station on Medina River	37.2	72°		5.0		Estimate. On right bank.
7	Medina River	200 ft below discontinued gaging station	37.3	74°	5.60			Rock and gravel streambed.
7	Medina River	At gaging station near Pipe Creek	39.0	75°	5.01			Rock streambed.
11	Medina River	At gaging station near Pipe Creek	39.0		3.8			Not measured. From continuous recorder record.
7	Red Bluff Creek	At mouth	39.8			.2		Estimate. Rock streambed.
7	Medina River	0.5 mi above tributary from left	43.0	79°	3.63			Gravel channel.
7	Medina River	0.5 mi below Bandera-Medina county line	46.1	77°	1.44			Gravel channel.
7	Cypress Creek	At mouth, from right bank	48.2			0		Gravel channel.
7	Medina River	At Turks Head Mountain	48.2	78°	.82			Gravel channel.

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Medina River December 9, 1924

Reach: From Main Dam to Riomedina Crossing near Riomedina, Tex.

During these measurements the river was at a constant stage.

Date 1924	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Dec. 9	Medina River	At road crossing ½ mi below Dam	0		20.6			
9	Medina River	Just below Diversion Dam	3.3		22.1			No flow in Medina Canal
9	Medina River	At Haby's crossing	4.1		24.4			
9	Medina River	At Yellow Bank School	8.1		25.9			
9	Medina River	At Riomedina crossing	10.9		27.2			

Medina River — July 1929 to December 1930

Reach: From Medina Dam to Losoya, Tex.

Staff gages, each having a range of about 3 feet, were installed at the stations listed below. From 11 to 15 discharge measurements were made at each station. On several occasions the stage rose above the gages; at those times and at times of apparent local run-off from rains daily discharge was not determined. Records good for stations near Cassin and below Von Ormy; fair for other stations.

Near Mico, Tex.--On left bank 600 feet above Stegall Bridge, 2,000 feet below Medina Dam, and 1 mile southwest of Mico post office, Medina County. Gates in dam closed Oct. 6-20, 23-30, Nov. 1-4, 8-20, 25-30, Dec. 1, 2, 7-14, 22-31. One discharge measurement made Mar. 20, 1931, while gates were closed, used as basis for estimating discharge for these periods. Period of record, Jan. 1 to Dec. 31, 1930.

Near Riomedina, Tex.--On right bank 2,000 feet below diversion dam and 6 miles west of north of Riomedina, Medina County. Period of record, Nov. 11, 1929, to Dec. 31, 1930.

Above Castroville, Tex.--Since Oct. 1, 1929, on right bank just above Draugel's road crossing and 2 miles north of Castroville, Medina County. Prior to Oct. 1, 1929, on right bank about half a mile below dam at Castroville and below return water of power plant. Period of record, July 9, 1929, to Sept. 30, 1930.

Below Von Ormy, Tex.--On left bank 50 feet below San Antonio-Somerset highway bridge and 2½ miles below International-Great Northern Railroad bridge at Von Ormy, Bexar County. Period of record, July 9, 1929, to Dec. 31, 1930.

Near Cassin, Tex.--On right bank about 500 feet northwest of J. N. Arnold's house and 1¼ miles above San Antonio, Uvalde & Gulf Railway bridge at Cassin, Bexar County. Period of record, July 10, 1929, to Dec. 31, 1930.

At Losoya, Tex.--On right bank just below bridge over Medina River on old San Antonio-Corpus Christi road, one-fourth mile from Losoya, Bexar County, and 3½ miles below Mitchell Lake. Period of record, Oct. 1, 1929, to Dec. 31, 1930.

Daily discharge records for the above temporary gaging stations are published in Water Supply Paper 703, pages 89-93.

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Medina River May 26-28, 1925

Reach: From Medina Valley Irrigation Company diversion dam to Losoya, Tex., near mouth.

During these measurements the river was at a constant stage. The diversion dam is 63.8 miles below initial measurement of low-flow investigation above the dam made June 3-5, 1925.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
May 26	Medina River	Just below diversion dam	0		15.5			
26	Medina River	At Haby's Crossing	.8		19.6			
26	Medina River	At Yellow Bank School Crossing	4.8		22.0			
26	Medina River	At Riomedina Crossing	7.6		24.8			
26	Windmills	From 3 to 5 mi SW of Riomedina	10.2 12.1				0.5	
26	Medina River	Just below dam at Castroville	17.2		17.2			
27	Medina River	Just below dam at Castroville	17.2		18.0			
27	Medina River	3 mi below Castroville	19.5		20.7			
27	H.J.Rice Irrigation Canal	Near LaCoste	23.3				.8	
27	John Biebert Canal	Near Idylwild School	26.2				1.2	
27	Medina River	½ mi N of Idylwild School	26.3		14.6			
27	Medina River	At Canyon Road 5¼ mi NW of Von Ormy	31.8		9.2			
28	Medina River	At Canyon Road 5¼ mi NW of Von Ormy	31.8		8.8			
28	Medina River	At Highway No. 2 about 1½ mi NW of Von Ormy	37.1		10.2			
28	Medina River	1-3/4 mi SE of Von Ormy	41.8		11.7			
28	Medina River	4 mi SE of Von Ormy	45.2		9.2			
28	Medina River	3½ mi SW of Earle	47.3		11.0			
28	Leon Creek	At mouth near Earle	51.1			1.4		
28	Medina River	At Highway No. 9 near Earle	51.3		10.0			
28	Seepage from Mitchell Lake		53.4			3.5		
28	Medina River	At Losoya near mouth	55.1		14.7			

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Cibolo Creek — January 17-19, 28-30, 1958

Reach: From a point 7.5 miles above Boerne, Kendall County, to stream-gaging station at Selma, Bexar County.

Problem: To determine gains and losses in streamflow in Cibolo Creek above the stream-gaging station near Selma, Bexar County.

Results: During this investigation Cibolo Creek developed a maximum base flow of 129 cfs, most of which originates in Kendall County. All of this flow is lost into holes and fissures in that section of channel from a point 2 miles below Boerne to a point above Selma, a distance of about 42 miles.

Related geology: References to geology in this report are based on findings of W. O. George in WSP 1138 "Geology and Ground Water Resources of Comal County, Texas". For convenience of reference, George (1952, p. 17) arbitrarily divided the Glen Rose limestone into two parts which were referred to as upper and lower members of the Glen Rose limestone. The formation in Kendall and Comal counties ranges from 650 to 1,200 feet thick and the division between upper and lower members is made at the top of a well-known fossiliferous zone called the "Salenia texana" zone which occurs somewhat below the middle of the formation. The contact of the upper and lower members of the Glen Rose limestone is shown on a map by George (1952, plate 2). The results of discharge measurements made in this investigation have been referenced to the map by George (1952, plate 2); references indicate that the heavy losing sections in lower Kendall County and upper Comal County are on the lower member of the Glen Rose limestone. This bears out the following statements made by George (1952, p. 58, 59): "Between the mouth of Balcones Creek and the Bulverde gaging station the bed of the creek is in the lower member of the Glen Rose limestone and the losses in this part of the stream appear to be large. Between the Bulverde station and the Bracken station, the bed of Cibolo Creek is in the upper member of the Glen Rose limestone and the losses in this area are relatively small. Between the Bracken gaging station and the bridge at Bracken the bed of the creek is in the Edwards limestone which is honeycombed and broken by many small faults. Here the losses are believed to be large in proportion to the amount of water that reaches this stretch of the stream. Most of the rainfall in the upper reaches of the Cibolo, however, is intercepted by infiltration into the Glen Rose limestone before it reaches the Edwards limestone at Bracken gaging station. It is believed that most of the water entering caverns in the lower member of the Glen Rose limestone in this area passes laterally through underground channels into the Edwards limestone."

Discussion: Current-meter measurements were made at points of critical interest; field estimates were made where flows were small or unimportant. No attempt was made to pace the measurements with the rate of change in flow as the investigation progressed downstream. The channel was investigated throughout the reach and the measurements were made as rapidly and as thoroughly as possible. Measurements from mile 27 to Selma gaging station, mile 56, were made during the period Jan. 17-19. The information obtained introduced questions which could be answered only by investigation of the upstream portion of the reach. This further investigation was made during the period Jan. 28-30 and check measurements at mile 28.7 and 35 were obtained in order to relate change in flow conditions during the intervening period. The rate of change in flow in the upper part of the reach is indicated by two measurements at mile 5.4. The discharge at this point dropped 2.7 cfs (7%) in 2 days. At the Bulverde gaging station the flow dropped 12 cfs (39%) from Jan. 30 to Feb. 1 and flow had ceased on Feb. 9.

The crevice at the mouth of Balcones Creek described by George (1952, p. 56) was observed and was found to be taking considerable water. It is near the head of backwater from a small channel dam and at present has a three-foot concrete wall around it. The water was flowing over the top of the wall and gave the appearance of a "Glory Hole" type spillway. The amount of water entering this crevice was estimated as between 2 and 4 cfs. Another hole in the rock was found in the center of the channel about 100 feet above the gage near Selma. There was no flow at this point during this investigation but the hole, which is large enough to admit a small man, leads to a sizable cavern a few feet below the surface. During times of flow a pool is formed at this point and a vortex appears over the hole. George (1952, p. 58) makes the following statement about this section of channel: "Between the bridge at Bracken and the Selma gaging station about one mile below the crossing, the creek bed is in the Austin chalk and the losses in this stretch are probably small."

Several channel dams were located, each with small storage capacity; no diversion was apparent. No portable irrigation pumps were located but a number of small acreages were noted that probably are irrigated during the growing season.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Jan. 28	Tributary	At mouth	0	55°		3.0		Estimate.
28	Cibolo Creek	75 ft below upper Cibolo road	0	55°	11.8			Rock streambed - gravel banks.
28	Ranger Creek	At mouth	5.4	58°		4.0		Estimate.
28	Cibolo Creek	175 ft below Ranger Creek road	5.4	58°	37.7			Rock streambed.
30	Cibolo Creek	175 ft below Ranger Creek road	5.4	52°	35.0			Second measurement made to indicate flow fluctuation.
28	Frederic Creek	0.5 mi above mouth	7.5	61°		30.1		Gravel and clay streambed.
28	Menger Creek	0.5 mi above mouth	9.6	62°		13.1		Gravel streambed.
28	Cibolo Creek	300 ft below Menger Creek	9.6	62°	98.7			Broken rock streambed. Grove of large cypress trees.
29	Cibolo Creek	Near Cascade cavern	12.5	56°	89.0			Smooth rock streambed.
29	Cibolo Creek	500 ft above Balcones Creek	14.6	57°	80.0			Gravel streambed.
28	Balcones Creek	At upper Balcones road - 8 mi above mouth	14.7	59°		6.06		Gravel and clay streambed.
29	Balcones Creek	900 ft above mouth	14.7	56°		28.6		Rock streambed.
30	Postoak Creek	3.5 mi above mouth	16.0			10		Estimate - rock streambed.
30	Postoak Creek	At mouth	16.0			1.5		Estimate - gravel and rock.
30	Cibolo Creek	On George Ranch - 1/2 mi below crossing	21.5	55°	72.3			Streambed of large gravel. Very rough.
30	Cibolo Creek	Schaeffer ranch - 500 ft below crossing	23.6	56°	68.0			Rough, broken rock streambed.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Jan. 17	Cibolo Creek	1/4 mi above Blanco road	27.0	49°	38.8			Gravel on rock streambed.
17	Cibolo Creek	50 ft below Specht's crossing	28.7	50°	32.1			Gravel on rock streambed.
30	Cibolo Creek	50 ft below Specht's crossing	28.7	59°	47.1			Gravel on rock streambed.
17	Cibolo Creek	2-1.2 mi above U. S. Highway 281	30.5	51°	29.3			Clay streambed.
30	Indian Creek	3 mi above mouth	32.2			0		Rock streambed.
17	Cibolo Creek	At gaging station near Bulverde	35.0	52°	20.4			Rock streambed.
30	Cibolo Creek	At gaging station near Bulverde	35.0	59°	27.5			Rock streambed.
17	Cibolo Creek	2 mi below gaging station - 50 ft above private water crossing	37.0	53°	20.0			
18	Cibolo Creek	2 mi above Dripping Springs Creek	37.7	52°	17.4			Gravel and silt streambed.
18	Dripping Springs Creek	2 mi above mouth	39.7			.1		Estimated.
18	Cibolo Creek	200 ft upstream from county road	42.6	50°	10.0			Rock and gravel streambed.
18	Cibolo Creek		44.0	57°	15.2			Gravel on rock streambed.
18	Clear Fork Cibolo Creek	At mouth	49.3					Not inspected.
18	Cibolo Creek	At discontinued gaging station near Bracken	49.5	54°	17.5			Gravel streambed.
19	Cibolo Creek	At N. J. Marback ranch 1/2 mi downstream from Yellow Bluff	51.6	52°	5.26			Gravel streambed.
19	Cibolo Creek	3/4 mi below Yellow Bluff	51.9		0			
19	Cibolo Creek	Gaging station at Selma	56.0		0			

LOW-FLOW INVESTIGATIONS - GUADALUPE RIVER BASIN

Cibolo Creek September 12, 13, 1949

Reach: From Schertz to gaging station near Falls City, Tex.

The investigation was made during a constant stage and determinations of gain or loss represent normal conditions. All tributaries were measured and there was no diversion in the reach.

Date 1949	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Sept. 12	Cibolo Creek	At farm road 78 at Schertz	0		0			
12	Cibolo Creek	.4 mi above Highway 90 near Zuehl	10		1.56			
12	Santa Clara Creek	Near mouth and 2½ mi east of Zuehl	18			0		
12	Martinez Creek	2 mi above mouth and 2½ mi south of Zuehl	22			0		
12	Cibolo Creek	¼ mi below county road at Lavernia	29		1.79			
12	Blue Creek	½ mi above mouth and 2 mi east of Lavernia	30.6			.05		
12	Cibolo Creek	3¼ mi above Sutherland Springs	33.6		3.95			
12	Cibolo Creek	1.0 mi above Sutherland Springs	36.0		10.8			
13	Cibolo Creek	.2 mi below Sutherland Springs	38.0		11.6			
13	Cibolo Creek	Near Falls City - gaging station	62.0		14.0			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River — March and August 1924

Reach: From Odley Creek 14 mi above Barksdale to La Pryor crossing 4.7 mi below S.A.U.& G. Railroad bridge, Tex.

Seepage measurements were made on the Nueces River from mouth of Odley Creek to La Pryor crossing during March and August 1924. There were no unusual conditions during this investigation, and the measurements represent the natural conditions.

Date 1924	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Mar. 10	Nueces River	At O.S.T. crossing	59.1		0.1			Estimate
10	Nueces River	At Tom Nunn crossing	61.1		25.3			
11	Nueces River	At Tom Nunn Hill damsite	62.7		26.9			
17	Nueces River	Just below Odley Creek near Vance	0		1.0			
17	Nueces River	Just above unnamed spring $1\frac{1}{2}$ mi below Odley Creek	1.5		.9			
17	Unnamed Spring	$1\frac{1}{2}$ mi below Odley Creek	1.5			11.2		
17	Nueces River	Near Vance	8.3		55.1			
18	Nueces River	At Barksdale 500 ft below highway crossing	14.2		39.2			
22	Nueces River	At Barksdale 500 ft below highway crossing	14.2		70.4			
22	Nueces River	At Camp Wood below Camp Wood Creek	18.1		126			
22	Nueces River	300 ft above Montell Creek at Montell	29.4		78.7			Large underground flow.
22	Montell Creek	At mouth	29.5			.2		Estimate.
22	Nueces River	At reservoir site above Laguna	37.2		142			
23	Nueces River	At gaging station at Laguna	40.2		149			
24	Nueces River	At Chalk Bluff	45.3		115			
24	Nueces River	At Riverview 3 mi below Chalk Bluff	49.3		123			
24	West Nueces River	At mouth	51.8			0		
24	Nueces River	Just below West Nueces R	51.8		64.7			
24	Nueces River	At Southern Pacific Railroad crossing	56.3		34.6			

Date 1924	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Mar. 25	Nueces River	At O.S.T. crossing 2½ mi below Southern Pacific Railroad	59.1		1.2			Estimate.
25	Nueces River	At Tom Nunn crossing	61.1		22.8			
25	Nueces River	At Tom Nunn Hill damsite	62.7		23.7			
25	Nueces River	At old Eagle Pass crossing (concrete slab)	66.6		37.6			
26	Nueces River	At S.A.U.& G. Railroad bridge	69.6		29.2			
26	Nueces River	At La Pryor road crossing	74.4		32.2			
Aug. 11	Nueces River	Near Vance	8.3		0			
12	Nueces River	At Barksdale	14.2		0			
12	Nueces River	At Camp Wood	18.1		20.0			
12	Nueces River	At Montell	29.4		0			
12	Montell Creek	At mouth	29.4			0		
13	Nueces River	At reservoir site above Laguna	37.2		24.0			
13	Nueces River	At gaging station at Laguna	40.2		17.1			
13	Nueces River	At Chalk Bluff	45.3		0			
13	Nueces River	At mouth of West Nueces R	51.8		0			
13	Nueces River	At Southern Pacific Railroad crossing	56.3		0			
13	Nueces River	At O.S.T. crossing	59.1		0			
18	Nueces River	At Tom Nunn crossing	61.1		27.0			
18	Nueces River	At La Pryor road crossing	74.4		21.0			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River — December 13-15, 1954; February 16, September 19-20, 1955; July 8-10, 1957

Reaches: From Barksdale, Edwards County to gaging station at Laguna, Uvalde County.
From Real-Uvalde County line to gaging station at Laguna, Uvalde County.

Problem: To determine gains and losses in streamflow in the section of Nueces River channel that is on the Glen Rose limestone between Barksdale and the gaging station at Laguna.

Results: Data obtained in the four sets of measurements made indicate that no material losses occurred in the 25 miles of channel investigated. Large contributions from springs and tributaries were found in the 8-mile reach from Barksdale to the Edwards, Real, Uvalde County line. Below the county line no inflow of consequence was found from any source. Throughout the reach the stream channel is composed of loose gravel of unknown depth which overlies the smooth rocks of the Glen Rose limestone.

Discussion: Current-meter measurements were made at all points of critical interest; many small flows were estimated. No attempt was made to pace the discharge measurements with the rate of change in flow as the investigation progressed downstream. The channel was investigated throughout the reach and the measurements were made as rapidly and as thoroughly as possible. The rate of change in flow was determined at the Laguna gaging station. Flow conditions were practically constant during the 1954-55 investigations but were dropping 2% per day during the July 1957 period, the recorder record showing a decrease in flow from 84 to 65 cfs from July 6 to 14.

All of the main stream measuring sections are on porous gravel except at mile 23.3 and discharge shown represents surface flow only. Section at mile 23.3 is on smooth rock but material amounts of water could have been flowing through the extensive gravel deposit to the right of the measuring section. The 1957 measurements indicate that as much as 50 cfs of surface flow had disappeared below the gravel at the upper Montell crossing (at mile 14.1). Very likely there was underflow through the gravels at all of the measuring sites including that at the Laguna gaging station.

The so-called "Spring Creeks" that flow along the edges of the wide gravel channel in the Montell area are probably flowing river water. Apparently, the gravel deposits are higher in the center of the channel having been built up by bed load gravel moving downstream during floods. The flood channel widens at the upper Montell crossing and velocities sufficient to move gravel do not extend into the wooded bays along the banks. Hence the surface of the gravel beds slope from the center toward the edges and have their lowest elevation near each bank. Water flowing laterally through the gravels appears in the "Spring Creek" channels. During the 1954-55 investigations there was no surface flow in the vicinity of the upper Montell crossing. At a short distance below the crossing the flow appears in the "Spring Creeks". No doubt the Montell settlement and the much earlier Indian Mission were located here because of the bountiful "spring flow" along the conglomerate bluff on the right bank. There is also evidence of ancient Indian camp grounds in the liveoak motts along this bluff.

No channel dams are in the reach investigated but several irrigation pumps were found. These pumps, trailer or skid mounted, are used in irrigating small acreages of alfalfa and other feed crops. During drought years this pumpage can deplete the surface flow to near zero.

Date 1954	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
	From Barksdale,	Edwards County to gaging station at Laguna, Uvalde County						
Dec. 14	Nueces River	Barksdale - 100 ft below highway	0	58°	9.11			Porous gravel streambed.
13	Spring	On right bank	0.6			0.5		Estimated. Not from river gravels.
13	Spring	On right bank	1.5			1.5		Estimated. Not from river gravels-not measurable.
13	Spring	On left bank	1.7			5-10		Boiling spring in flowing river channel.
13	8" pump	On left bank	1.9				0	Not pumping.
13	Nueces River	About 2 mi below Barksdale	1.9	61°	14.8			Porous gravel streambed.
13	Camp Wood Creek	At mouth	3.1			0		Porous gravel streambed.
13	Pulliam Creek	At mouth	3.2			1.0		Estimated. Very porous gravel streambed.
13	Unnamed Spring Branch	Near mouth	3.5			1.0		Estimated. Flow from large spring 0.5 mi from river-Camp Wood City supply.
13	Nueces River	Camp Wood - Gravel water crossing	3.7	63°	27.3			Wide gravel streambed.
13	Tributary	From right	4.2			1.0		Estimated. Gravel streambed.
13	Tributary	From right	5.6			0		Gravel streambed.
13	4" pump	On left bank	5.9				0	Not pumping.
13	Nueces River	About 3 mi below Camp Wood	6.4	63°	26.4			Wide porous gravel streambed.
13	Tributary	From left	7.4			0		Gravel streambed.
13	4" pump	On right bank	7.5				0	Not pumping.
13	Pump site	On left bank	7.9				0	Pump removed.
14	Nueces River	500 ft below county line	8.4	54°	26.4			Porous gravel streambed.
14	Tributary	From right	10.7			0		Gravel streambed.
14	Nueces River	About 4 mi below county line	12.3	57°	22.1			Wide porous gravel streambed.
14	3" pump	On right bank	12.3				0	Not pumping.
14	Nueces River	0.7 mi above gravel crossing	13.8	64°	15.7			Wide porous gravel streambed.
14	Tributary	From left	13.8			0		Gravel streambed.
14	Nueces River	0.4 mi above gravel crossing	14.1		0			Last of water disappears in gravel at this point.
	From mile 14-17	river channel is 1/2 to 3/4 mile wide and composed of porous deposits of large gravel.						
14	"Spring Creek"	Along left side of wide river channel	14.5		1.5			Estimated. So called "Spring Creek" which flows intermittently along left side of river channel.
14	"Spring Creek"	Along right side of wide river channel	15.2		1.0			Estimated. "Spring Creek" along right bank.
14	"Spring Creek"	Along right side of wide river channel	15.7		10.0			Estimated. "Spring Creek" along right bank.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1954	From Barksdale, Edwards County to gaging station at Laguna, Uvalde County - Continued.							
Dec. 14	"Spring Creek"	Along right side of wide river channel	16.2		0			Estimated. "Spring Creek" along right bank.
14	"Spring Creek"	Along left side of wide river channel	17.1		0.8			Estimated. "Spring Creek" along left bank.
	The above "Spring Creeks" (local name) flow river water in varying amounts along both banks - Main channel dry from mile 14.1 to 17.							
14	Montell Creek	At mouth	17.1			0		Gravel streambed.
14	Nueces River		17-20		0-15			Surface flow varies.
15	Nueces River		20.8	52°	10.9			Gravel streambed.
15	Tributary	From left	22.0			0		Gravel streambed.
15	Springs	From left bank	23.3			1.0		Estimated. Several springs and seeps along left bank. Springs 10-15 feet above water surface in river.
15	Nueces River	About 1.5 mi above Sycamore Creek	23.3	62°	19.3			Smooth rock streambed - large bar of loose gravel bar on right.
15	Sycamore Creek	At mouth	24.8			0		Gravel streambed.
15	Nueces River	At Laguna - Gaging station	25.2	62°	21.1			Measured on riffle of large, loose gravel.
19	Nueces River	At Laguna - Gaging station	25.2		22			Not measured. Determined from recording gage.
	From Real-Uvalde County line to gaging station at Laguna, Uvalde County							
1955 Feb. 16	Nueces River	500 ft below county line	8.4	63°	31.1			Porous gravel streambed.
16	Nueces River	About 1 mi above Montell - at crossing	14.1		0			Wide porous gravel streambed.
16	Nueces River	200 ft below water crossing (gravel)	20.8		17.8			Gravel streambed.
16	Nueces River	At Laguna - Gaging station	25.2		29.5			Measured on riffle of large, loose gravel.
	From Barksdale, Edwards County to gaging station at Laguna, Uvalde County							
Sept.19	Nueces River	Barksdale - 50 ft below highway	0	82°	9.12			Porous gravel streambed.
19	Spring	On left bank	1.7			1-3		Estimated. Boiling spring in edge of flowing river channel.
19	8" pump	On left bank	1.9				0	Not pumping.
19	Nueces River	About 2 mi below Barksdale	1.9	81°	14.8			Porous gravel streambed.
19	Camp Wood Creek	At mouth	3.1			0		Wide gravel channel.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Barksdale, Edwards County to gaging station at Laguna, Uvalde County, Continued							
Sept.19	Pulliam Creek	In vicinity of mouth	3.2			0-5		Inspected for ½ mi above mouth flow varies. 4 mi above mouth creek flowing 15-25 cfs in wide gravel channel.
19	Unnamed spring	Near mouth	3.5			2.5		Estimated. Flow from large spring 0.5 mi from river - Camp Wood City supply.
19	Nueces River	Camp Wood - Gravel water crossing	3.7	81°	33.9			Wide gravel streambed.
19	Tributary	From right	4.2			0.1		Estimated. Gravel streambed.
19	8" pump	On right bank	4.7				2	Estimated.
19	Tributary	From right	5.6			0		Gravel streambed.
19	4" pump	On left bank	5.9				0	Not pumping.
19	Nueces River	About 3 mi below Camp Wood	6.4	83°	31.8			Wide porous gravel streambed.
19	Tributary	From left	7.4			0		Gravel streambed.
19	4" pump	On right	7.5				0	Not pumping.
19	Nueces River	500 ft below county line	8.4	84°	34.3			Porous gravel streambed.
19	Tributary	From right	10.7			0		Gravel streambed.
20	Nueces River	About 4 mi below county line	12.3	79°	27.3			Wide porous gravel streambed.
20	Nueces River	0.7 mi above gravel crossing	13.8	81°	19.3			Wide porous gravel streambed.
20	Tributary	From left	13.8			0		Gravel streambed.
20	Nueces River	0.4 mi above gravel crossing	14.1		0			Last of water disappears in gravel at this point.
	From mile 14-17 river channel is 1/2 to 3/4 mile wide and composed of porous deposits of large gravel.							
20	"Spring Creek"	Along left side of wide river channel	14.5		1.5			Estimated. So called "Spring Creek" which flows intermittently along left side of river channel.
20	"Spring Creek"	Along right side of wide river channel	15.2		3			Estimated. "Spring Creek" along right bank.
20	"Spring Creek"	Along right side of wide river channel	15.7		15			Estimated. "Spring Creek" along right bank.
20	"Spring Creek"	Along right side of wide river channel	16.2	"Spring Creek" enters main channel - Flow diminishing.				
20	"Spring Creek"	Along left side of wide river channel	17.1		1.5			Estimated. "Spring Creek" along left bank.
	The above "Spring Creeks" (local name) flow river water in varying amounts along both banks. Main channel dry from mile 14.0-16.2.							
20	Montell Creek	At mouth	17.1			0		Gravel streambed.
20	Nueces River	0.2 mi below Montell Creek	17.3		4			Estimated. Main channel.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1955	From Barksdale, Edwards County to gaging station at Laguna, Uvalde County, Continued							
Sept. 20	Nueces River	0.5 mi below Montell Creek and below "Spring Creek" on left	17.6		20			Estimated. Main channel.
20	Nueces River		17-20		4-20			Surface flow varies.
20	Nueces River	200 ft below low crossing	20.8	82°	18.7			Gravel streambed.
20	Tributary	From left	22.0			0		Gravel streambed.
20	Nueces River	About 1.5 mi above Sycamore Creek	23.3	83°	27.6			Smooth rock streambed. Large bar of loose gravel on right.
20	Sycamore Creek	At mouth	24.8			0		Gravel streambed.
20	Nueces River	At Laguna - Gaging station	25.2	83°	30.0			Measured on riffle of large, loose gravel.
23	Nueces River	At Laguna - Gaging station	25.2		30			Not measured. Determined from recording gage.
1957 July 8	8" pump	On left bank	-.5				1-2	Estimated. pumping - 40 ac.(est.) alfalfa.
8	Nueces River	Barksdale - 600 ft below highway	0	78°	29.7			Porous gravel streambed.
9	2 springs	On right bank	0.5-1.5					Not inspected.
	Large, high bar of loose gravel deposited by record flood of Sept. 24, 1955		1-2					
9	Spring	On left bank	1.7			3.0		Estimated. This spring partly covered by gravel bar.
9	Nueces River	About 2 mi below Barksdale	1.8	78°	32.2			Probably only part of flow - tremendous loose gravel bar here.
9	8" pump	On left bank	1.9				1-2	Estimated pumping - 50 ac. (est.) alfalfa.
9	Camp Wood Creek		3.1			0		Wide gravel channel at mouth.
9	Pulliam Creek		3.2			5		Estimated at mouth - Porous gravel. 4 mi upstream creek flowing 15-20 cfs in wide gravel channel.
9	Unnamed Spring Branch	Near mouth	3.5			3		Estimated. Flow from large spring 0.5 mi from river - Camp Wood City supply.
9	Nueces River	Camp Wood - Gravel water crossing	3.7	78°	57.9			Wide gravel streambed.
9	8" pump	On left bank	3.9				1-2	Estimated. Pumping.
9	Tributary	From right	4.2					Not inspected.
9	8" pump	On right bank	4.7				1-2	Estimated. Pumping.
9	Tributary	From right	5.6			0		Gravel streambed.

Date 1957	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Barksdale, Edwards County to gaging station at Laguna, Uvalde County, Continued							
July 9	6" pump	On left bank	6.3				1-2	Estimated. Pumping.
9	Nueces River	About 3 mi below Camp Wood	6.7	82°	65.6			Porous gravel streambed.
9	Tributary	From left	7.4			0		Gravel streambed.
9	Nueces River	0.6 mi below county line - 300 ft below concrete crossing	9.2	82°	69.7			Porous gravel streambed.
9	Tributary	From right	10.7			0		Gravel streambed.
9	Nueces River	About 3½ mi below county line	12.1	83°	66.1			Porous gravel streambed.
9	Nueces River	About 0.3 mi above upper Montell crossing	13.8	80°	51.0			Gravel streambed.
10	Nueces River	500 ft below upper Montell crossing	14.1		20.7			Porous gravel streambed.
	From mile 14-17 river channel is 1/2 to 3/4 mi wide and composed of deposit of large gravel.							
10	"Spring Creek"	Along left side of wide river channel	14.7		10			Estimated. So called "Spring Creek" which flow along left side of river channel.
10	"Spring Creek"	Along right side of wide river channel	15.5		20			Estimated.
10	"Spring Creek"	Along right side of wide river channel	16.5		30			Estimated. "Spring Creek" enters main channel here.
	The "Spring Creek" (local name) flow river water in varying amounts along both banks.							
10	"Spring Creek"	Along left side of wide river channel	16.9		5			Estimated
	Main channel flowing through this reach (mile 14-17). Minimum surface flow probably 20 cfs.							
10	Montell Creek	At mouth	17.1					Gravel streambed.
10	"Spring Creek"	Along left bank	17.2					Impossible to measure. Flows into main channel here.
10	Nueces River	0.5 mi below lower Montell crossing	17.4		55.8			Porous gravel streambed.
10	Nueces River	¼ mi below low crossing	20.8		47.1			Porous gravel streambed.
10	Nueces River	About 2 mi above Laguna gage	23.3		62.6			Smooth rock streambed. Large bar of loose gravel on right.
10	Nueces River	At Laguna - Gaging station	25.2		72.9			Measured on riffle of large, loose gravel.
6	Nueces River	At Laguna - Gaging station	25.2		84			Discharge shown on July 6, 14, not measured. Determined from recording gage record.
14	Nueces River	At Laguna - Gaging station	25.2		65			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River April 30-May 8, 1925

Reach: From gaging station at Laguna to Cinonia, Tex.

Discharge measurements were made to determine seepage gains or losses on the Nueces River from Laguna to Cinonia, Tex., in April and May 1925. During this series of measurements the river was at a constant stage.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Apr. 30	Nueces River	At gaging station at Laguna	0		35.3			
30	Nueces River	At Chalk Bluff	5.1		13.5			
30	Nueces River	At Cline (O.S.T.) crossing west of Uvalde	18.9		0			
30	Nueces River	At Tom Nunn crossing	20.9		4.3			
30	Nueces River	At Tom Nunn Hill	22.8		1.5			
May 1	Nueces River	At old Eagle Pass road crossing	26.8		9.0			
1	Nueces River	S.A.U.& G. Railroad crossing	29.8		2.8			
8	Nueces River	At Habey Ranch	31.6		0			
8	Nueces River	At mouth of Live Oak Creek	34.5		.5			
1	Nueces River	At Uvalde-La Pryor crossing	34.5		.5			
1	Nueces River	Due east of La Pryor	40.7		0			
1	Nueces River	At La Pryor Ranch house	43.2		0			
1	Nueces River	4 mi below La Pryor Ranch house	47.4		8.0			
2	Nueces River	2 mi above Cinonia at Old Ranch Ford	54.9		5.4			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River — May-August 1931

Reach: From gaging station at Laguna to Cinonia, Tex.

During the investigations the river was at a constant stage, and measurements represent natural conditions.

The discharge measurements of the Nueces River were made to determine seepage gain or loss from gaging station at Laguna, Tex., to former gaging station near Cinonia, Tex. in 1931.

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
May 16	Nueces River	At gaging station at Laguna	0		316			
16	Nueces River	At mouth of West Nueces R	13.0		259			
16	Nueces River	At S. P. Railway bridge	18.0		222			
16	Nueces River	At Uvalde-Del Rio road crossing	20.6		199			
16	Nueces River	At gaging station near Uvalde	22.7		219			From rating curve.
17	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		229			
17	Nueces River	At S.A.U.& G. Railway bridge	31.6		227			
17	Nueces River	At old Uvalde-La Pryor road crossing	36.3		221			
17	Nueces River	At gas well 5 mi NE of La Pryor	39.6		219			
17	Nueces River	At La Pryor-Batesville road crossing	44.8		208			
17	Nueces River	At old gaging station site near Cinonia	56.5		240			
19	Nueces River	At gaging station at Laguna	0		275			
19	Nueces River	6.8 mi above West Nueces R	6.2		279			
19	Nueces River	2.6 mi above West Nueces R	10.4		274			
19	Nueces River	At gaging station near Uvalde	22.7		196			
June 4	Nueces River	At gaging station at Laguna	0		192			
4	Nueces River	2.6 mi above West Nueces R	10.4		187			
4	Nueces River	At mouth of West Nueces R	13.0		157			
4	Nueces River	At S. P. Railway bridge	18.0		116			
5	Nueces River	At Uvalde-Del Rio road crossing	20.6		84.6			
5	Nueces River	At gaging station near Uvalde	22.7		114			
5	Nueces River	At S.A.U.& G. Railway bridge	31.6		118			
5	Nueces River	At gas well 5 mi NE of La Pryor	39.6		111			

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 6	Nueces River	At La Pryor-Batesville road crossing	44.8		107			
6	Nueces River	3½ mi above Cinonia bridge	53.0		108			
15	Nueces River	At gaging station at Laguna	0		156			
15	Nueces River	2.6 mi above West Nueces R	10.4		140			
15	Nueces River	At mouth of West Nueces R	13.0		106			
15	Nueces River	At S. P. Railway bridge	18.0		69.7			
15	Nueces River	At Uvalde-Del Rio road crossing	20.6		46.6			
16	Nueces River	At gaging station near Uvalde	22.7		63.7			
16	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		81.2			
16	Nueces River	At S.A.U.& G. Railway bridge	31.6		75.7			
16	Nueces River	At gas well 5 mi NE of La Pryor	39.6		65.1			
16	Nueces River	At La Pryor-Batesville road crossing	44.8		60.4			
17	Nueces River	3½ mi above Cinonia bridge	53.0		69.0			
17	Nueces River	At old gage site near Cinonia	56.5		82.4			
22	Nueces River	At gaging station at Laguna	0		138			
22	Nueces River	2.6 mi above West Nueces R	10.4		124			
22	Nueces River	At mouth of West Nueces R	13.0		84.1			
22	Nueces River	At S. P. Railway bridge	18.0		43.4			
22	Nueces River	At Uvalde-Del Rio road crossing	20.6		21.5			
23	Nueces River	At gaging station near Uvalde	22.7		40.2			
23	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		57.2			
23	Nueces River	At S.A.U.& G. Railway bridge	31.6		50.1			
23	Nueces River	At gas well 5 mi NE of La Pryor	39.6		40.9			
23	Nueces River	At La Pryor-Batesville road crossing	44.8		33.2			
24	Nueces River	3½ mi above Cinonia bridge	53.0		45.3			
24	Nueces River	At old gage site near Cinonia	56.5		46.1			
July 2	Nueces River	At gaging station at Laguna	0		118			
2	Nueces River	2.6 mi above West Nueces R	10.4		101			
2	Nueces River	At mouth of West Nueces R	13.0		63.8			
2	Nueces River	At S. P. Railway bridge	18.0		27.5			
2	Nueces River	At Uvalde-Del Rio road crossing	20.6		6.3			

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
July 3	Nueces River	At gaging station near Uvalde	22.7		26.9			
3	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		43.9			
3	Nueces River	At S.A.U.& G. Railway bridge	31.6		39.6			
3	Nueces River	At gas well 5 mi NE of La Pryor	39.6		29.6			
3	Nueces River	At La Pryor-Batesville road crossing	44.8		24.2			
4	Nueces River	3½ mi above Cinonia bridge	53.0		35.8			
4	Nueces River	¼ mi below Cinonia bridge	56.5		35.5			
July 9	Nueces River	At gaging station at Laguna	0		98.9			
9	Nueces River	2.6 mi above West Nueces R	10.4		69.4			
9	Nueces River	At mouth of West Nueces R	13.0		36.5			
9	Nueces River	At S. P. Railway bridge	18.0		4.6			
9	Nueces River	At Uvalde-Del Rio road crossing	20.6		1.5			Estimate.
9	Nueces River	At gaging station near Uvalde	22.7		21.6			
13	Nueces River	At gaging station near Uvalde	0		17.5			From rating curve.
13	Nueces River	At Uvalde-Eagle Pass road crossing	5.5		33.6			
13	Nueces River	At S.A.U.& G. Railway bridge	8.9		29.0			
13	Nueces River	At gas well 5 mi NE of La Pryor	16.9		17.9			
13	Nueces River	At La Pryor-Batesville road crossing	22.1		11.5			
13	Nueces River	3½ mi above Cinonia bridge	30.3		23.4			
13	Nueces River	¼ mi below Cinonia bridge	33.8		21.5			
16	Nueces River	At gaging station at Laguna	0		91.8			
16	Nueces River	6.8 mi above West Nueces R	6.2		79.9			
16	Nueces River	2.6 mi above West Nueces R	10.4		63.8			
16	Nueces River	At mouth of West Nueces R	13.0		25.1			
16	Nueces River	At Uvalde-Del Rio road crossing	20.6		0			
17	Nueces River	At gaging station near Uvalde	22.7		18.8			
Aug. 29	Nueces River	At gaging station at Laguna	0		119			
29	Nueces River	2.6 mi above West Nueces R	10.4		56.8			
29	Nueces River	At mouth of West Nueces R	13.0		40.2			
29	Nueces River	At S. P. Railway bridge	18.0		15.2			
30	Nueces River	At Uvalde-Del Rio road crossing	20.6		7.8			
30	Nueces River	At gaging station near Uvalde	22.7		26.9			

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Aug. 30	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		36.3			
30	Nueces River	At S.A.U.& G. Railway bridge	31.6		38.8			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River — November 14-16, 1931; January 24-25, 1932

Reach: From gaging station at Laguna to gas well 5 mi NE of La Pryor, Tex.

During the investigations the river was at a constant stage, and measurements represent natural conditions.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1931 Nov. 14	Nueces River	At gaging station at Laguna	0		64.2			
14	Nueces River	6.8 mi above West Nueces R	6.2		43.0			
15	Nueces River	2.6 mi above West Nueces R	10.4		14.9			
15	Nueces River	At mouth of West Nueces R	13.0		0			
15	Nueces River	At S. P. Railway bridge	18.0		0			
15	Nueces River	At Uvalde-Del Rio road crossing	20.6		0			
15	Nueces River	At gaging station near Uvalde	22.7		9.0			
15	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		16.8			
16	Nueces River	At S.A.U.& G. Railway bridge	31.6		12.7			
16	Nueces River	At gas well 5 mi NE of La Pryor	39.6		4.0			
1932 Jan. 24	Nueces River	At gaging station at Laguna	0		64.0			
24	Nueces River	6.8 mi above West Nueces R	6.2		46.2			
24	Nueces River	2.6 mi above West Nueces R	10.4		22.9			
24	Nueces River	At mouth of West Nueces R	13.0		0			
24	Nueces River	At S. P. Railway bridge	18.0		0			
24	Nueces River	At Uvalde-Del Rio road crossing	20.6		0			
24	Nueces River	At gaging station near Uvalde	22.7		8.1			
25	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		14.4			
25	Nueces River	At S.A.U.& G. Railway bridge	31.6		12.8			
25	Nueces River	At old Uvalde-La Pryor road crossing	36.3		8.3			
25	Nueces River	At gas well 5 mi NE of La Pryor	39.6		4.5			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River — November 1932, July 1933

Reach: From gaging station at Laguna to old gage site near Cinonia, Tex.

During the investigation the river was at a constant stage, and measurements represent natural conditions.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1932 Nov. 1	Nueces River	At gaging station at Laguna	0		244			
1	Nueces River	6.8 mi above West Nueces R	6.2		247			
1	Nueces River	2.6 mi above West Nueces R	10.4		298			
1	Nueces River	At mouth of West Nueces R	13.0		240			West Nueces dry.
2	Nueces River	At S. P. Railway bridge	18.0		218			
2	Nueces River	At Uvalde-Del Rio road crossing	20.6		218			
2	Nueces River	At gaging station near Uvalde	22.7		251			
2	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		262			
3	Nueces River	At S.A.U.& G. Railway bridge	31.6		249			
3	Nueces River	At old Uvalde-La Pryor road crossing	36.3		256			
3	Nueces River	At gas well 5 mi NE of La Pryor	39.6		246			
4	Nueces River	At La Pryor-Batesville road crossing	44.8		244			Pumpage added to measurement.
4	Nueces River	3½ mi above Cinonia bridge	53.0		255			Pumpage added to measurement.
4	Nueces River	At old gage site near Cinonia	56.5		272			Pumpage added to measurement.
1933 July 23	Nueces River	At gaging station at Laguna	0		23.1			
23	Nueces River	5.2 mi above West Nueces R	7.8		22.9			
23	Nueces River	2.6 mi above West Nueces R	10.4		0			
23	Nueces River	At mouth of West Nueces R	13.0		0			West Nueces dry.
23	Nueces River	At S. P. Railway bridge	18.0		0			
23	Nueces River	At Uvalde-Del Rio road crossing	20.6		0			
24	Nueces River	At gaging station near Uvalde	22.7		16.3			
24	Nueces River	At Uvalde-Eagle Pass road crossing	28.2		20.6			
24	Nueces River	At S.A.U.& G. Railway bridge	31.6		16.3			
24	Nueces River	At old Uvalde-La Pryor road crossing	36.3		11.3			

Date 1933	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
July 25	Nueces River	At gas well 5 mi NE of La Pryor	39.6		7.2			No pumps operating.
26	Nueces River	At La Pryor-Batesville road crossing	44.8		4.1			
25	Nueces River	3½ mi above Cinonia bridge	53.0		13.9			
25	Nueces River	At old gage site near Cinonia	56.5		14.4			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River — June 14-30, 1939

Reach: From gaging station at Laguna to a point 3.8 mi SE of Cinonia, Tex.

A series of discharge measurements was made during the period June 14-30, 1939, on the Nueces River and tributaries, Tex., between the gaging station at Laguna and a point 3.8 miles southeast of Cinonia, to determine seepage gains or losses. The river distance was 61.4 miles. The investigation was made during a period of constant stage of the river, and the determinations of gain or loss represent natural conditions. All flowing tributaries were measured.

Date 1939	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 14	Nueces River	1,200 ft above gaging station at Laguna	-.2		26.6			
14	Nueces River	1,200 ft below gaging station at Laguna	+.2		25.7			
15	Nueces River	At 19 mi crossing on U. S. Highway 83-B	1.8		21.6			
15	Nueces River	1.8 mi below U. S. Highway 83-B	3.6		17.8			
15	Nueces River	5.4 mi above mouth of West Nueces R	6.6		5.6			
16	Nueces River	4.4 mi above mouth of West Nueces R	7.6		10.1			
16	Nueces River	3.8 mi above mouth of West Nueces R	8.2		0			
16	Nueces River	Just below mouth of West Nueces R	12.0		0			
16	Nueces River	At Texas and New Orleans Railway bridge	16.9		0			
17	Nueces River	At U. S. Highway 90 bridge	19.6		0			
17	Nueces River	1 mi below U. S. Highway 90 bridge	20.6		0			
17	Nueces River	At old gage site at Tom Nunn crossing	21.6		8.9			
17	Nueces River	1 mi below gage site at Tom Nunn crossing	22.6		10.0			
19	Unnamed spring	2 mi above present gaging station below Uvalde	24.6			0.3		Estimated.
19	Nueces River	Just below unnamed spring	24.6		7.3			
19	Unnamed spring	100 ft below previous measurement	24.6			.2		Estimated.
19	Nueces River	At gaging station 4 mi above Highway 83	26.6		11.8			

Date 1939	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 22	Nueces River	1 mi below gaging station	27.6		10.2			
20	Nucces River	At U. S. Highway 83 bridge	30.6		5.5			
20	Nueces River	1 mi below old Uvalde-La Pryor road crossing	35.7		5.3			
21	Nueces River	At gas well 5 mi NE of La Pryor	38.0		1.1			
21	Nueces River	At La Pryor-Batesville road crossing	43.2		0			
30	Nueces River	3.3 mi below La Pryor-Batesville road crossing	46.5		7.0			
29	Nueces River	3.6 mi above Mitt-Smith crossing	50.0		4.8			
29	Nueces River	At Mitt-Smith crossing 3½ mi NE of Cinonia	53.6		4.8			
29	Nueces River	3.3 mi below Mitt-Smith crossing	56.9		4.7			
30	Nueces River	On Thoren-Walker ranch 3.8 mi SE of Cinonia	61.4		3.4			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River — May, July, August, September 1940

Reach: From 0.4 mi above gaging station at Laguna to 4.8 mi SE of La Pryor, Tex.

A series of discharge measurements was made during each of the periods May 2, 3, July 9, 10, Aug. 28, 29, and Sept. 26, 27, on the Nueces River and Tributaries, Tex., between a point 0.4 mile upstream from gaging station at Laguna and a point 4.8 miles southeast of La Pryor. The river distance is 46.5 miles. The investigations were made during periods of constant stage of the river, and determinations of gain or loss represent normal conditions. All tributaries and diversions were measured. Tributaries not listed were not flowing.

Date 1940		Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Discharge, in cfs Tributary	Discharge, in cfs Diversion	Remarks
May	2	Nueces River	0.4 mi above gaging station at Laguna	-0.4		72.4			
	2	Nueces River	200 ft above Spring Branch	7.6		54.9			
	2	Spring Branch	At mouth, 4.4 mi above West Nueces R	7.6			4.0		
	2	Nueces River	3.2 mi above West Nueces R	8.8		18.4			
	2	Nueces River	Just below West Nueces R	12.0		0			
	2	Nueces River	At U. S. Highway 90 bridge	19.6		0			
	2	Nueces River	At old gage site 7 mi SW of Uvalde	21.6		8.6			
	2	Nueces River	1 mi below present gage 9 mi SW of Uvalde	27.6		15.0			
	3	Nueces River	1,000 ft above U. S. Highway 83 bridge	30.4		9.3			
	3	Nueces River	1 mi below old Uvalde-La Pryor road crossing	35.7		6.0			
	3	Nueces River	1,300 ft above gas well, 5 mi NE of La Pryor	37.8		0			
	3	Nueces River	500 ft above gas well, 5 mi NE of La Pryor	37.9		4.6			
	3	Nueces River	.2 mi below Batesville-La Pryor road bridge	43.4		2.2			
	3	Nueces River	3.3 mi below Batesville-La Pryor road bridge	46.5		12.6			

Date 1940	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
July 9	Nueces River	.4 mi above gaging station at Laguna	-0.4		74.6			
9	Nueces River	500 ft above Spring Branch	7.5		64.1			
9	Spring Branch	At mouth, 4.4 mi above West Nueces R	7.6			3.1		
9	Nueces River	3.2 mi above West Nueces R	8.8		21.2			
9	Nueces River	500 ft below West Nueces R	12.0		0			
9	Nueces River	At U. S. Highway 90 bridge	19.6		0			
9	Nueces River	At old gage site	21.6		10.8			
9	Nueces River	1 mi below present gage	27.6		18.4			
10	Nueces River	900 ft above U. S. Highway 83 bridge	30.4		11.3			
10	Nueces River	1 mi below old Uvalde-La Pryor road crossing	35.7		8.8			
10	Nueces River	.2 mi above gas well	37.8		0			
10	Nueces River	300 ft above gas well	37.9		5.2			
10	Nueces River	.2 mi below Batesville-La Pryor road bridge	43.4		1.4			
10	Nueces River	3.3 mi below Batesville-La Pryor road bridge	46.5		11.0			
Aug. 28	Nueces River	.4 mi above gaging station at Laguna	-0.4		56.7			
28	Nueces River	500 ft above Spring Branch	7.5		45.9			
28	Spring Branch	At mouth, 4.4 mi above West Nueces R	7.6			3.6		
28	Nueces River	3.2 mi above West Nueces R	8.8		5.4			
28	Nueces River	500 ft below West Nueces R	12.0		0			
28	Nueces River	At U. S. Highway 90	19.6		0			
28	Nueces River	At old gage site	21.6		8.2			
28	Nueces River	1 mi below present gage	27.6		13.7			
29	Nueces River	At U. S. Highway 83 bridge	30.6		6.8			
29	Nueces River	1 mi below Uvalde-La Pryor road crossing	35.7		5.3			
29	Nueces River	1,300 ft above gas well	37.8		0			
29	Nueces River	500 ft above gas well	37.9		.2			
29	Nueces River	.2 mi below Batesville-La Pryor road bridge	43.4		.3			
29	Nueces River	3.3 mi below Batesville-La Pryor road bridge	46.5		8.0			

Date 1940	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Sept. 26	Nueces River	.4 mi above gaging station	-0.4		37.5			
26	Nueces River	500 ft above Spring Branch	7.5		25.9			
26	Spring Branch	500 ft above mouth	7.6			3.2		
26	Nueces River	3.2 mi above West Nueces R	8.8		0			
26	Nueces River	500 ft below West Nueces R	12.0		0			
26	Nueces River	At U. S. Highway 90 bridge	19.6		0			
26	Nueces River	At old gage site	21.6		7.0			
26	Nueces River	1 mi below present gage	27.6		12.1			
27	Nueces River	At U. S. Highway 83 bridge	30.6		6.5			
27	C & M Produce Company Pump	.6 mi below old Uvalde-La Pryor road crossing	35.3				5.0	
27	Nueces River	1 mi below old Uvalde-La Pryor road crossing	35.7		.1			
27	Nueces River	500 ft above gas well	37.9		.1			
27	Nueces River	At Batesville-La Pryor road bridge	43.2		.1			
27	Nueces River	3.3 mi below Batesville-La Pryor road bridge	46.5		7.8			

LOW FLOW INVESTIGATIONS - NUECES RIVER BASIN

West Nueces River — Dec. 13-14, 1954; Sept. 11-12, 1955

Reach: From Black Water Hole to discontinued stream-gaging station near Brackettville

Problem: To determine gains and losses in streamflow in the West Nueces River above the site of the discontinued stream-gaging station near Brackettville. The reach is 48 miles long and extends 24 miles upstream from the Edwards-Kinney county line.

Results and Discussion: There was no base flow in this reach of the West Nueces River during these investigations. Tributary spring flow reaching the river is lost in the porous rock and immense gravel beds. The flow of Kickapoo Springs in Edwards County, 2-6 cfs, disappears a short distance below the mouth of Kickapoo Creek. Schwandner Springs, the only other source of inflow found, enters from the left at a point about 13 miles below the county line; however, the flow from this spring, 3-5 cfs, disappears in less than 4 miles into gravel beds downstream from the mouth of the creek in which the spring is located. Several so called lakes and water holes found in the reach have been scoured from the gravel and probably have underground springs that sustain them. At times water flows from some of these pools but it is usually lost in the gravel bed a short distance downstream. The surface flows found in this reach are probably a small part of the total flow below and into the gravel deposits.

Date 1954	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Dec. 14	West Nueces R	At Black Water Hole	0		0			
14	West Nueces R	1 mi below Five Mile Draw	4.8		0			
14	West Nueces R	1/2 mi above Two Mile Draw	7.8		0			
14	West Nueces R	1800 ft above Kickapoo Springs	10.5		0.5			Estimate
14	Kickapoo Springs	At mouth on Mayes ranch	10.6	68°		1.98		
14	West Nueces R	800 ft below Kickapoo Springs	10.7	62°	6.21			Large gravel
14	West Nueces R	1-1/2 mi below Bluff Creek	13.4		0			End of flow
14	West Nueces R	2-1/2 mi below Bluff Creek	14.5		0			
14	West Nueces R	1-1/2 mi below Four Mile Draw	16.7		0			
14	West Nueces R	1 mi below Cave Creek	24.3		0			
14	West Nueces R	At mouth of Griffen Creek	29.3		0			
14	West Nueces R	At Dutch Water Hole	32.6		0			
13	Silver Lake	At Schwandner ranch	37.5			0		
13	Schwandner Spr	At Schwandner ranch	37.6			2.97		
13	Water hole	Below Schwandner ranch	38.7		0	0		
13	West Nueces R	1/2 mi above Leona Draw	43.6		0			
13	West Nueces R	2 mi below Leona Draw	46.1		0			
13	West Nueces R	At discontinued stream-gaging station near Brackettville	47.7		0			

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Sept. 11	West Nueces R	At Black Water Hole	0		0			
11	West Nueces R	1 mi below Five Mile Draw	4.8		0			
11	West Nueces R	1/2 mi above Two Mile Draw	7.8		0			At Thurman ranch
11	West Nueces R	1000 ft above Kickapoo Creek	10.5		0			Beginning of flow
11	Kickapoo Sprs	At mouth	10.7	74°		1.81		Flow of Kickapoo Creek
12	West Nueces R	600 ft below Kickapoo Creek	10.8	81°	2.35			Gravel channel
12	West Nueces R	2.3 mi above Four Mile Draw	13.4		0			
12	West Nueces R	1.2 mi above Four Mile Draw	14.5		0			
12	West Nueces R	1.4 mile below Four Mile Draw	16.7		0			At McNealy ranch
12	West Nueces R	1 mi below Cave Creek	24.3		0			At Brice ranch
12	West Nueces R	At mouth of Griffen Creek	29.3		0			On DeLong ranch
11	West Nueces R	At Dutch Water Hole	32.6		0			
11	West Nueces R	At Silver Lake on Schwandner ranch	37.5		0			
11	Schwandner Spr	At Schwandner ranch	37.6			5.14		
11	West Nueces R	2-1/2 mi below Schwandner ranch	40.1	84°	2.73			At concrete crossing
11	West Nueces R	2-1/2 mi above Leona Draw	41.6		0			
11	West Nueces R	1-1/2 mi above discontinued stream-gaging station	46.1		0			
11	West Nueces R	At discontinued stream-gaging station near Brackettville	47.7		0			

West Nueces River — May 13, 1941

Reach: From a point 1,000 ft above stream-gaging station near Brackettville, Tex. to a point 0.8 mi above mouth, near Uvalde, Tex.

A series of discharge measurements was made on May 13, 1941, on the West Nueces River and tributaries, Tex., between a point 1,000 ft above gaging station near Brackettville and a point 37 mi downstream (0.8 mi upstream from mouth), to determine the seepage gains or losses. The river was falling about 0.5 cfs per day at gaging station. All flowing tributaries were measured.

Date 1941	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
May 13	West Nueces River	1,000 ft above gaging station near Brackettville	0		2.3			
13	West Nueces River	2.6 mi above Live Oak Creek	9.2		8.3			
13	Live Oak Creek	½ mi above mouth	11.8			4.8		
13	West Nueces River	1.6 mi below Live Oak Creek	13.4		21.1			
13	West Nueces River	.8 mi above mouth	37.0		0			

River was falling about 0.5 cfs per day at gaging station.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Frio River June 26-28, 1925

Reach: From a point 11.8 mi above Leakey to a point 7.0 mi below Concan, Tex.

During this series of measurements the river was at a constant stage, and the measurements represent natural conditions.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 26	East Fork Frio River	Just above Big Spring Creek 11.8 mi above Leakey	0		1.71			
26	Big Spring Creek	At mouth 12 mi above Leakey	.05			8.86		
26	East Fork Frio River	200 ft below Big Spring Creek 11.7 mi above Leakey	.1		9.46			
26	East Fork Frio River	8.5 mi above Leakey	3.3		12.1			
26	Cypress Creek	At mouth 8.0 mi above Leakey	3.8			.96		
26	Grigsby-Horton Ditch	5.5 mi above Leakey	6.3				0.74	
26	Weston-Cox Ditch	3.1 mi above Leakey	8.7				.88	
26	East Fork Frio River	At concrete road crossing 3.0 mi above Leakey	8.8		8.91			
26	West Fork Frio River	At mouth 1.5 mi above Leakey	10.3			0		
26	Frio River	1.0 mi above Leakey	10.8		0			Flow 100 ft above and ½ mi below.
27	Frio River	¼ mi above Spring Branch at Leakey	11.8		4.53			
27	Spring Branch	½ mi above mouth at Leakey	11.8			13.9		
27	Frio River	½ mi below Leakey	12.3		25.0			
27	Frio River	3 mi below Leakey below road crossing	14.8		27.1			
27	Lombardy Ditch	At headgate of dam 4 mi below Leakey	15.8				11.1	Part of diversion re-enters river.
27	Lombardy Ditch	7 mi below Leakey	18.8			5.0		Estimate.
27	Frio River	At road crossing 11.5 mi below Leakey	23.3		26.4			
27	Frio River	At road crossing 15.0 mi below Leakey	26.8		39.5			

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
June 27	Frio River	At Concan - gaging station	31.3		40.5			
27	Frio River	$1\frac{1}{2}$ mi below Concan	32.3		32.5			
27	Frio River	$23\frac{1}{2}$ mi below Leakey	35.3		20.1			
27	Frio River	At road crossing 26 mi below Leakey	37.8		6.30			
28	Frio River	$\frac{1}{2}$ mi below road crossing 26.3 mi below Leakey	38.1		2.5			Estimate.
28	Frio River	.7 mi below road crossing 26.5 mi below Leakey	38.3		0			No flow below long deep pool.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Frio River — **May 17-23, 1954**

Reach: From Wolf Ranch on East Fork 11 mi above Leakey to end of flow 3.7 mi below gage at Concan, Tex.

During the period May 17-23, 1954 a series of discharge measurements was made on the Frio River, Texas from Wolf Ranch, on the East Fork about 11 miles upstream from Leakey, to the end of flow about 3.7 miles downstream from gaging station at Concan. These measurements were made primarily for a ground water study of gains and losses in river flow and no attempt was made to measure all tributary inflow. The gaging station record at Concan indicated that the river maintained a constant flow during the investigation.

Date 1954	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Discharge, in cfs Tributary	Discharge, in cfs Diversion	Remarks
May 22	East Fork Frio River	On Wolf Ranch 3,300 ft above upper dam	0		2.25			
23	East Fork Frio River	On Perry Ranch 60 ft below small falls	4.1		2.77			
23	Big Spring Creek	On Perry Ranch 190 ft above small dam	4.2	75		4.58		
20	Irrigation Canal	2 mi N of Rio Frio Post Office	16.5				8.40	
19	Frio River	185 ft above Buffalo Creek	20.8		12.8			
18	Frio River	1,500 ft below Farm Road 1050	22.5		19.6			
18	Frio River	At Garner Park concession bldg.	24.6		18.3			
20	Frio River	2,000 ft below Cherry Creek	26.5		19.5			
17	Frio River	200 ft below concrete road crossing 4 mi above Concan	30.0		20.4			
17	Frio River	At gaging station at Concan	34.8		18.4			
17	Frio River	2,800 ft below Echols Dam	35.8		9.44			
17	Frio River	6,000 ft below Echols Dam	36.5		3.27			
17	Frio River	6,100 ft below Echols Dam	36.5		0			
18	Frio River	3,200 ft above gravel dam	37.4		2.71			
18	Frio River	1,500 ft below gravel dam	38.1		.72			
18	Frio River	3,300 ft below gravel dam	38.5		0			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Frio River

Jan. 4- 7, 1955
Feb. 14-15, 1955
Sept. 7-10, 1955
July 8- 9, 1957

Reach: From Prade ranch, 16 miles above Leakey to gaging station at Concan, Tex.

Problem: To determine gains or losses in streamflow in the reach of Frio River that is on the Glen Rose limestone upstream from the stream-gaging station at Concan.

Results: No material losses were found in the reach investigated which covers 39.5 miles of the main stream and 11.0 miles of its main tributary, East Frio River. The Frio River, East Frio River and most of the tributary streams above Leakey have headwater springs that issue from the Edwards and associated limestones. These headwater springs together with springs in a small area in the vicinity of the Real-Uvalde county line contribute the greater part of the streamflow found in this investigation. The springs and seeps in the county line areaprobably flow from the Glen Rose limestone.

Discussion: Current-meter measurements were made at points of critical interest; field estimates were made where flows were small or unimportant. No attempt was made to pace the discharge measurements with the rate of change in flow as the investigation progressed downstream. The channel was investigated throughout the reach, and the measurements were made as rapidly and as thoroughly as possible. The rate of change in flow was determined at the Concan stream-gaging station. Flow was not stable during the investigation, a condition normal for this stream; it is probably not possible to have stable base flow conditions in any of the streams that head in the Edwards plateau. Related conditions during the investigations are indicated by two determinations of discharge at the Concan stream-gaging station for each set of measurements.

"Spring Branch" that flows from the river gravels at Leakey is probably flowing river water that had disappeared in the gravels further upstream and should not be considered a tributary contribution.

Several channel dams were located, each with small storage capacity. The only diversion of consequence found was an irrigation canal that diverts from the left bank about 2 miles upstream from Rio Frio. No portable irrigation pumps were located but small acreages were noted that probably are irrigated during the growing season.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Prade ranch, 16 miles above Leakey to gaging station at Concan							
Jan. 4	Frio River	At Prade ranch	0		0.1			Estimated; rock channel.
4	Frio River	At first crossing below Prade ranch	.5		0			
4	Frio River	At second crossing below Prade ranch	.8		0			
4	Frio River	1-1/2 mi below Prade ranch; below dam	1.4		1.67			Rock channel.
4	Frio River	2.2 mi below Prade ranch	2.2		1.92			Rock channel.
4	W. Fork Frio R	3.2 mi above mouth	-			1.52		Rock channel.
4	W. Fork Frio R	At small dam near mouth	2.3			1.52		Estimate; same as upstream meas.
4	Frio River	0.6 mi below West Fork Frio R	3.0		3.82			Gravel channel.
4	Tributary	1.3 mi below West Fork Frio R	3.7			.1		Estimate.
4	Frio River	2.2 mi below West Fork Frio R	4.5		4.47			Rock and gravel channel.
4	Bluff Creek	At mouth	6.0			.1		Estimate.
4	Frio River	500 ft above Kent Creek	7.8		6.11			Rock channel.
4	Kent Creek	At mouth	7.9			1.13		
5	Frio River	2 mi below Kent Creek	9.9		5.09			Gravel channel.
5	Frio River	Just below Lewis ranch airfield	11.6		0			Wide gravel channel.
5	Frio River	1-1/2 mi above Leakey	14.5		0			Wide gravel channel.
5	Frio River	At mouth of East Frio River	16.1		0			Wide gravel channel.
5	East Frio River	Above upper dam on H. E. Butt ranch; 11.0 mi above Frio River	-			1.22		Rock channel; head springs 0.5 mi upstream.
5	East Frio River	100 ft above spring; 6.9 mi above Frio River	-			1.11		Rock channel.
5	Spring Branch	Near mouth	-	66°		4.80		Rock channel; spring at cave 0.7 mi upstream.
5	East Frio River	1.3 mi below Perry ranch	-	63°		5.30		Rock channel.
6	Tributary	From left; 1.6 mi below Perry ranch	-			.1		Estimate.
6	East Frio River	At road, above Cypress Creek; 5.2 mi above Frio River	-			6.63		Rock and gravel channel.
6	Cypress Creek	At mouth; 5.1 mi above Frio R	-			.89		Gravel channel.
6	East Frio River	At Harrison Stockade ranch; 2.6 mi above Frio River	-			2.61		Gravel channel.
6	East Frio River	2 mi above Frio River	-			0		Gravel channel.
6	East Frio River	Above bridge on Grady ranch; 1.0 mi above Frio River	-			0		Gravel channel.
6	East Frio River	200 ft below bridge on Grady ranch	-			1.94		Rock channel.
6	East Frio River	At mouth	16.1		0			Gravel channel.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	Frio River continued							
Jan. 6	Frio River	Road crossing at Leakey	17.0		0			Gravel channel.
6	Spring Branch	Road crossing at Leakey	17.1	65°	4.56			Gravel channel; probably flowing river water.
6	Frio River	At Ranch Road 1120; 2 mi below Leakey	19.7	62°	10.6			Gravel channel.
6	Irrigation Canal	2.7 mi above Rio Frio	21.6				3.89	Diverts from left bank at river.
6	Frio River	At road; 2 mi above Rio Frio	22.3		8.49			Gravel channel.
6	Frio River	Just above Cold Springs	26.5		8.34			Rock channel.
6	Cold Springs	At mouth	26.5	62°		0.5		On left bank.
7	Frio River	At Garner Park; 400 ft above concession building	29.5	54°	11.1			Gravel channel.
7	Frio River	2.6 mi above Concan	35.7		11.4			Rock channel.
7	Frio River	At gaging station at Concan	39.5	57°	9.62			Rock and gravel channel.
10	Frio River	At gaging station at Concan	39.5		13.0			Not measured. Mean daily discharge from recorder record.
	From Kent Creek, 8 miles above Leakey to gaging station at Concan							
Feb. 14	Frio River	500 ft above Kent Creek	7.8	62°	5.01			Rock channel; gravel banks.
14	Kent Creek	At mouth	7.9			.6		Estimate.
14	Frio River	At mouth of East Frio River	16.1		0			Wide gravel channel.
14	East Frio River	At road above Cypress Creek; 5.2 mi above Frio River	-	65°		5.95		Gravel channel.
14	Cypress Creek	At mouth; 5.1 mi above Frio R	-			1.0		Estimate; gravel channel.
14	East Frio River	Above bridge on Grady ranch; 1.0 mi above Frio River	-			0		Wide gravel channel.
14	East Frio River	200 ft below bridge on Grady ranch	-	66°		3.53		Rock channel.
14	East Frio River	At mouth	16.1		0			Wide gravel channel. No defined low water channel.
	Frio River continued							
15	Frio River	At Ranch Road 1120; 2 mi below Leakey	19.7	59°	14.1			Gravel channel.
15	Frio River	2.6 mi above Concan	35.7	58°	16.5			Rock channel; gravel banks.
15	Frio River	At gaging station at Concan	39.5	59°	17.2			Rock and gravel channel.
18	Frio River	At gaging station at Concan	39.5		18.0			Not measured. Mean daily discharge from recorder record.

Date 1955	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Prade ranch, 16 mi above Leakey to gaging station at Concan							
Sept. 8	Frio River	At hydraulic ram on Prade ranch	0		0.03			Rock channel.
8	Frio River	At first crossing below Prade ranch	.5		0			
8	Frio River	At second crossing below Prade ranch	.8		0			
8	Frio River	1-1/2 mi below Prade ranch; below dam	1.4	86°	1.95			Rock channel.
8	Frio River	2.2 mi below Prade ranch	2.2	89°	2.20			Rock channel.
8	W. Fork Frio R	3.2 mi above mouth	2.3	82°		1.53		Rock channel.
8	Frio River	0.6 mi below W. Fork Frio River	3.0	83°	2.94			Gravel channel.
8	Tributary	1.3 mi below W. Fork Frio River	3.7			0		
8	Frio River	2.2 mi below W. Fork Frio River	4.5	81°	3.33			Rock channel.
8	Bluff Creek	At mouth	6.0			.3		Estimate.
9	Frio River	500 ft above Kent Creek	7.8	76°	3.21			Rock channel.
9	Kent Creek	At mouth	7.9			.45		
9	Frio River	2 mi below Kent Creek	9.9	77°	2.11			Gravel channel.
9	Frio River	Just below Lewis ranch airfield	11.6		0			Wide gravel channel.
9	Owl Hollow	At mouth	11.6			0		
9	Frio River	3 mi below Lewis ranch	14.5		0			Wide gravel channel.
9	Frio River	At Highway 83	16.0		0			Wide gravel channel.
9	Frio River	At mouth of East Frio River	16.1		0			Wide gravel channel.
7	East Frio River	Above upper dam on H. E. Butt ranch; 11.0 mi above Frio River	-			0		Rock channel.
7	East Frio River	At upper dam on H. E. Butt ranch	-			.83		Rock channel.
7	East Frio River	Just above Spring Branch on Perry ranch 6.9 above Frio River	-	75°		2.55		Rock channel.
7	Spring Branch	150 ft above mouth	-	73°		4.0		Rock channel; spring 0.7 mi upstream.
7	East Frio River	1.3 mi below Perry ranch	-	83°		6.45		Rock channel.
7	Tributary	From left; 1.6 mi below Perry ranch	-			.02		Estimate.
7	East Frio River	Above Cypress Creek, at road 5.2 mi above Frio River	-	86°		5.57		Rock and gravel channel.
7	Cypress Creek	At mouth, 5.1 mi above Frio R	-	77°		.09		Gravel channel.
7	East Frio River	At Harrison Stockade ranch; 2.6 mi above Frio River	-	79°		.36		Gravel channel.
7	East Frio River	Above bridge on Grady ranch; 1.0 mi above Frio River	-			.0		Gravel channel.
7	East Frio River	200 ft below bridge on Grady ranch	-	71°		.76		Rock channel.
9	East Frio River	At mouth	16.1		0			Gravel channel.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1955	Frio River continued							
Sept. 9	Frio River	Road crossing at Leakey	17.0		0			Gravel channel.
9	Spring Branch	Road crossing at Leakey	17.1	72°	1.86			Gravel channel. Probably flowing river water.
9	Frio River	At Ranch Road 1120, 2 mi below Leakey	19.7	81°	6.40			Gravel channel.
9	Irrigation Canal	2.7 mi above Rio Frio	21.6	78°			2.96	Diverts from left bank of river.
9	Frio River	At road, 2 mi above Rio Frio	22.3	82°	4.60			Rock channel.
9	Frio River	Just above Cold Springs	26.5	83°	6.44			Rock channel.
9	Cold Springs	At mouth	26.5	73°		0.6		On left bank.
10	Frio River	At Garner Park; 500 ft above concession building	29.5	78°	10.6			Gravel channel.
10	Frio River	2.6 mi above Concan	35.7	81°	8.37			Gravel channel.
10	Frio River	At gaging station at Concan	39.5	84°	8.49			Rock and gravel channel.
13	Frio River	At gaging station at Concan	39.5		8.2			Not measured. Mean daily discharge from recorder record.
1957	From a point 11.6 mi upstream from confluence with East Frio River to gaging station at Concan							
July 8	Frio River	2.2 mi below West Fork Frio R	4.5	90°	5.76			Smooth rock channel.
8	Frio River	500 ft above Kent Creek	7.8	88°	6.69			Smooth rock channel.
8	Kent Creek	At mouth	7.9			1.78		
8	Frio River	2.0 mi below Kent Creek	9.9	87°	4.52			Gravel channel.
8	Owl Hollow	At mouth	11.6			0		
8	Frio River	Just below Lewis ranch airfield	11.6		0			Wide gravel channel.
8	Frio River	1-1/2 mi above Leakey	14.5		0			Wide gravel channel.
8	Frio River	At mouth of East Frio River	16.1		0			Wide gravel channel.
9	East Frio River	At road above Cypress Creek; 5.2 mi above Frio River	-	79°		8.59		Gravel channel.
9	Cypress Creek	At mouth; 5.1 mi above Frio R	-			.94		Gravel channel.
9	East Frio River	Above bridge on Grady ranch; 1.0 mi above Frio River	-			.01		Estimate; gravel channel.
9	East Frio River	200 ft below bridge on Grady ranch	-	73°		3.20		Rock channel.
9	East Frio River	At mouth	16.1	74°	1.04			Gravel channel.
	Frio River continued							
9	Frio River	Road crossing at Leakey	17.0	80°	1.59			Gravel channel.
9	Spring Branch	Road crossing at Leakey	17.1	70°	10.8			Gravel channel. Probably flowing river water.
9	Frio River	At gaging station at Concan	39.5	88°	38.4			Rock and gravel channel.
12	Frio River	At gaging station at Concan	39.5		34.0			Not measured. Mean daily discharge from recorder record.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Frio River July 1, 1931

Reach: From road crossing above Concan to road crossing below Concan, Tex.

Discharge measurements were made to determine seepage on the Frio River from Concan to Uvalde-Concan road crossing, Tex., July 1931. During the investigation the river was at a constant stage, and the measurements represent the natural conditions. No diversions from portion of river covered by measurements; no inflow from tributaries.

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Discharge, in cfs Tributary	Discharge, in cfs Diversion	Remarks
July 1	Frio River	At Concan-Leakey road crossing	0		112			
1	Frio River	At gaging station at Concan	1.0		114			
1	Frio River	1½ mi below gaging station	2.5		116			
1	Frio River	3½ mi below gaging station	4.5		107			
1	Frio River	¼ mi above Uvalde-Concan road crossing	6.0		86.3			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Frio River

November 5, 6 and December 20, 1932

Reach: From stream-gaging station at Concan, Tex. to U. S. Highway 90 crossing near Knippa, Tex.

Date 1932	Stream	Location	River Miles	Water Temp	Discharge in cfs Main Stream	Tributary	Diversion	Remarks
Nov. 5	Frio River	At gaging station at Concan	0		233			
5	Frio River	1.2 mi below gaging station	1.2		226			
5	Frio River	3.0 mi below gaging station	3.0		253			
6	Frio River	¼ mi above Uvalde-Concan road crossing	5.0		220			
6	Frio River	At road crossing on Uvalde-Sabinal Highway	18.5		0			
Dec. 20	Frio River	At gaging station at Concan	0		124			
20	Frio River	1.2 mi below gaging station	1.2		108			
20	Frio River	3.0 mi below gaging station	3.0		123			
20	Frio River	¼ mi above Uvalde-Concan road crossing	5.0		98.8			
20	Frio River	At road crossing on Uvalde-Sabinal Highway, U. S. Highway 90	18.5		0			

No diversion or inflow during investigation.

Dry Frio River — December 16, 1954; September 9, 1955; January 15-16, 1958

Reaches: From a point 2.0 miles above Real-Uvalde county line to a point 2.2 miles below stream-gaging station near Reagan Wells, Tex.
From a point 10.2 miles upstream from Real-Uvalde county line to a point 1.9 miles below stream-gaging station near Reagan Wells, Tex.
From a point 10.2 miles upstream from Real-Uvalde county line to stream-gaging station near Reagan Wells, Tex.

Problem: To determine gains and losses in the Dry Frio River in the reach that is on the Glen Rose limestone above the stream-gaging station near Reagan Wells, Tex.

Results: Data obtained in the three sets of measurements indicate that no material losses other than those normally attributed to evaporation and transpiration occurred in the 28 miles of channel investigated. A few points were found where the flow partially, and in one case wholly, disappeared into the river gravels; in every instance, the water soon returned to the surface with no apparent losses. The streamflow, principally from the Edwards and associated limestones gradually increased between the initial point and the gaging station.

Although the scope of these investigations did not include any portion of channel below the gaging station near Reagan Wells, observations were made at and below the point of contact of the Glen Rose and the Edwards limestone, this point being about two miles further downstream. In 1954 and 1955 all of the flow disappeared in the gravel deposits immediately after crossing the fault line that marks the upper contact of the Edwards limestone; in 1958 the Edwards absorbed the 28 cfs of flow within the first two miles of channel below the fault line.

Discussion: Current-meter measurements were made at all points of critical interest and at all points where appreciable amounts of flow were involved; many small flows were estimated. No attempt was made to pace the discharge measurements with the rate of change in flow as the investigation progressed downstream. The channel was investigated throughout the reach and the discharge measurements were made as rapidly and as thoroughly as possible. The rate of change in flow was determined at the Reagan Wells stream-gaging station. Flow was practically constant during the 1954 and the 1955 investigations, and was slowly decreasing during the January 1958 period, recorder record showing a decrease in flow from 28 to 27 cfs from January 16 to 20: it probably is not possible to have a constant rate of flow in this reach if any appreciable amount of flow is present, near constant flow being found only when rate approaches zero and very small flow remains. Whenever possible, measurements were made on rock streambed to eliminate possibility of underflow through the gravels; however, only two sections were found in which it was judged that total flow was measured; the large gravel deposits in this canyon store considerable water, and water probably percolates through the gravels at nearly all of the measuring sections. No channel dams were located on the main stream. Several portable irrigation pumps were found; used to irrigate small acreages of alfalfa and other feed crops. This use probably is small but may be significant during the growing season when natural losses are high and amounts of streamflow are small.

Unlike adjacent streams that head in the Edwards plateau this stream does not obtain significant amounts of base flow from the reach of channel that is on the Glen Rose limestone, which in this region covers only a small area along the floor of the generally deep, narrow canyon.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 2.0 miles above Real-Uvalde county line to a point 2.2 miles below stream-gaging station near Reagan Wells, Tex.							
1954								
Dec. 16	Dry Frio River	At gravel ford	8.2		0.0			Gravel channel.
16	Dry Frio River	--	8.9		0.2			Estimate. On gravel.
16	Big Burn Creek	At mouth	11.1			0		Rock channel.
16	Dry Frio River	--	11.1		0			Gravel channel.
16	Dry Frio River	--	12.2		1.0			Estimate. On gravel.
16	Dry Frio River	--	13.1		0			Estimate. On gravel.
16	Dry Frio River	--	13.3		0.4			Estimate. On gravel.
16	Dry Frio River	--	13.9		0			Estimate. On gravel.
16	Dry Frio River	--	14.2		0.1			Estimate. On gravel.
16	Mine Creek	1,500 ft above mouth	14.7			0		Rock channel.
16	Dry Frio River	At natural rock ford to ranch	15.3		1.0			Estimate. Rock channel.
16	Dry Frio River	Just above tributary from right	16.4	49°	1.29			Gravel channel.
16	Honey Creek	At mouth	16.8			0		Rock streambed.
16	Dry Frio River	0.2 mi below gravel ford from ranch	18.7	55°	1.24			Rock streambed and gravel banks.
16	Spring	On right bank, 300 ft from river	20.9			.15		Estimate.
16	Tributary	From right	20.9			0		Gravel streambed.
16	Spring	On right bank	21.1			.1		Estimate.
16	Spring	On right bank	21.2			.1		Estimate.
16	Dry Frio River	20 ft below FM 1051	22.6	60°	1.17			Gravel channel.
16	Dry Frio River	400 ft below tributary	24.1	62°	1.83			Rock streambed.
16	Tributary	From left	25.9			0		Gravel channel.
16	Fusch Creek	Near mouth	25.9			.4		Estimate. Rock streambed with gravel banks.
16	Dry Frio River	400 ft above gaging station	26.1	64°	1.99			Smooth rock streambed.
20	Dry Frio River	400 ft above gaging station	26.1		2.0			Not measured. From automatic recorder record.
16	Dry Frio River	Below gravel ford	28.2		0			Gravel channel.
	From a point 10.2 miles upstream from Real-Uvalde county line to a point 1.9 miles below stream-gaging station near Reagan Wells, Tex.							
1955								
Sept. 9	Dry Frio River	300 ft above cedar hunting cabin	0		1.5			Estimate. Rock and gravel channel
9	Tributary	From right	0.1			0		Rock channel. 6-ft dam 50 ft above mouth. Lake full.
9	Trough Spring	On left bank	0.2			.5		Estimate. Flows from bluff 25-30 ft above river.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 10.2 miles upstream from Real-Uvalde county line to a point 1.9 miles below stream-gaging station near Reagan Wells, Tex., continued							
1955								
Sept. 9	Dry Frio River	50 ft below rock ford	0.8	74°	2.56			Rock streambed and gravel banks.
9	Dry Frio River	50 ft above rock ford	2.5	77°	2.24			Rock streambed and gravel banks.
9	Dry Frio River	--	6.2		0			Gravel.
9	Dry Frio River	--	7.4		.8			Estimate.
9	Dry Frio River	--	7.7		.2			Estimate.
9	Dry Frio River	At gravel ford	8.2		0			Gravel.
9	Dry Frio River	--	8.9		1.0			Estimate. On gravel.
9	Big Burn Creek	At mouth	11.1			0		Rock streambed.
9	Dry Frio River	--	11.1		0			Gravel.
9	Dry Frio River	--	12.2		1.0			Estimate. On gravel.
9	Dry Frio River	--	13.0		.2			Estimate. On gravel.
9	Dry Frio River	--	13.2		1.5			Estimate. On gravel.
9	Dry Frio River	--	13.5		.5			Estimate. On gravel.
9	Dry Frio River	--	13.7		0			Gravel.
9	Dry Frio River	--	14.5		1.0			Estimate. On gravel.
9	Dry Frio River	50 ft above natural rock ford to ranch	15.3	84°	2.82			Rock channel. Measured 100% of flow here.
9	Dry Frio River	0.2 mi below gravel ford from ranch	18.7	83°	1.68			Rock streambed and gravel banks.
9	Spring	On right bank	20.9			.15		Estimate.
9	Spring	On right bank	21.1			0		
9	Spring	On right bank	21.2			.03		Estimate.
9	Dry Frio River	400 ft below tributary	24.1	85°	.88			Rock streambed.
9	Dry Frio River	400 ft above gaging station	26.1	83°	1.24			Rock streambed.
13	Dry Frio River	400 ft above gaging station	26.1		1.2			From automatic recorder record.
9	Dry Frio River	At gravel ford	28.0		0			Gravel.
	From a point 10.2 miles upstream from Real-Uvalde county line to stream-gaging station near Reagan Wells, Tex.							
1958								
Jan. 15	Dry Frio River	300 ft above cedar hunting cabin	0	43°	1.99			Rock and gravel channel.
15	Tributary	From right	0.1			.05		Estimate. Rock channel. Dam 50 ft above mouth.
15	Trough Spring	On left bank	0.2			1.00		Estimate. Flows from bluff 25-30 ft above river.
15	Dry Frio River	15 ft above rock ford	0.8	47°	3.95			Gravel channel.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 10.2 miles upstream from Real-Uvalde county line to stream-gaging station near Reagan Wells, Tex., continued							
Jan. 15	Tributary	From right	2.3			0.5		Estimate. Spring located 1/2 mi upstream from river. Flow disappears in gravel before entering river.
15	Dry Frio River	100 ft above rock ford	2.5	49°	3.44			Rock streambed with gravel banks.
15	Tributary	From right	2.6			.15		Estimate. Enters river over low rock falls.
15	Dry Frio River	50 ft below rock ford	4.8	51°	3.74			Rock streambed with gravel banks.
15	Tributary	From left	6.7			.0		Gravel channel.
15	Dry Frio River	At gravel crossing	6.7		0.0			Gravel channel. Natural gravel dam 300 ft (est.) long.
15	Dry Frio River	20 ft below gravel ford	7.7	56°	4.33			Gravel channel. Seepage from both banks.
15	Tributary	From right	8.3			.15		Estimate. Gravel channel.
15	Big Burn Creek	600 ft above mouth	11.1	59°		1.53		Rock streambed with gravel banks.
15	Dry Frio River	25 ft above tributary from left	12.0	59°	7.11			Rock channel.
15	Tributary	From left	12.0			.4		Estimate. Loose gravel streambed.
15	Tributary	From right	12.1			.0		Gravel. Probably flow below gravel.
15	Tributary	From left	13.0			.5		Loose gravel streambed.
15	Tributary	From right	13.4			.0		Estimate. Probably flow below gravel.
16	Mine Creek	1,500 ft above mouth	14.7	49°		1.78		Rock streambed.
16	Dry Frio River	50 ft above natural rock ford to ranch	15.3	51°	14.8			Rock channel. Measured 100% of flow here.
16	Tributary	From right	16.4			.2		Estimate. Loose gravel streambed.
16	Honey Creek	From right	16.8			.6		Estimate. Rock streambed. Small seeps from high alluvium banks.
16	Tributary	From left	18.3			.02		Estimate. Gravel streambed and high alluvium banks.
16	Dry Frio River	0.2 mi below gravel ford from ranch	18.7	55°	19.1			Rock streambed and gravel banks.
16	Spring	On right bank;300 ft from river	20.9			.5		Estimate. This spring has had long use as domestic supply.
16	Tributary	From right; just below spring draw	20.9			.0		Gravel. May have underflow.
16	Dry Frio River	100 ft above rock ford to hunters cabin.	21.1	57°	20.3			Rock streambed and gravel banks.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
	From a point 10.2 miles upstream from Real-Uvalde county line to stream-gaging station near Reagan Wells, Tex., continued							
Jan. 16	Spring	On right bank; just above hunters cabin	21.1			0.3		Estimate. Flows from crevice in bed of rock draw; 100 ft from river.
16	Spring	On right bank; 400 ft below hunters cabin	21.2			.3		Estimate. Similar to above spring; 25 ft from river.
16	Tributary	From right	24.0			.7		Estimate. Rock channel. Enters river over low falls.
16	Dry Frio River	400 ft below tributary	24.1	59°	22.0			Rock streambed with gravel bar on left.
16	Tributary	From left	25.9			.5		Estimate. Gravel; spring reported 1/2 mile upstream.
16	Fusch Creek	From left. Above crossing; 1,500 ft above mouth	25.9	59°		5.82		Rock streambed with gravel bank. Reported to have headwater springs
16	Dry Frio River	600 ft above gaging station	26.1	57°	28.0			Smooth rock channel.
20	Dry Frio River	At gaging station	26.1		27.0			Not measured; from automatic recorder record.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Dry Frio River June 28, 1925

Reach: From Clark's Ranch house to a point 9½ miles below Reagan Wells, Tex.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 28	Dry Frio River	At Clark Ranch house 6 mi above Reagan Wells	0		0.5			Estimate.
28	Dry Frio River	Near Hurd School 3.6 mi above Reagan Wells	2.4		1.65			
28	Mine Creek	At Hurd School 3.5 mi above Reagan Wells	2.5			0.5		Estimate.
28	Dry Frio River	½ mi below Reagan Wells	6.5		5.16			
28	Dry Frio River	4½ mi below Reagan Wells	10.5		6.74			
28	Dry Frio River	8 mi below Reagan Wells	14.0		9.66			
28	Dry Frio River	9½ mi below Reagan Wells	15.5		0			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Sabinal River — December 15-16, 1954; September 10-11, 1955

Reach: From a point 8 miles upstream from Vanderpool, Bandera County to gaging station "near Sabinal", located 12.4 miles downstream from Utopia, Tex.

Problem: To determine gains and losses in river flow in the section of Sabinal River channel that flows on the Glen Rose limestone formation above the gaging station "near Sabinal".

Results: No conclusions could be reached due to insufficient flow in the streams involved. The larger flows found in December 1954 over those found in September 1955 were probably the result of decreased evaporation and transpiration. The 1955 investigation was made prior to first frost and no doubt the December flows were comparable to the preceding year.

Accuracy of Results: Only a few actual current-meter measurements were possible but those made were rated "Good - 5%". A considerable number of estimates were made of small flows, which are important only as an indication of visible surface flow. Flow conditions were stable during these investigations and data represent natural conditions.

Date 1954	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Dec. 15	Sabinal River	8.2 mi upstream from Vanderpool	0		0			Pool of water.
15	Sabinal River	7.0 mi upstream from Vanderpool	1.2		.2			Estimate.
15	Sabinal River	At Frank Weed Ranch - 4 mi above Vanderpool	4.2	50°	.96			Rock streambed.
15	Unnamed tributary	3.9 mi upstream from Vanderpool	4.3			0		Gravel streambed
15	Brushy Creek	1.5 mi upstream from Vanderpool	6.7			.15		Estimated. Rock streambed.
15	Sabinal River	At Vanderpool	8.2	61°	1.02			Gravel streambed.
15	Mill Creek	0.7 mi downstream from Vanderpool	8.9	52°		.88		Rock streambed.
16	Sabinal River	1.2 mi downstream from Vanderpool	9.4	44°	1.84			Rock streambed - gravel banks.
16	Sabinal River	2.1 mi downstream from Vanderpool	10.3		0			Gravel bar.
16	Sabinal River		11.6		.5			Estimated. Gravel bar.
16	Sabinal River		12.5		.75			Estimated. Gravel streambed.
16	Sabinal River		13.2		0			Gravel bar.
16	Sabinal River		14.4		.5			Estimated. Gravel streambed.
16	Sabinal River		14.8		0			Gravel bar
16	Sabinal River		15.7		0			Rock streambed.
16	Sabinal River	0.2 mi upstream from Canon Creek	17.9		0			Gravel streambed.
16	Canon Creek	300 ft above mouth at Utopia	18.1			.5		Estimated. Gravel streambed.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Discharge, in cfs: Tributary	Discharge, in cfs: Diversion	Remarks
	From a point 8 mi upstream from Vanderpool, Bandera County to gaging station "Near Sabinal", located 12.4 mi downstream from Utopia, Tex. - Continued.							
1954 Dec. 16	Sabinal River	Crossing FM road 1050	19.0		0			Gravel streambed.
16	Sabinal River	0.2 mi upstream from Turkey Creek	24.5		.5			Estimated. Gravel streambed.
16	Turkey Creek	1,500 ft above mouth	24.7			0		Gravel streambed.
16	Sabinal River	0.8 mi downstream from Turkey Creek	25.5		0			Gravel streambed.
16	Sabinal River	0.4 mi above Onion Creek	28.8		.5			Estimated. Rock streambed and gravel banks.
16	Onion Creek	At mouth	29.2			0		Rock streambed.
16	Sabinal River	Near Sabinal - Gaging station	31.4		0			Gravel streambed.
1955 Sept. 11	Sabinal River	8.2 mi upstream from Vanderpool	0		0			
11	Sabinal River	7.0 mi upstream from Vanderpool	1.2		0			
11	Sabinal River	At Frank Weed Ranch - 4 mi above Vanderpool	4.2	81°	.26			Rock streambed.
11	Unnamed tributary	3.9 mi upstream from Vanderpool	4.3			0		Gravel streambed.
11	Brushy Creek	1.5 mi upstream from Vanderpool	6.7			.02		Estimated. Rock streambed.
11	Sabinal River	At Vanderpool	8.2		.2			Rocky gravel streambed.
11	Mill Creek	0.7 mi downstream from Vanderpool	8.9			.25		Estimated. Rock streambed.
11	Sabinal River	1.2 mi downstream from Vanderpool	9.4		.4			Estimated. Rock streambed.
11	Sabinal River	2.1 mi downstream from Vanderpool	10.3		0			Gravel bar.
11	Sabinal River		11.6		.1			Estimated. Gravel bar.
11	Sabinal River		12.5		.15			Estimated. Gravel streambed.
11	Sabinal River		13.2		0			Gravel bar.
11	Sabinal River		14.4		.3			Estimated. Gravel streambed.
11	Sabinal River		14.8		.1			Estimated. Gravel bar.
11	Sabinal River		15.7		0			Rock streambed.
10	Sabinal River	0.2 mi upstream from Canon Creek	17.9		0			Gravel streambed.
10	Canon Creek	300 ft above mouth at Utopia	18.1			.81		Gravel streambed.
10	Sabinal River	Crossing FM road 1050	19.0		0			Gravel streambed.
10	Sabinal River	0.2 mi upstream from Turkey Creek	24.5		.3			Estimated. Gravel streambed.
10	Turkey Creek	1,500 ft above mouth	24.7			0		Gravel streambed.
10	Sabinal River	0.8 mi downstream from Turkey Creek	25.5		0			Gravel streambed.
10	Sabinal River	0.4 mi upstream from Onion Creek	28.8		.1			Estimated. Rock streambed and gravel banks.
10	Onion Creek	At mouth	29.2			0		Rock streambed.
10	Sabinal River	Near Sabinal - Gaging station	31.4		0			Gravel streambed.

LOW FLOW INVESTIGATIONS - NUECES RIVER BASIN

Sabinal River   April 8-11, 1958

Reach: From a point 8 miles upstream from Vanderpool, Bandera County, to gaging station on Highway 90 at Sabinal, Uvalde County, Tex.

Problem: 1. To determine gains and losses in streamflow in the section of Sabinal River channel on the Glen Rose limestone above the stream-gaging station near Sabinal.

2. To determine the effectiveness of the two existing stream-gaging stations "near" and "at" Sabinal, in indicating losses of flow in the section of channel that crosses the Balcones fault zone above Sabinal.

Results: No material losses were found in the reach on the Glen Rose limestone. This section of channel, 31.4 miles long, contributed all of the flow measured at the upper gaging station, which is point of maximum flow found in this investigation. Sixty-one cfs (58%) of the 105 cfs maximum flow was lost between the two gaging stations, a distance of 17.6 miles. Only about 30 cfs was lost in the 5.4 miles of the losing reach which is on the Edwards limestone; the remainder of the lost water is absorbed into other formations that crop out downstream from the Edwards.

The data obtained in this investigation indicate that the two gaging stations are well located to determine total losses in the faulted zones of this river above Sabinal. The lower station might have been located 8-10 miles further upstream had a logical site been found; however, investigation of the channel in the area did not reveal another site suitable for a gaging station. A good record at all stages can be obtained at the Sabinal site.

Discussion: Current-meter measurements were made at all points of critical interest; many small flows were estimated. No attempt was made to pace the discharge measurements with the rate of change in flow as the investigation progressed downstream. The channel was investigated throughout the reach, and the measurements were made as rapidly and as thoroughly as possible. The rate of change in flow was computed at three points in the reach by two determinations of flow at each of these points. The flow was dropping 5.4% per day at Utopia (mile 17.9), 3.8% per day at the upper gaging station (mile 31.4) and 4.6% per day at lower gaging station (mile 49.0). It is probably not possible to have a constant rate of flow in this reach of the stream if any appreciable amount of flow is present. The sources of base flow respond quickly to rainfall and probably reach their maximum flow before surface runoff is completely gone. Immediately after surface or flood flow has ended the base flow begins to decline and rate of flow falls off rapidly. Near constant flow is found only when rate of flow approaches zero and very small flows remain.

Several small channel dams were found but none that stored an appreciable amount of water. No diversions were observed; no irrigation pumps were located, but it is likely that some water is used for irrigation during the growing season.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Tributary	Diversion	Remarks
From a point 8 mi upstream from Vanderpool, Bandera County, to gaging station on Hwy 90 at Sabinal, Uvalde County, Tex.								
Apr. 8	Sabinal River	8.2 mi upstream from Vanderpool	0		0			Deep gravel in channel
8	Unnamed Trib.	8 mi upstream from Vanderpool	.2			0		Deep gravel in channel
8	Sabinal River	6.9 mi upstream from Vanderpool	1.3		.3			Est. - gravel streambed
8	Unnamed Trib.	5.4 mi upstream from Vanderpool	2.8			.5		Rock streambed
8	Sabinal River	At Frank Weed Ranch - 4 mi above Vanderpool	4.2	59°	3.04			Rock streambed
8	Unnamed Trib.	3.9 mi upstream from Vanderpool	4.3			.5		Est. - gravel streambed
8	Brushy Creek	1.5 mi upstream from Vanderpool	6.7			2.0		Est. - rock streambed
8	Unnamed Trib.	0.4 mi upstream from Vanderpool	7.8			.8		Est. - gravel streambed
8	Sabinal River	Vicinity of Vanderpool	8.2	Many springs and seeps along right bank for 1.5 mi above to 2 mi below Vanderpool				
8	Mill Creek	0.7 mi downstream from Vanderpool	8.9	63°		9.33		Gravel streambed - large cypress trees here.
8	Sabinal River	800 ft below low-water road crossing	9.5	62°	21.5			Smooth rock streambed. Springs and large seeps along right bank - cypress and pecan trees.
8	Sabinal River	300 ft below abandoned crossing	12.0	62°	21.3			Gravel streambed. Small springs flowing from low rock right bank. Large cypress trees.
8	Sabinal River	300 ft above creek from left	14.4	65°	21.4			Streambed composed of small boulder embedded in gray clay. Banks low - no cypress trees.
8	Unnamed Trib.	300 ft below above measurement	14.5			2.0		Est. - flow starts in conglomerate creek bed 1/4 mi above mouth.
8	Unnamed Trib.		14.6			0		No cut banks - shallow sloping banks - pecan & mesquite flats.
8	Sabinal River	500 ft above Canon Creek - at Utopia	17.9	66°	39.4			Gravel streambed - grove of large cypress trees - 2nd meas. made to show rate of change in flow.
11	Sabinal River	500 ft above Canon Creek - at Utopia	17.9	63°	33.6			Dropped 5.8 cfs in 65 hours.
8	Canon Creek	300 ft above mouth - at Utopia	18.1	65°		28.1		Gravel streambed - grove of large cypress trees. 2nd meas. made to show rate of change in flow.
11	Canon Creek	300 ft above mouth - at Utopia	18.1	64°		26.0		Dropped 2.1 cfs in 65 hours.
8	Sabinal River	Below Canon Creek	18.2		67.5			Not meas. Sum of above measurements.
11	Sabinal River	Below Canon Creek	18.2		59.6			Not. meas. Sum of above measurements made Apr. 11.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu- tary	Diver- sion	Remarks
Apr. 9	Sabinal River	Below Utopia - 100 ft above concrete slab crossing	21.6	64°	70.8			Solidified gravel streambed. Grove of large cypress trees. Smooth rock (Glen Rose) shows in streambed a short distance down-stream.
9	Sabinal River	300 ft above Turkey Creek	24.6	66°	73.7			Gravel streambed - smooth rock shoal 300' upstream. A few cypress trees (dead) along right bank.
9	Turkey Creek	1500 ft above mouth - Sabine Grande Ranch	24.7	68°		14.3		Gravel streambed - banks of loam & sparsely wooded.
9	Sabinal River	1500 ft below Ranch Road 187 - 200 ft above Onion Creek	29.1	69°	96.9			Shallow gravel streambed over smooth rock - large cypress trees.
9	Onion Creek	400 ft above mouth	29.2	70°		6.0		Smooth rock streambed. Banks of loam - pecan trees & scattered cypress.
9	Sabinal River	Near Sabinal - gaging station	31.4	70°	105			Solidified gravel streambed.
11	Sabinal River	Near Sabinal - gaging station	31.4		98			Not measured. From recorder record. Flow dropped 7.0 cfs in 42 hours.
Gaging station at mile 31.4 is point of maximum flow. Stream leaves Glen Rose limestone formation and flows onto Edwards limestone about 1/4 mile below gaging station. Flow immediately starts to decrease. No tributary inflow below this point.								
9	Sabinal River	At abandoned highway crossing	33.2	69°	92.3			Very rough streambed, broken rock, gravel & boulders - water weeds & moss. No cypress trees.
10	Sabinal River	1.5 mi above Recharge Dam	35.4	69°	80.0			Streambed of solidified gravel and clay - water weeds and moss.
Downstream edge of Edwards limestone is located 1.4 miles downstream, at mile 36.8								
10	Sabinal River	300 ft above abandoned crossing	39.0	72°	50.2			Streambed of gravel - 100' down-stream begins 1/4 mi long rock shoal. Rough & cracked.
10	Sabinal River	At upper edge of rock shoal	42.4	72°	47.0			Rock & gravel streambed
10	Sabinal River	200 ft below State Highway 127	45.8	71°	45.4			Gravel streambed
11	Sabinal River	At Sabinal - gaging station at U. S. Highway 90	49.0	69°	44.0			Rock streambed
13	Sabinal River	At Sabinal - gaging station at U. S. Highway 90	49.0		40.0			Not measured. Discharge deter-mined from gage reading by observer. Dropped 4.0 cfs in 48 hours.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Sabinal River   January 10, 1934

Reach: From a point .8 mi below to 18.8 mi below Utopia, Tex.

Discharge measurements of Sabinal River from a point 0.8 mile below Utopia, Tex., to 18.8 miles below Utopia were made on January 10, 1934 to determine the seepage gains or losses. During the investigation the river was at a constant stage, and measurements represent natural conditions.

Date 1934	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Jan. 10	Sabinal River	.8 mi below Utopia	0		4.98			
10	Sabinal River	7.8 mi below Utopia	7.0		7.82			
10	Sabinal River	18.3 mi below Utopia	17.5		6.46			
10	Sabinal River	18.8 mi below Utopia	18.0		5.90			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Sabinal River May and August 1942

Reaches: From a point 1.0 miles south of Utopia to 6.0 miles north of Sabinal, Tex.
From Onion Creek to a point 6.0 miles north of Sabinal, Tex.

A series of discharge measurements were made during each of the periods May 8, 18, 1942, and August 5, 1942 on the Sabinal River and tributaries, Tex., in reaches 9.5 and 17.5 miles in length between points below Utopia and a point 6.0 miles north of Sabinal, Uvalde County. The investigations were made during periods of constant stage of the river except as noted, and the determinations of gain or loss represent normal conditions.

Date 1942	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 1.0 mi south of Utopia to 6.0 mi north of Sabinal							
May 8	Sabinal River	1.0 mi S of Utopia	0		32.0			Rock channel.
8	Sabinal River	$\frac{1}{4}$ mi above first road crossing below Utopia	3.0		36.3			Rock channel.
8	Onion Creek	At mouth $7\frac{1}{2}$ mi below Utopia	8.0			0.7		Estimate.
8	Sabinal River	Just below Onion Creek	8.0		45.5			Gravel channel.
8	Sabinal River	Just below second road crossing above Sabinal	10.0		45.1			Rock channel.
9	Sabinal River	Just below second road crossing above Sabinal	10.0		42.3			Rock channel.
8	Sabinal River	At first road crossing above Sabinal	12.0		35.1			Rock channel.
9	Sabinal River	At first road crossing above Sabinal	12.0		33.2			Rock channel.
7	Sabinal River	At side road crossing 6 mi N of Sabinal	17.5		0			8 p.m.
8	Sabinal River	At side road crossing 6 mi N of Sabinal	17.5		1.5			Estimate 8 a.m.
8	Sabinal River	At side road crossing 6 mi N of Sabinal	17.5		7.2			8 p.m.
	From Onion Creek to a point 6.0 mi north of Sabinal							
May 18	Onion Creek	At mouth $7\frac{1}{2}$ mi below Utopia	0			1.2		
18	Sabinal River	Just below Onion Creek	0		32.3			Gravel channel.
18	Sabinal River	At second road crossing above Sabinal	2.0		31.8			Rock channel.
18	Sabinal River	At first road crossing above Sabinal	4.0		23.0			Rock channel.

Date 1942	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
	From Onion Creek to a point 6.0 mi north of Sabinal, continued							
May 18	Sabinal River	At side road crossing 6 mi N of Sabinal	9.5		0			
Aug. 5	Onion Creek	At mouth $7\frac{1}{2}$ mi below Utopia	0			0.4		Estimate.
5	Sabinal River	Just below Onion Creek	0		6.55			Gravel channel.
5	Sabinal River	At second road crossing above Sabinal	2.0		3.03			Rock channel.
5	Sabinal River	At first road crossing above Sabinal	4.0		0			
5	Sabinal River	At side road crossing 6 mi N of Sabinal	9.5		0			

Hondo Creek April 5-7, 1958

Reach: From near the headwaters in Bandera County, 6 miles above Tarpley, to U. S. Highway 90 in Medina County, Tex.

Problem: To determine gains and losses in streamflow in Hondo Creek in the reach from near the headwaters in Bandera County to U. S. Highway 90 in Medina County.

Results: To simplify the description of this investigation the section of Hondo Creek covered is divided into three sub-reaches as follows:

Sub-reach 1: That portion lying above the stream-gaging station near Tarpley. This stretch, 12.2 miles long, is entirely on the Glen Rose limestone. It extends from a short distance above Pigeon Roost Creek to the gaging station near Tarpley.

Sub-reach 2: The central portion lying between the stream-gaging stations near Tarpley and Hondo. About 10.5 miles of the 11.9 mile reach is on the Edwards limestone.

Sub-reach 3: This reach extends 13.1 miles downstream from the stream-gaging station near Hondo to U. S. Highway 90, about 5 miles east of Hondo. In this interval the streambed crosses numerous geologic formations and faults.

Note: All references to geology (except those in Bandera County) were taken from Texas Board of Water Engineers Bulletin 5601, "Geology and Ground-Water Resources of Medina County, Texas." This bulletin was prepared in cooperation with the Geological Survey, United States Department of the Interior and was written by Charles L. R. Holt, Jr., Geologist, USGS.

Results, Sub-reach 1: No losses were found in this reach and the flow increased from 7.11 cfs to 58.8 cfs in 12.2 miles. This section of channel is on the Glen Rose limestone and contributes a major portion of the maximum of 58.8 cfs measured at its lower contact. A previous investigation found springs in the Edwards limestone at the head of this stream; therefore, it is presumed that a portion of the 7.11 cfs of initial flow measured is contributed by these springs. Williams Creek, which enters Hondo Creek about 1.0 mile below Tarpley, likewise has Edwards limestone springs at its source and was contributing 15.4 cfs at this time. There were many springs and seeps throughout the reach.

Results, Sub-reach 2: About one-fourth mile above the gaging station near Tarpley, Hondo Creek channel crosses the fault line separating the Glen Rose limestone from the Edwards limestone. Here the character of the channel changes and the flow begins to diminish. The smooth rock of the Glen Rose has given way to the gravel and alluvium on the Edwards. Of the 58.8 cfs at the upper contact of the Edwards limestone, 28.7 cfs (49%) is lost in the 11.9 miles between the gaging stations. Possibly a part of this loss was absorbed by the Buda limestone or the Austin chalk just above the lower gaging station. No contributions of any type were observed in sub-reach 2.

Results, Sub-reach 3: In the first 3.5 miles of this reach 16.5 cfs of a total of 30.1 cfs was lost into the formations that are crossed in this section. This loss averages 4.7 cfs per mile and it seems reasonable to assume that some water likewise is lost in the short section of these same formations extending above the gaging station into sub-reach 2, and that the losing section extends somewhat below the 3.5 miles mentioned above. Below mile 29 the losses appear to be about normal and can be attributed to evaporation and transpiration. The slight gain indicated in the section near the mouth of Verde Creek probably can be attributed to springs and seeps in the Leona formation. It is possible that the contribution from the Leona may increase below Highway 90 where the formation is more extensive.

Discussion: Chart records from the two stream-gaging stations indicate that the rate of flow throughout the reach investigated was slowly decreasing. The change was determined to be -0.5 cfs (0.8%) per day at the gage near Tarpley and -1.47 cfs (4.9%) per day at gage near Hondo. Check measurements are usually made at several points in the reach a few days after completion of an investigation, to indicate comparative flow conditions in the stream. A local rain shower on the immediate basin a few hours after this series of measurements was completed disturbed the rate of change in flow, and made check measurements impossible. The rates of change shown above were computed from gage-height charts for short periods just prior to the rain.

Measurements were started at 9:40 a.m. on April 5 at the mouth of Pigeon Roost Creek, which is about 1.0 mile above the crossing of F.M. 470. They were completed at 4:40 p.m. on April 7 at Highway 90 crossing 5 miles east of Hondo. The starting point was purposely selected far enough upstream to indicate contributions and losses in the Glen Rose limestone. Twenty current-meter measurements were made in the 37.2 miles of the stream investigated. Several estimates were made of springs and smaller tributaries.

The channel in sub-reach 1 is smooth rock, rather precipitous, with falls, rock riffles, deep erosion in places, and here and there a thin covering of gravel. There are numerous springs, and long stretches of channel with seepage of quantity from the alluvium and from cracks and crevices in the limestone. Several channel dams were located but no lakes of consequence. No irrigation or other diversion was found.

In sub-reach 2 the channel is rougher with large deposits of gravel, steep gravel and boulder riffles, and no smooth rock streambed. No springs or seeps were found and all tributaries were dry. The measuring sections are composed principally of large gravel that has a solidified appearance, with vegetation growing in the channel. The streambed on the riffles is extremely rough, and is composed of large gravel and boulders. There are no loose, porous gravel beds in this reach.

The first few miles of sub-reach 3 crosses several geologic formations and faults; rough, broken rock and large gravel beds are the rule in the streambed. In the lower section of the reach, the streambed, rather wide and flat, is principally of fine to medium-sized gravel, with much of it grown up in brush and weeds. Several small seeps were found in this lower section but no springs of consequence.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
From near the headwaters in Bandera County, 6 miles above Tarpley, to U. S. Highway 90 in Medina County								
Apr. 5	Hondo Creek	100 ft above Pigeon Roost Creek	0		7.11			Smooth rock; seeps along left bank.
5	Pigeon Roost Cr	200 ft above mouth	0.1			2.76		Gravel over rock; seepage along left bank.
5	Spring	1000 ft below Pigeon Roost Creek	0.2			.5		Flowing from left bank.
5	Hondo Creek	3 mi above Tarpley	3.2	73°	12.6			Fine gravel and sand; large seeps from right bank.
5	Hondo Creek	500 ft above Williams Creek	6.1	69°	16.7			Smooth rock and cut down 8-10 ft into rock.
5	Williams Creek	4.7 mi above Hondo Creek	-	72°		5.04		Light gravel over rock, seepage along left bank.
5	2 Springs	3.2 mi above Hondo Creek left bank	-			1.0		Estimate.
5	Tributary to Williams Creek	3.1 mi above Hondo Creek from left	-			1.5		
5	Williams Creek	2.4 mi above Hondo Creek	-			9.14		Rock, partly rough.
5	Tributary to Williams Creek	1.5 mi above Hondo Creek from left	-			1.5		Rock.
5	Williams Creek	1600 ft above Hondo Creek	6.2	74°		15.4		Smooth rock. Bed cut down 10' into rock; strong seeps along left bank at top of rock.
5	Hondo Creek	At mouth of Williams Creek	6.2		32.1			Sum of Hondo and Williams Creek.
5	Tributary	From left - at mouth	6.4			0.2		Estimate; rock.
5	Tributary	From left - at mouth	6.5			3.0		Estimate; rock.
5	Tributary	From left - at mouth	7.2			.3		Estimate; rock.
6	Hondo Creek	50 ft above sharp bend to right	8.3	64°	41.8			Smooth rock. Seeps along left bank.
6	Tributary	From right, 1/4 mi above mouth	9.6	69°		5.66		Smooth rock. No seepage.
6	Hondo Creek	0.5 mi above Bandera Creek	10.0	72°	51.5			Gravel over rock. Small seeps along right bank.
6	Bandera Creek	600 ft above mouth	10.5	74°		3.45		Light gravel over rock. Small seeps along right bank.
6	Hondo Creek	At gaging station near Tarpley	12.2	74°	58.8			Large gravel.
8	Hondo Creek	At gaging station near Tarpley	12.2		57.8			Not measured; determined from recording gage record.
6	Hondo Creek	150 ft below concrete crossing	14.9	70°	49.1			Heavy gravel.
7	Tributary	From left	18.6			0		Gravel and boulders.
7	Hondo Creek	0.2 mile below tributary	18.8	68°	43.9			Gravel and boulders.
7	Hondo Creek	400 ft above Farm Road 462	21.4	65°	35.6			Firm gravel and boulders.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Apr. 7	Hondo Creek	1000 ft below gaging station near Hondo	24.1	67°	30.1			Firm gravel.
8	Hondo Creek	1000 ft below gaging station near Hondo	24.1		28.2			Not measured; determined from recording gage record.
7	Hondo Creek	At abandoned ranch crossing	27.6	72°	13.6			Loose gravel.
7	Hondo Creek	0.5 mi below low concrete county crossing	31.1	73°	11.0			Broken and disturbed rock.
7	Hondo Creek	1/4 mi upstream from county road	34.7	72°	9.76			Loose gravel.
7	Verde Creek	0.2 mi above mouth	36.9			0.5		Estimate - loose gravel.
7	Hondo Creek	At U. S. Highway 90	37.2	72°	11.1			Medium firm gravel.

Verde Creek — January 14, 1958

Reach: From a point on Middle Verde Creek about 0.5 mile below Joe Short ranch house and 5.5 miles above East Verde Creek to County Road 4 miles west of Quihi, Medina County, Tex.

Problem: To determine the amount of flow in Verde Creek above and below the outcrop of the Edwards limestone in Medina County, Tex.

Results: Total measured streamflow at or just above the upper contact of the Edwards limestone formation was 58.4 cfs, distributed as follows: 48.0 cfs in Middle Verde Creek, mainstream of Verde Creek; 10.4 cfs in East Verde Creek; no flow in Turkey Roost Creek. An estimated 5 to 10 cfs was flowing in Verde Creek at the approximate lower edge of the Edwards limestone, which point is below East Verde and Turkey Roost Creeks. This remaining streamflow had disappeared about 3 miles further downstream; at a concrete crossing on a county road 5-1/2 miles west of Quihi and 0.5 miles above F.M. Road 689. A trickle (0.1 cfs) was found at F.M. 689 and at a county road 1.3 miles below F.M. 689. No springs, seeps, or tributary inflows were found other than that which was measured in East Verde Creek; no reservoirs or diversions were located.

Note: Data for references to geologic formations and fault lines were obtained from Texas Board of Water Engineers Bulletin 5601, Plate 1, "Geology and Ground-Water Resources of Medina County, Texas."

Discussion: Current-meter measurements were made on Middle Verde Creek at a point about 100 feet below a ranch crossing of natural rock about 1/2 mile below the Joe Short ranch house, and on East Verde Creek 400 feet below the lower crossing of the county road from Bandera to Hondo, about 2.2 miles southeast of the Joe Short ranch house. Turkey Roost Creek was inspected at a point about 2-1/2 miles southwest of the Joe Short ranch house and at several other points in the remaining 9 miles to its mouth. No flow was found and the creek, which throughout this reach is on the Edwards limestone, has a poorly defined channel with no definite low-water banks. No additional site suitable for a current-meter measurement was found on the main stream. An estimate of flow (10 cfs) was made at the concrete crossing 0.4 mile upstream from Turkey Roost Creek; and another estimate (5 cfs) at a point 5.2 miles further downstream. At this downstream point the streambed is composed of large gravel and 6-inch to 12-inch boulders on a series of steep rough rapids. The lower edge of the Edwards limestone is located about 2 miles upstream. The first point at which zero flow was observed was at a county concrete crossing 1.3 miles further downstream, about 1/2 mile upstream from the Haby Crossing Fault.

On January 17 a second current-meter measurement was made on East Verde Creek at the same site used on January 14. The second measurement was made to indicate the rate of change in streamflow during this period, there being no stream-gaging station on Verde Creek. The flow had fallen off 2.34 cfs in the three day interval, from 10.4 to 8.06 cfs, or 7.5% per day.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point on Middle Verde Creek about 0.5 mile below Joe Short ranch house and 5.5 miles above East Verde Creek to County Road 4 miles west of Quihi, Medina County							
Jan. 14	Middle Verde Cr	1.3 mi below West Verde Creek	0	58°	48.0			Rock streambed.
14	East Verde Cr	3.8 mi above mouth	5.5	58°		10.4		Gravel streambed.
17	East Verde Cr	3.8 mi above mouth	5.5	53°		8.06		Gravel streambed. Second measurement made to indicate rate of change in streamflow.
14	Verde Cr	0.4 mi above Turkey Roost Creek	11.2		10			Estimate; very rough rock streambed.
14	Turkey Roost Cr	9.0 mi above mouth	-			0		Rough broken rock streambed; channel poorly defined.
14	Turkey Roost Cr	1.4 mi above mouth	11.2			0		Rough broken rock streambed; channel poorly defined.
14	Verde Cr	4.8 mi below Turkey Roost Creek	16.4		5			Estimate; very rough, steep riffles composed of large gravel and small boulders.
14	Verde Cr	At county road 1/2 mi above F.M. 689	17.7		0			Rock streambed.
14	Verde Cr	At F.M. 689	18.2		0.1			Estimate; loose gravel streambed.
14	Verde Cr	At county road, 4 mi west of Quihi	19.5		0.1			Estimate; gravel streambed.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Seco Creek April 1-4, 1958

Reach: From near headwaters in Bandera County (3.2 miles above F. M. 470) to U. S. Highway 90 (1 mile west of D'Hanis), Medina County, Tex.

Problem: To determine gains and losses in streamflow in Seco Creek in the reach from near the headwaters in Bandera County to U. S. Highway 90 in Medina County.

Results: To simplify the description of this investigation the section of Seco Creek covered is divided into four sub-reaches as follows:

Sub-reach 1: That portion on the Glen Rose limestone above the upper contact of the Edwards limestone. This stretch is 16.4 miles long and extends 2.1 miles downstream from the gaging station near Utopia.

Sub-reach 2: The short middle portion about 2.8 miles long that is on the Edwards limestone.

Sub-reach 3: This reach 7.6 miles long extends from the lower contact of the Edwards limestone to the point of zero flow which is located about 7.1 miles downstream from the gaging station near D'Hanis.

Sub-reach 4: The 12.2 miles of channel from the point of zero flow to U. S. Highway 90.

Note: All references to geology in this report except those in Bandera County were taken from Texas Board of Water Engineers Bulletin 5601, "Geology and Ground-Water Resources of Medina County, Texas". This bulletin was prepared in cooperation with the Geological Survey, United States Department of the Interior and was written by Charles L. R. Holt, Jr., Geologist, USGS.

Results, Sub-reach 1: This reach, which is on the smooth rocks of the Glen Rose limestone, contributes most of the flow found in the section of Seco Creek investigated. A part of the initial flow (1.5 cfs) probably comes from springs in the Edwards limestone near the head of the creek. A few small springs and seeps were found a few miles above U. S. Highway 90. The flow increased from 1.5 cfs to about 33.5 cfs in the upper 13 miles of the reach; all tributaries were flowing and many springs and seeps were found. No losses were located in the upper 13 miles of the reach. The losing section begins about 1 mile above the gaging station near Utopia; about 5.3 cfs was lost from that point to the upper contact of the Edwards limestone 2.0 miles below the gage. There were no contributions in the losing section.

Results, Sub-reach 2: The losses in this reach, which flows on the Edwards limestone, could not be determined accurately but were small in comparison with losses in adjacent upstream and downstream reaches. The measurement at mile 16.4 (28.3 cfs) was made at the upper contact of the Edwards limestone. The lower contact is found in the small lake formed by the concrete dam at the Woodard ranch. This dam is built on the upper edge of a very rough rock outcrop which extends downstream below the mouth of Little Seco Creek. Two measurements were made as near the lower contact as possible, one above at mile 18.5 (27.3 cfs) and one below at mile 19.7 (25.4 cfs). Results of the measurements indicate a small loss to the Edwards, a minimum of 1.0 cfs and a maximum of 2.9 cfs. The formation that crops out below the Edwards and above mile 19.7 probably takes more water than the Edwards; losses from mile 19.7 to 21.8 (sub-reach 3) run 5.6 cfs per mile, whereas the Edwards absorbs only 1.0 cfs in 2.1 miles from mile 16.4 to 18.5. No tributary inflow or other contribution to flow was found in this reach.

Results, Sub-reach 3: The formations in this reach absorb 23.5 cfs of flow in 5.5 miles and the flow disappears completely at a point 7.1 miles below the gaging station near D'Hanis. No springs, seeps, or tributary inflow was found in this reach.

Results, Sub-reach 4: Gains or losses could not be defined in this reach due to lack of flow. Several pools were found in the creek a few miles above Highway 90. These are reputed to have springs as their source. A trickle of flow (0.2 cfs) was found on rock 3 miles above the highway; 0.01 cfs was estimated at the highway bridge. The pools and the two small flows above was all the water found in this reach.

Discussion: Current-meter measurements were made at all points of critical interest and a majority of them were made at good measuring sections. Field estimates were made where flows were small or unimportant. No attempt was made to pace the discharge measurements with the rate of change in flow as the investigation progressed downstream. Channel conditions were investigated throughout the reach and measurements were made as rapidly and as thoroughly as possible. The rate of change in flow was determined at three points in the reach by two determinations of flow at each point. The flow dropped 3.48 cfs in 96 hours (6.6% per day) at mile 3.5; 7.3 cfs in 96 hours (5.7% per day) at mile 11.8 (point of maximum flow); and 3.68 cfs in 97 hours (6.8% per day) at mile 21.8. It probably is not possible to have a constant rate of base flow in this stream except as the rate approaches zero and only very small flows are involved.

Measurements were started at 2:50 p.m. April 1, about 1 mile above the Smartt ranch house on West Fork of Seco Creek and about 3.2 miles upstream from Farm Road 470. They were completed at 5:30 p.m. on April 4 at U. S. Highway 90. The starting point was purposely selected far enough upstream to indicate gains or losses of flow in the Glen Rose limestone,

In sub-reach 1 the channel flows on the smooth rocks of the Glen Rose limestone, deeply eroded in places, with falls, steep rock riffles, and here and there a thin covering of gravel. A few springs were found and long stretches of channel where there was seepage of quantity from the banks. No dam nor lake was found except at Woodard ranch; no diversion.

In sub-reach 2 the channel becomes much rougher with broken rocks, boulders, and large deposits of coarse gravel. Measuring conditions in this type of channel are generally poor, and the one measurement made in the reach, at mile 18.5 is so rated. Woodard Cave is found on the right bank of the creek at mile 17.4. This is a vertical hole in the cavernous Edwards limestone about 30 feet in diameter and 200-300 feet deep, located in the flood plain of Seco creek. During extreme floods, a large amount of water flows into this cave. At the peak of the June 17,1958 flood an estimated 200 cfs was flowing into the Edwards limestone through this opening; a much larger quantity of water flowed into it during the flood in May 1935 when the peak stage was 6-7 feet higher than that of June 17, 1958.

The channel in sub-reaches 3 and 4 crosses several geologic formations and about 10 fault lines. Generally the streambed is composed of immense deposits of gravel with here and there shoals of rock. Further measurements should be made in this section when sufficient flow is found to carry through to U. S. Highway 90.

Reconnaissance of Nov. 7, 1958

The following observations were made by the hydrographer who made the above investigation.

Mile 19.7: Flow was determined to be 100 cfs at the recording gage near D'Hanis. Determination made by reference to recording gage and rating curve.

Mile 21.8: Flow estimated to be 60-70 cfs. Channel is composed of gravel.

Mile 22.3: Bartz Spring Creek enters from the left at this point. No flow was found in this creek with its very rough bed of broken rock, large and small boulders and gravel.

Mile 24.2: Flow estimated to be 40-50 cfs in a gravel channel with rock showing here and there.

Mile 24.9: Flow estimated to be 30 cfs in a tight gravel channel which has the appearance of conglomerate. One-fourth mile downstream from this point channel is composed of rock.

Mile 26.2: Flow estimated to be 30 cfs in a gravel channel. Rocky Creek which comes in from the left just upstream from this point was dry.

Mile 27.0: Last of flow disappears at this point. Channel is wide and composed of loose gravel. Last of flow tails out into gravel at lower end of a long pool. Velocity could be observed in the water flowing into the gravel.

Mile 28.2: No flow at FM 1796 crossing where channel is composed of gravel and small boulders.

Mile 32.8: No flow in streambed composed of loose gravel.

Mile 36.0: Estimated flow, 1.5 cfs on rock streambed. This flow is reported to come from springs and seeps in pools a short distance upstream.

Mile 39.0: Estimated flow, 1.5 cfs at U. S. Highway 90. Channel composed of gravel and clay.

Mile 49.0: Estimated flow, 1.5 cfs at Deer Creek road crossing which is about 10 miles below U. S. Highway 90. Channel composed of gravel and clay.

Mile 56.0: Estimated flow, 3.0 cfs at point about 17 miles downstream from U. S. Highway 90. Flow was estimated at a rock shoal in a narrow crooked channel.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From near headwaters in Bandera County (3.2 mi above FM 470) to U.S. Hwy 90 (1 mi west of D'Hanis) Medina County							
Apr. 1	West Seco Creek	Smartt ranch - 3.2 mi above FM 470	0	62°	1.50			Gravel. Seeps along both banks.
1	Tributary	From right; below above measurement	0	62°		0.57		Gravel. Seeps along both banks.
1	Spring	On right bank, 1/2 mi above Smartt house	.5			.02		Estimated. Did not go dry during drought.
1	Tributary	From left	.7			.1		Estimate.
1	West Seco Creek	300 ft above East Seco Creek	2.3	65°	3.90			Loose gravel and boulders.
1	East Seco Creek	600 ft above mouth	2.4	66°		3.55		Smooth rock.
2	Tributary	From left, 0.1 mi below FM 470	3.3			1.0		Estimate. Rock.
2	Tributary	From left	3.4	63°		1.80		Smooth rock. Creek enters Seco over 10 ft falls.
2	Seco Creek	1,500 ft below FM 470	3.5	63°	13.1			Smooth rock.
6	Seco Creek	1,500 ft below FM 470	3.5	57°	9.62			Smooth rock. Second measurement made to indicate rate of change of flow.
2	Tributary	From right	4.0			1.5		Estimate. Smooth rock. 25-30 ft fall at mouth.
2	Tributary	From left	4.5			1.0		Estimate. Smooth rock. 15-20 ft falls at mouth.
2	Seco Creek	--	5.5	65°	16.1			Smooth rock. Seeps along left bank.
2	Tributary	From right	6.5			.25		Estimate. Smooth rock.
2	Tributary	From right	7.2			.75		Estimate. Rock channel.
2	Seco Creek	--	7.6	68°	19.6			Smooth rock. Seeps along left bank.
2	Tributary	From right	8.2			.2		Estimate. Rock channel.
2	3 tributaries	From left	8.4	70°		5.11		Rock channel.
2	Seco Creek	At sharp bend to left	9.7	69°	25.8			Gravel. No seepage here.
2	Tributary	From left	10.4			3.0		Estimate. Smooth rock.
2	Tributary	From left	10.7			.8		Estimate. Smooth rock.
2	Tributary	From right	11.6			.2		Estimate. Broken rock.
2	Seco Creek	--	11.8	69°	32.1			Gravel over rock. Seepage along rock bluff on left.
6	Seco Creek	--	11.8	73°	24.8			Gravel over rock. Seepage along rock bluff on left. Second measurement made to indicate rate of change of flow.
2	Tributary	From left	13.2			1.5		Estimate. Rock.

Date 1958	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Apr. 2	Tributary	From right	14.0			0		First with zero flow. No tributary flow below this point.
3	Seco Creek	At gaging station near Utopia	14.4	68°	30.6			Smooth rock. No seepage.
3	Seco Creek	125 ft above north fence of Woodard ranch (Valdina farms)	16.4	72°	28.3			Rock. Some rough.
3	Seco Creek	0.5 mi above Woodard dam	18.5	78°	27.3			Gravel and boulders - rough.
3	Little Seco Cr	9 mi above mouth	-			.0		Gravel.
3	Little Seco Cr	7.1 mi above mouth	-			.1		Estimate. Rock - conglomarate bank.
3	Little Seco Cr	5.7 mi above mouth	-			1.5		Estimate. Rock.
3	Little Seco Cr	4.8 mi above mouth	-			1.5		Estimate. Rock.
	Rough rock falls and riffle. Flow starts disappearing in gravel just below the falls.							
	Light loose gravel with smooth rock showing here and there.							
3	Little Seco Cr	4.6 mi above mouth	-			0		Gravel.
3	Little Seco Cr	3.4 mi above mouth	-			0		Gravel and small boulders.
3	Little Seco Cr	At mouth	19.5			0		Gravel and boulders.
	Seco Creek continued.							
3	Seco Creek	At gaging station near D'Hanis	19.7	82°	25.4			Gravel and small boulders.
3	Seco Creek	100 ft above private concrete bridge.	21.8	75°	13.6			Loose gravel, some large.
7	Seco Creek	100 ft above private concrete bridge.	21.8	71°	9.92			Loose gravel, some large. Second measurement made to indicate rate of change of flow.
4	Bartz Spring Cr	At mouth	22.2			0		Gravel and boulders.
4	Seco Creek	1.3 mi above Rocky Creek	24.6	70°	1.88			Heavy gravel.
4	Seco Creek	Just above Rocky Creek	25.9		1.5			Estimate. Large gravel.
4	Rocky Creek	At mouth	25.9			0		Gravel.
4	Seco Creek	Just below Rocky Creek	26.0		.1			Large bar of loose gravel.
4	Seco Creek	--	26.6		.05			Loose gravel.
4	Seco Creek	--	26.8		0			Wide bed of gravel and small boulders.
4	Seco Creek	Low crossing - FM 1796	28.2		0			Wide bed of gravel and small boulders.
4	Seco Creek	--	32.8		0			Bed of loose gravel.
	There are several large pools from mile 33.7 to 36.0 which are reported to be everlasting.							
4	Seco Creek	--	36.0		.2			Estimate. Rock channel.
4	Seco Creek	At U. S. Highway 90	39.0		.01			Gravel.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Leona River April 25-28, 1925

Reach: From Uvalde-Friotown Highway bridge to old Woodward Ranch near Batesville, Tex.

Discharge measurements on Leona River from Highway bridge southeast of Uvalde to the old Woodward Ranch, were made in April 1925, to determine seepage gains or losses. The river was at a constant stage during this series of measurements.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Apr. 25	Leona River	At Uvalde-Friotown Highway crossing	0		3.78			
25	Leona Valley Irrigation Co.	Diversion No. 1	2.0				7.24	
25	Leona River	100 ft below Dam No. 1	2.1		1.96			
27	Leona River	At White place above Kincaid Dam	6.1		3.38			
27	Kincaid Canal	300 ft below Dam	8.1				7.66	
27	Leona River	Just below Kincaid Dam	8.1		0			All water diverted.
27	Leona River	3 mi below Kincaid Dam	11.0		12.0			
28	Leona River	At Hackberry crossing	17.0		8.01			
28	Batesville Canal	200 ft below Dam	20.1				4.77	
28	Leona River	Just below Batesville Dam	20.1		1.08			
28	Leona River	1½ mi below Batesville Dam	22.1		.4			Estimate.
28	Leona River	3 mi below Batesville Dam	23.3		.5			Estimate.
28	Leona River	At Ottenhouse Ranch	26.4		.3			Estimate.
28	Leona River	At old Woodward Ranch	33.5		0			Dry downstream.

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Leona River June 11-12, 1931

Reach: From Highway bridge 1.7 mi SE of Uvalde to Rogers Ranch 35 mi SE of Uvalde, Tex.

Discharge measurements of Leona River near Uvalde, Tex., were made on June 11, 12, 1931, to determine seepage gains or losses. During the investigation the river was at a constant stage, and the measurements represent the natural conditions. There were no diversions from the river or inflow from tributaries during this seepage investigation.

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 11	Leona River	At Highway bridge 1.7 mi SE of Uvalde	0		3.1			
11	Leona Valley Irrigation Co.	At headgate, Diversion No. 1	2.0				0	
11	Leona River	Just below Leona Valley Irrigation Dam	2.1		8.0			
11	Leona River	At White's place crossing above Kincaid Dam	6.6		16.4			
11	Kincaid Canal	At headgate	8.1				0	
11	Leona River	Just below Kincaid Dam	8.1		7.2			
11	Leona River	3 mi below Kincaid Dam	11.0		19.1			
12	Leona River	At Hackberry crossing	17.0		9.5			
12	Batesville Canal	At headgate	20.1				0	
12	Leona River	Just below Batesville Dam	20.1		6.9			
12	Leona River	1½ mi below Batesville	22.1		4.7			
12	Leona River	3 mi below Batesville	23.3		3.6			
12	Leona River	At Ottenhouse Ranch	26.4		2.2			
12	Leona River	At old Woodward Ranch	33.5		.5			
12	Leona River	At Rogers Ranch	37.5		0			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Leona River November 7, 1932

Reach: From Highway bridge 1.7 mi SE of Uvalde to Hackberry crossing near Batesville, Tex.

Discharge measurements of Leona River near Uvalde, Tex., were made on November 7, 1932, to determine seepage gains or losses. During the investigation the river was at a constant stage, and measurements represent natural conditions. There were no diversions from the river or inflow from tributaries during this investigation.

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Discharge, in cfs Tributary	Discharge, in cfs Diversion	Remarks
Nov. 7	Leona River	At Highway bridge 1.7 mi SE of Uvalde	0		18.6			
7	Leona Valley Irrigation Co.	At headgate, Diversion No. 1	2.0				0	
7	Leona River	At S. L. Gilbert Ranch	5.5		40.8			
7	Kincaid Canal	At headgate	8.1				0	
7	Leona River	Just below Kincaid Canal	8.1		40.1			
7	Leona River	At Hackberry crossing	17.0		39.8			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Leona River June 21, 22, 1934

Reach: From Highway bridge 1.7 mi SE of Uvalde to Rogers Ranch near Batesville, Tex.

Discharge measurements of Leona River near Uvalde, Tex., were made on June 21, 22, 1934, to determine seepage gains or losses. During the investigation the river was at a constant stage, and measurements represent natural conditions. There was no inflow from tributaries during this seepage investigation.

Date 1934	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
June 21	Leona River	At Highway bridge 1.7 mi SE of Uvalde	0		6.8			
21	Lane-Taylor Canal	At headgate	2.0				0	Formerly Leona Valley Irrigation Company.
21	Leona River	Just below Lane-Taylor Dam	2.1		14.4			
21	Leona River	At crossing at White's Place	6.6		18.8			
21	Kincaid Canal	1/4 mi below headgate	8.1				3.7	
21	Leona River	1/2 mi below Kincaid Dam	8.6		7.7			
22	Leona River	5 mi below Kincaid Dam	13.0		12.9			
22	Leona River	At Hackberry crossing	17.0		8.9			
22	Batesville Canal	At headgate	20.1				0	
22	Leona River	Just below Batesville Dam	20.1		5.3			
22	Leona River	3 mi below Batesville	23.3		2.4			
22	Leona River	At Ottenhouse Ranch	26.4		1.6			
22	Leona River	At Rogers Ranch	34.6		0			
	No inflow from tributaries during investigation							

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Leona River October 18-20, 1934

Reach: From Highway bridge 1.7 mi SE of Uvalde to Rogers Ranch near Batesville, Tex.

Discharge measurements of Leona River near Uvalde, Tex., were made on October 18-20, 1934, to determine seepage gains or losses. During the investigation the river was at a constant stage, and measurements represent natural conditions. There was no inflow from tributaries during this investigation.

Date 1934	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Oct. 18	Leona River	At Highway bridge 1.7 mi SE of Uvalde	0		1.4			
18	Lane Taylor Canal	At headgate	2.0				0	
18	Leona River	Just below Lane Taylor Dam	2.1		6.6			
19	Leona River	At S. L. Gilbert Ranch	5.8		11.4			
19	Kincaid Canal	500 ft below headgate	8.1				3.8	
19	Leona River	250 ft below Kincaid Dam	8.1		3.3			
19	Leona River	1 mi below Kincaid Dam	9.1		8.9			
19	Leona River	5 mi below Kincaid Dam	13.0		7.7			
19	Leona River	At Hackberry crossing	17.0		5.2			
19	Batesville Canal	At headgate	20.1				0	
19	Leona River	Just below Batesville Dam	20.1		3.6			
19	Leona River	3 mi below Batesville	23.3		2.6			
20	Leona River	At Ottenhouse Ranch	26.4		.8			
20	Leona River	At Rogers Ranch	34.6		0			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Leona River   June and July 1939

Reaches: From Kincaid Dam 10 mi below Uvalde to Rogers Ranch near Batesville, Tex.
From Highway bridge 1.7 mi SE of Uvalde to a point 3 mi below Batesville, Tex.

A series of discharge measurements was made on June 8 and 10 on the Leona River and tributaries, Tex., between Kincaid Dam, about 10 miles below Uvalde, and Rogers Ranch, 36.3 miles below Uvalde. Another series of measurements was made during the period July 5-7 between a point 1.7 miles southeast of Uvalde and a point 23 miles downstream, near Batesville, to determine the seepage gains or losses. The investigations were made during periods of constant stage of the river; however a short flood, reaching a 4-foot stage, occurred about June 3. All flowing tributaries were measured.

Date 1939	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Kincaid Dam 10 mi below Uvalde to Rogers Ranch near Batesville, Tex.							
June 10	Kincaid Canal	200 ft below headgate	0				3.8	
10	Leona River	½ mi below Kincaid Dam	.5		12.7			
10	Leona River	1 mi below Kincaid Dam	1.0		19.5			
10	Leona River	300 ft below Hackberry crossing	8.9		14.7			
8	Batesville Canal	700 ft below headgate	12.0				5.2	
8	Leona River	400 ft below Batesville Dam	12.0		9.5			
8	Batesville Drain	250 ft above entrance to river	13.7			4.3		Wasteway return from Batesville Canal.
8	Leona River	250 ft below Batesville drain	13.7		11.8			
8	Leona River	3 mi below Batesville Dam	15.2		11.4			
8	Leona River	At Ottenhouse Ranch	18.3		9.7			
8	Leona River	At Rogers Ranch	26.5		8.0			
	From Highway bridge 1.7 mi SE of Uvalde to a point 3 mi below Batesville							
July 5	Leona River	At Highway bridge 1.7 mi SE of Uvalde	0		7.1			
5	Van Ham pump	1,000 ft above Cooks Slough	1.5				.4	Estimate.
5	Leona River	At White's crossing - gaging station	4.8		13.6			
5	Kincaid Canal	300 ft below headgate	8.1				7.9	
5	Leona River	300 ft below Kincaid Dam	8.1		5.9			
6	Leona River	At T.P. Lee Lodge 1.0 mi below Kincaid Dam	9.1		11.8			
6	T.P.Lee Ranch pump	2 mi below Kincaid Dam	10.1				1.6	

Date 1939	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Highway bridge 1.7 mi SE of Uvalde to a point 3 mi below Batesville, continued							
July 6	Leona River	5 mi below Kincaid Dam	13.0		9.6			
6	Leona River	At Hackberry crossing	17.0		6.5			
6	Batesville Canal	½ mi below headgate	20.1				3.1	
6	Leona River	Just below Batesville Dam	20.1		.9			
6	Leona River	1 mi below Batesville Dam	21.0		.3			Estimate.
6	Leona River	2 mi below Batesville Dam	22.0		.1			Estimate.
6	Leona River	3 mi below Batesville Dam	23.0		0			

Leona River

February and August 1946

Reaches: From old Highway bridge 1.7 mi SE of Uvalde to a point .2 mi E of Zavalla-Frio County line, Tex.
From a point 2,500 ft below Kincaid Dam to Kincaid Camp 9.5 mi SE of Uvalde, Tex.
From Highway bridge 1.7 mi SE of Uvalde to a point on George West Ranch 7.1 mi SE of Batesville, Tex.

Three series of discharge measurements were made on Leona River and tributaries in February and August 1946. All of the measurements were made in the reach from the old Uvalde-Pearsall road, 1.7 miles southwest of Uvalde, Uvalde County and a point about 0.2 mile east of Zavalla-Frio County line.

The measurements were made in cooperation with the Ground Water Branch to establish a relation between flow of river with water table in the river valley. Investigations were made during a constant stage and determinations represent natural conditions. Distances along the river were measured on tracings from aerial photographs and U. S. Department of Agriculture Soil Survey Maps.

Date 1946	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From old Highway bridge 1.7 mi SE of Uvalde to a point .2 mi E of Zavalla-Frio County line							
Feb. 5	Leona River	At old Highway bridge 1.7 mi SE of Uvalde	0		0			
5	Leona River	At McKinney Ranch 3.1 mi SE of Uvalde	1.9		4.7			
5	Leona River	At gaging station 4.6 mi SE of Uvalde	3.8		4.7			
5	Leona River	On W. E. Lee Ranch 6.6 mi SE of Uvalde	6.3		9.8			
5	Kincaid Canal	At headgate	8.8				0	
5	Leona River	½ mi below Kincaid Dam	9.3		8.0			
5	Leona River	At Kincaid Camp 9½ mi SE of Uvalde	9.8		13.4			
5	Leona River	At Dockery Camp 9-3/4 mi SE of Uvalde	10.1		13.6			
5	Leona River	300 ft above Leona Lodge crossing	11.0		14.6			
6	Leona River	About .3 mi SE of Leona Lodge	11.3		14.1			
6	Leona River	About .4 mi SE of Leona Lodge	11.6		13.8			
6	Leona River	About .4 mi N of Uvalde-Zavalla County line	11.8		14.0			
6	Leona River	About .3 mi N of Uvalde-Zavalla County line	12.3		15.5			
6	Leona River	About .1 mi below Uvalde-Zavalla County line	12.9		12.2			

Date 1946	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
	From old Highway bridge 1.7 mi SE of Uvalde to a point .2 mi E of Zavalla-Frio County line, continued							
Feb. 6	Leona River	About .3 mi S of Uvalde-Zavalla County line	13.5		12.8			
6	Leona River	At Smith's crossing 7.2 mi NW of Batesville	15.9		12.3			
7	Leona River	6.2 mi NW of Batesville	17.2		12.8			
7	Leona River	1.4 mi above Hackberry crossing	19.3		10.8			
7	Leona River	At Hackberry crossing	20.8		10.0			
7	Leona River	Near Clay Sherer house	21.3		10.6			
7	Batesville Canal	.4 mi below headgate	23.1				4.4	
7	Leona River	300 ft below Batesville Dam	23.2		3.4			
7	Leona River	.9 mi NE of Batesville	24.5		3.7			
7	Leona River	At bridge 2 mi NE of Batesville	25.4		3.0			
7	Batesville Canal Waste	.7 mi SE of Batesville	26.2			2.6		
7	Leona River	Just below Canal Wasteway	26.2		5.4			
7	Leona River	At Leona Farms Mexican Camp	28.4		4.4			
8	Leona River	At O'Keefe Bros. cattle pen	30.4		3.9			
8	Leona River	3.8 mi SE of Batesville	31.5		3.5			
8	Leona River	Near Otterhouse Ranch house	34.0		2.3			
8	Leona River	On George West Ranch 7.1 mi SE of Batesville	36.3		2.4			
8	Leona River	On Carmichael Ranch 8.1 mi SE of Batesville	38.3		2.0			
8	Leona River	10.6 mi SE of Batesville	42.1		1.2			
8	Leona River	On Rogers Ranch 13.0 mi SE of Batesville	46.2		.5			
8	Leona River	.2 mi E of Zavalla-Uvalde County line	49.4		.2			
	From a point 2,500 ft below Kincaid Dam to Kincaid Camp 9.5 mi SE of Uvalde							
Feb. 19	Leona River	On W. E. Lee Ranch 5.2 mi SE of Uvalde	4.6		8.7			
19	Leona River	On W. E. Lee Ranch 5.8 mi SE of Uvalde	5.5		9.0			
19	Kincaid Canal	At Kincaid Dam	8.8		Not measured - pumping			
19	Leona River	2,500 ft below Kincaid Dam	9.3		3.4			
19	Leona River	2,700 ft below Kincaid Dam	9.4		5.6			

Date 1946	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 2,500 ft below Kincaid Dam to Kincaid Camp 9.5 mi SE of Uvalde, continued							
Feb. 19	Leona River	3,000 ft below Kincaid Dam	9.5		8.2			
19	Leona River	At Kincaid Camp 9½ mi SE of Uvalde	9.8		9.4			
	From Highway bridge 1.7 mi SE of Uvalde to a point on George West Ranch 7.1 mi SE of Batesville							
Aug. 7	Leona River	At Highway bridge 1.7 mi SE of Uvalde	0		0			
7	Leona River	At McKinney Ranch 3.1 mi SE of Uvalde	1.9		.6			
7	Leona River	At gaging station 4.6 mi SE of Uvalde	3.8		.5			
7	Leona River	On W. E. Lee Ranch 5.2 mi SE of Uvalde	4.6		3.0			
7	Leona River	On W. E. Lee Ranch 5.8 mi SE of Uvalde	5.5		2.6			
7	Leona River	On W. E. Lee Ranch 6.6 mi SE of Uvalde	6.3		2.1			
8	Kincaid Canal	At Kincaid Dam	8.8				0.3	
7	Leona River	2,500 ft below Kincaid Dam	9.3		.4			
7	Leona River	2,700 ft below Kincaid Dam	9.4		1.4			
8	Leona River	At Kincaid Damp 9.5 mi SE of Uvalde	9.8		4.1			
8	Leona River	300 ft above crossing at Leona Lodge	11.0		4.4			
8	Leona River	.4 mi SE of Leona Lodge	11.6		4.3			
8	Leona River	.1 mi below Uvalde-Zavalla County line	12.9		3.3			
8	Leona River	At Smith's crossing 7.2 mi NW of Batesville	15.9		1.9			
8	Leona River	6.2 mi NW of Batesville	17.2		1.4			
9	Leona River	1.4 mi above Hackberry crossing	19.3		0			
9	Leona River	300 ft below Hackberry crossing	20.8		0			
9	Leona River	300 ft below Batesville Dam	23.2		0			
9	Leona River	At Batesville bridge	25.4		0			
9	Leona River	.7 mi SE of Batesville below wasteway	26.2		0			
9	Leona River	At O'Keefe Bros. cattle pen 3.1 mi SE of Batesville	30.4		0			
9	Leona River	On George West Ranch 7.1 mi SE of Batesville	36.3		0			

Leona River — March 1, 1947

Reach: From Highway bridge 1.7 mi SE of Uvalde to Kincaid Camp 9.5 mi SE of Uvalde, Tex.

A series of five discharge measurements was made on Leona River and tributaries, Tex. The series was made in March between the old Uvalde-Pearsall road bridge, 1.7 miles southeast of Uvalde, Uvalde County, and Kincaid Camp, 9.5 miles southeast of Uvalde. Measurements were made to establish relation between flow of river and water table in the river valley. See report of Texas Board of Water Engineers (page 9), "Relationship of Ground Water to the Discharge of the Leona River in Uvalde and Zavala Counties, Tex." - April 1947.

Investigation was made during a constant stage and determinations represent natural conditions. Distances along river measured on tracings from aerial photographs and U. S. Department of Agriculture Soil-Survey Map.

Date 1947	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Mar. 1	Leona River	At Highway bridge 1.7 mi SE of Uvalde	0		3.49			
1	Leona River	At gaging station 4.6 mi SE of Uvalde	3.8		10.0			
1	Leona River	W. E. Lee Ranch 5.2 mi SE of Uvalde	4.6		17.0			
1	Leona River	2,500 ft below Kincaid Dam	9.3		12.9			
1	Leona River	At Kincaid Camp 9.5 mi SE of Uvalde	9.8		18.4			

Atascosa, Frio and Nueces Rivers — January and April 1951

Reach: From Campbellton to head of Lake Corpus Christi near Mathis, Tex.

During January and April 1951, three series of discharge measurements were made on the Atascosa, Frio and Nueces Rivers, Tex. The purpose was to determine seepage gains or losses along the river, and losses in transmission of water, from artesian wells near Campbellton to the head of Lake Corpus Christi near Mathis. The channels of the Atascosa, Frio and Nueces Rivers were used to transport the water. The Atascosa River is tributary to the Frio River and the Frio River is tributary to the Nueces River which flows into Lake Corpus Christi.

During the period January 23-26, 1951, prior to drilling of artesian well at Campbellton, a seepage investigation of a reconnaissance nature was made from a point near Poteet to the head of Lake Corpus Christi. At this time measurements were made only at those points on main stream and tributaries which were easily accessible.

During period April 19 to May 1, 1951, two series of measurements were made from Campbellton to head of Lake Corpus Christi. The first of these was made with one artesian well flowing into the river. All inflow and diversions were measured throughout the reach. The second was made of river and tributary flow after the artesian well was cut off. An additional measurement was made at miles 87.4, 96.4 and 103.8 as it was suspected that some well water was still present when the first ones were made (see table).

For complete report on transmission of well water from Campbellton to Lake Corpus Christi see U. S. Geological Survey Open File Release No. 42, October 1951, Austin, Texas (SW).

Date 1951	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Jan. 23	Atascosa River	3.0 mi SW of Poteet	0		0			
23	Atascosa River	1.3 mi south of Poteet	2.9	75	0.96			
23	Atascosa River	2.0 mi SE of Poteet	5.1	75	2.73			
23	Atascosa River	3.0 mi NW of Pleasanton	9.0	75	2.30			
23	Atascosa River	At Pleasanton	15.0	77	3.35			
23	Bonita Creek	South edge of Pleasanton	15.3			0.02		
23	Galvan Creek	2.0 mi NE of Pleasanton	17.0			0		
23	Atascosa River	At Coughran	21.0	77	3.82			Artesian wells flowing
24	Atascosa River	0.5 mi east of McCoy	35.1	65	3.84			
24	Unnamed Creek	4.0 mi NW of Campbellton	42.0	70		.20		
24	Borrego Creek	3.0 mi north of Campbellton	46.0	57		.06		
24	Atascosa River	At Campbellton	47.1	57	4.38			
24	Lapan Creek	1.5 mi SE of Campbellton	52.5	65		.10		

Date 1951	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
Jan. 24	Matate Creek	3.0 mi SW of Campbellton		55		0.44		
24	La Parita Creek	5.0 mi SW of Campbellton	55.9	58		.39		
25	Atascosa River	At gaging station at Whitsett	59.7	45	4.80			
25	Olmos Creek	1.0 mi SE of Whitsett	61.0			0		
25	Merriman Hollow	2.0 mi SE of Whitsett				.05		
25	San Christoval Creek	5.0 mi SE of Whitsett				0		
25	Atascosa River	4.5 mi north of Three Rivers	71.4	49	4.32			
25	Frio River	1.0 mi above mouth of Atascosa R	73.9			0		
25	City Pump	At Three Rivers water intake	77.1				0.90	
25	Nueces River	4.0 mi above Three Rivers	80.3			0		
25	Nueces River	At gaging station near Three Rivers	80.5	68	3.48			
25	Sulphur Creek	At mouth near Oakville	87.3			.10		
25	Nueces River	1.5 mi SW of Oakville	87.4	60	4.34			
25	Nueces River	1.8 mi NW of George West	96.4	56	5.49			
26	Spring Creek	2.5 mi SW of George West	99.3			0		
26	Nueces River	.8 mi north of Mikeska	103.8	49	5.29			
Apr. 19	Atascosa River	At highway bridge at Campbellton-above well	47.1	70	3.36			
19	Atascosa River	At Campbellton - below well	47.6	97	5.65			
19	Unnamed Creek	Below Campbellton	47.9			.12		
19	Unnamed Creek	Above Lapan Creek	52.1			0		
19	Atascosa River	Above Lapan Creek	52.4	86	6.02			
19	Lapan Creek	At mouth	52.5	79		.30		
19	Atascosa River	Above La Parita Creek	55.8	83	5.36			
19	La Parita Creek	At mouth	55.9	73		.69		
19	Unnamed Creek	.2 mi below La Parita Creek	56.1			0		
19	Unnamed Creek	2 mi above Whitsett	57.9			.10		
19	Sulphur Well	1.6 mi above Whitsett	58.3			.01		
19	Atascosa River	At gaging station at Whitsett	59.7	78	6.30			
20	Olmos Creek	At mouth	61.0	76		.08		
20	Atascosa River	Below Olmos Creek	61.1	77	5.56			
20	Unnamed Creek	½ mi below Olmos Creek	61.3			0		
20	3 unnamed Creeks	Below Olmos Creek				0		
20	Atascosa River	At Falls above Three Rivers	69.0	80	5.61			
20	Atascosa River	At temporary recorder 2½ mi above Three Rivers	71.4	84	5.43			

Date 1951	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
Apr. 20	Atascosa River	300 ft above mouth	73.9	80	4.88			
20	Frio River	At mouth of Atascosa R	73.9			0		
21	City Pump	At Three Rivers water intake	77.1				0.56	
20	Nueces River	At mouth of Frio River	80.3			0		
21	Nueces River	At gaging station near Three Rivers	80.5	76	4.30			
21	Sulphur Creek	At mouth near Oakville	87.3			.21		
21	Nueces River	500 ft below Sulphur Creek	87.4	78	4.78			
21	Nueces River	3 mi below Sulphur Creek	89.7		4.99			
21	Nueces River	Near George West	96.4	88	6.12			
21	Spring Creek	Below George West	99.3			.04		
21	Nueces River	At temporary recorder near Mikeska	103.8	82	4.06			
21	Nueces River	Near ruins of Old Fort Merrill below Mikeska	107.3	78	5.48			
27	Atascosa River	At Campbellton	47.6	82	1.94			
27	Unnamed Creek	Below Campbellton	47.9			.12		
27	Lapan Creek	At mouth	52.5	83		.33		
27	Atascosa River	Above La Parita Creek	55.8	83	1.86			
27	La Parita Creek	At mouth	55.9	80		.35		
27	Unnamed Creek	2 mi above Whitsett	57.9			.10		
27	Atascosa River	1.6 mi above Whitsett	58.3	81	1.87			
27	Sulphur Well	1.55 mi above Whitsett	58.3			.03		
27	Atascosa River	At gaging station at Whitsett	59.7	78	1.79			
28	Atascosa River	Above Olmos Creek	61.0	75	1.80			
28	Olmos Creek	At mouth	61.0			0		
28	Atascosa River	At Falls above Three Rivers	69.0	75	1.43			
28	Atascosa River	At temporary recorder 2½ mi above Three Rivers	71.4	75	1.52			
28	Frio River	At mouth at Atascosa R	73.9			0		
28	City Pump	At Three Rivers water intake	77.1				.56	
28	Nueces River	At mouth of Frio River	80.3			0		
28	Nueces River	At gaging station near Three Rivers	80.5		0.46			
28	Sulphur Creek	At mouth near Oakville	87.3			.08		
28	Nueces River	600 ft below Sulphur Creek	87.4	81	1.33			
30	Nueces River	600 ft below Sulphur Creek	87.4	90	0.85			
28	Nueces River	3 mi below Sulphur Creek	89.7	82	1.88			

Date 1951	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Apr. 28	Nueces River	Near George West	96.4	81	2.60			
30	Nueces River	Near George West	96.4	87	1.58			
28	Nueces River	At temporary recorder near Mikeska	103.8	82	3.10			
May 1	Nueces River	At temporary recorder near Mikeska	103.8	75	1.87			
1	Nueces River	Near Old Fort Merrill below Mikeska	105.9	76	2.17			

LOW-FLOW INVESTIGATIONS - NUECES RIVER BASIN

Nueces River April 20-22, 1948

Reach: From gaging station near Mathis to Corpus Christi Water Works at Calallen, Tex.

A series of discharge measurements was made Apr. 20-22, 1948, on the Nueces River and its tributaries, Tex., between the gaging station near Mathis and a point 25½ miles downstream, to determine the seepage gains or losses between the gaging station near Mathis and the city of Corpus Christi Water Works Plant at Calallen. The gates on Mathis Dam were not changed for several days preceding or during the investigation, thereby maintaining a constant stage of the river. All tributaries were investigated for inflow but none were found.

The last measurement made is 10 miles upstream from Corpus Christi Water Works Plant. Pool conditions prevented additional discharge measurements. There was no inflow between point of last measurement and water works.

Date 1948	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Tributary	Diversion	Remarks
Apr. 20	Nueces River	At gaging station near Mathis	0		35.3			
20	Nueces River	4.1 mi SSW of Mathis	1.0		30.6			
20	Nueces River	4.1 mi south of Mathis	2.6		35.0			
20	Arroyo (no name)	At mouth 4 mi SSE of Mathis	4.5			0		
20	Arroyo Nombre de Dios	At mouth 4.3 mi SSE of Mathis	4.9			0		
20	Nueces River	4.4 mi SSE of Mathis	5.0		33.2			
20	Nueces River	3.7 mi NNW of San Patricio	7.0		33.0			
21	Nueces River	2.7 mi NNW of San Patricio	8.9		33.4			
21	Nueces River	2.2 mi NNW of San Patricio	10.9		35.8			
21	Javelin Creek	At mouth 2.4 mi WNW of San Patricio	11.7			0		
21	Sandy Hollow	At mouth 2.5 mi WNW of San Patricio	12.0			0		
21	Nueces River	2.3 mi WNW of San Patricio	13.4		34.0			
21	Nueces River	2.4 mi SW of San Patricio	15.7		35.9			
22	Nueces River	1.7 mi south of San Patricio	18.1		36.5			
22	Nueces River	2.5 mi SSE of San Patricio	19.9		38.0			
22	Dismero Slough	4.7 mi SSE of San Patricio	23.5			0		
22	Nueces River	4.7 mi SSE of San Patricio	23.6		35.6			
22	Nueces River	6.2 mi SE of San Patricio and 10 mi above Water Works Plant - no inflow between	25.5		34.6			

Pecos River — May 28-30, 1918

Reach: From Angeles gaging station to Girvin, Tex.

From May 28 to 30, 1918, a study of losses and gains from seepage was made on Pecos River between the New Mexico-Texas State line and Girvin, Tex. Recording gages are maintained at Angeles (near State line), above Barstow, and near Grandfalls. Although data were insufficient to warrant a correction of discharge for time interval, the gages showed that the river was at a practically constant stage previous to and during the investigation so that few corrections for time interval were necessary. From Angeles gage to the Arno-Porterville highway bridge there was a gain of 25 cfs; from Arno-Porterville highway bridge to Barstow gage there was a loss of 30 cfs; and between Barstow and Girvin a gain of 48 cfs. Between the Arno-Porterville highway bridge and Barstow the river flows over a bed of deep sand, the seepage into which, in addition to the natural loss from evaporation might easily account for the loss of 30 cfs between these points.

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
May 28	Pecos River	Near Angeles - gaging station	0		81.7			
29	Pecos River	At Olds Ranch near Angeles	22		73.9			
29	Pecos River	Below the Falls near Riverton	43		86.8			
29	Pecos River	At road crossing near Arno	56		107			Porterville pump not running.
29	Farmers Independent Canal	At headgate 10 mi below Arno	75				12.5	
29	Biggs Canal	At diversion dam	84.8				.5	
29	Pecos River	Above Barstow - gaging station	85.0		64.5			
29	Barstow Canal	At headgate	86.5				64.4	
29	Pecos River	Below Barstow Canal	86.5		1.7			
29	Pecos River	Above Marguretta Flume	90		2.9			
29	Pecos River	Below Marguretta Flume	90		4.1			Leakage in flume.
29	Pecos River	At T.P. Railroad bridge	102		5.0			
29	Toyah Creek	At mouth below Pecos	112			0		
29	Pecos River	Just below Big Valley Dam	117		13.1			No pumping.
30	Pasaino Creek	At mouth	130			0		
30	Imperial Feeder Canal	At headgate 3 mi above Grandfalls	134				15.5	
30	Pecos River	Just below Imperial Canal	134		9.0			
29	Pecos River	Just below Grandfalls Dam	137		8.4			No pumping.
30	Second Imperial Division	At headgate	150				4.2	
30	Pecos River	Just below Second Imperial Div.	150		3.4			
30	Pecos River	Near Grandfalls - gaging station	154		4.6			

Date 1918	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Angeles gaging station to Girvin, continued							
May 30	Zimmerman Canal	At headgates	160				2.5	
30	Pecos River	Just below Zimmerman Canal	160		0			
30	Pecos River	Near Buena Vista	180		16.0			
30	Comanche Creek	At mouth	183			0		
30	Pecos River	At highway crossing at Girvin	203		30.4			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Madera Canyon — September 1932-August 1933

Reach: From a point 13.3 mi above to a point 3.5 mi above Toyahvale, Tex.

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Sept. 1	Madera Canyon	At gaging station	13.3		23.2			
1	Madera Canyon	Madera Springs road crossing	7.1		3.9			
1	Madera Canyon	8.2 mi below gage	5.1		0			
2	Madera Canyon	At gaging station	13.3		67.5			
2	Madera Canyon	Madera Springs road crossing	7.1		41.8			
2	Madera Canyon	8.2 mi below gage	5.1		2.2			
2	Madera Canyon	At Duncan-Kingston crossing	3.5		.5			
3	Madera Canyon	At gaging station	13.3		41.8			
3	Madera Canyon	Madera Springs road crossing	7.1		16.1			
3	Madera Canyon	8.2 mi below gage	5.1		8.3			
3	Madera Canyon	At Duncan-Kingston crossing	3.5		4.5			
12	Madera Canyon	At gaging station	13.3		28.7			
12	Madera Springs Creek	At mouth	11.3			0.5		
12	Madera Canyon	At Madera Springs road crossing	7.1		7.2			
12	Madera Canyon	8.2 mi below gage	5.1		2.5			
15	Madera Canyon	At gaging station	13.3		14.5			
15	Madera Canyon	At Madera Springs road crossing	7.1		.3			
15	Madera Canyon	8.2 mi below gage	5.1		.2			
21	Madera Canyon	At gaging station	13.3		5.2			
21	Madera Canyon	At rock outcrop	7.5		0			
21	Madera Canyon	At Madera Springs road crossing	7.1		.3			
21	Madera Canyon	.2 mi below Madera Springs road crossing	6.9		0			
21	Madera Canyon	8.2 mi below gage	5.1		.6			
24	Madera Canyon	At gaging station	13.3		6.7			
24	Side Canyon	At mouth	13.2			.3		
24	Madera Canyon	1.5 mi below gage	11.8		6.7			
24	Madera Canyon	2.5 mi below gage	10.8		1.0			
24	Madera Canyon	3.5 mi below gage	9.8		.2			

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1932	From a point 13.3 mi above to a point 3.5 mi above Toyahvale, continued							
Oct. 6	Madera Canyon	At gaging station	13.3		37.3			
6	Madera Springs Creek	At mouth	11.3			1.5		
6	Madera Canyon	2.6 mi below gage	10.7		22.6			
6	Madera Canyon	3.7 mi below gage	9.6		4.5			
6	Madera Canyon	At limestone outcrop	9.3		0			
1933								
Aug. 27	Madera Canyon	At gaging station	13.3		17.5			
27	Madera Canyon	At Madera Springs road crossing	7.1		11.4			
27	Madera Canyon	At Duncan-Kingston crossing	3.5		0			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Little Aguja Canyon — August 17-October 6, 1932

Reach: From a point 15.5 mi above to 2.2 mi above Toyahvale, Tex.

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Aug. 17	Little Aguja Canyon	At temporary staff gage	15.5		1.3			
17	Little Aguja Canyon	2.8 mi below staff gage	12.7		1.0			
17	South Fork Little Aguja	.2 mi above mouth	11.5			0.4		
17	Little Aguja Canyon	5.5 mi below staff gage	10.0		.4			
17	Little Aguja Canyon	7.0 mi below staff gage	8.5		.6			
17	Little Aguja Canyon	8.5 mi below staff gage	7.0		.4			
17	Little Aguja Canyon	9.6 mi below staff gage	5.9		.2			
17	Little Aguja Canyon	300 ft above limestone bluff	4.3		.1			
17	Little Aguja Canyon	At upper end limestone bluff	4.3		0			
17	Little Aguja Canyon	At lower end limestone bluff	4.0		.2			
17	Little Aguja Canyon	At mouth	2.2		0			
Sept. 1	Little Aguja Canyon	3 mi below staff gage	12.5		12.1			
1	South Fork Little Aguja	.2 mi above mouth	11.5			6.4		
1	Little Aguja Canyon	At mouth	2.2		0			
13	Little Aguja Canyon	50 ft below South Fork	11.3		22.8			
13	Little Aguja Canyon	100 ft above limestone bluff	4.3		0			

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 15.5 mi above to 2.2 mi above Toyahvale, continued							
Sept. 13	Little Aguja Canyon	50 ft above limestone bluff	4.3		0.1			
13	Little Aguja Canyon	.1 mi below limestone bluff	3.9		0			
14	Little Aguja Canyon	50 ft below South Fork	11.3		11.2			
14	Little Aguja Canyon	.5 mi below White bluff	8.2		0			
20	Little Aguja Canyon	60 ft below South Fork	11.3		4.1			
20	Little Aguja Canyon	150 ft above upper Duncan road	9.5		0			
20	Little Aguja Canyon	100 ft above White bluff	8.7		.6			
20	Little Aguja Canyon	600 ft below White bluff	8.6		0			
20	Little Aguja Canyon	At second White bluff	7.8		.6			
20	Little Aguja Canyon	.1 mi below second White bluff	7.7		0			
Oct. 6	Little Aguja Canyon	200 ft below South Fork	11.2		26.8			
6	Little Aguja Canyon	At lower Duncan road crossing	6.0		26.5			
6	Wet Weather Springs	At limestone bluff	4.3			0.2		
6	Little Aguja Canyon	50 ft below limestone bluff	3.9		2.2			
6	Little Aguja Canyon	4,000 ft above mouth	3.0		0			

Big Aguja Canyon — September 1-October 6, 1932

Reach: From a point 11.8 mi above to 2.2 mi above Toyahvale, Tex.

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Sept. 1	Big Aguja Canyon	At temporary staff gage	11.8		18.7			
1	Big Aguja Canyon	Above Seven Springs Creek	7.3		4.4			
1	Seven Springs Creek	At mouth	7.2			0.5		
1	Big Aguja Canyon	At mouth	2.2		0			
3	Big Aguja Canyon	At temporary staff gage	11.8		45.4			
3	Big Aguja Canyon	Above Seven Springs Creek	7.3		35.7			
3	Seven Springs Creek	At mouth	7.2			.4		
3	Big Aguja Canyon	At mouth	2.2		19.2			
13	Big Aguja Canyon	At temporary staff gage	11.8		8.6			
13	Walnut Canyon	At mouth	7.5			.2		
13	Big Aguja Canyon	Above Seven Springs Creek	7.3		5.6			
13	Seven Springs Creek	At mouth	7.2			4.8		
13	Big Aguja Canyon	At mouth	2.2		0			
Oct. 6	Big Aguja Canyon	At temporary staff gage	11.8		10.3			
6	Big Aguja Canyon	Above pipe line crossing	9.6		5.6			
6	Break in pipe line	At Canyon crossing	9.5			1.5		
6	Big Aguja Canyon	Below pipe line crossing	9.5		7.1			
6	Walnut Canyon	At mouth	7.5			.6		
6	Big Aguja Canyon	Above Seven Springs Creek	7.3		14.0			
6	Seven Springs Creek	At mouth	7.2			6.1		
6	Big Aguja Canyon	3 mi above mouth	5.2		0			
6	Big Aguja Canyon	½ mi above mouth	2.7		0			
6	Big Aguja Canyon	.4 mi above mouth	2.6		.1			
6	Big Aguja Canyon	At mouth	2.2		.1			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Reeves County Water Improvement District No. 1 near Balmorhea, Tex. July 27, 1922

Reach: From Main Canal headgate to a point near Barlow diversion near Balmorhea, Tex.

Date 1922	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
July 27	Main Canal	At headgates (San Solomon Springs)			34.0			
27	Giffin Springs	Just above confluence with Main Canal				4.65		
27	Bruces Diversion	At headgate below Giffin Springs					3.02	
27	Main Canal	Just below Bruces Diversion			36.1			
27	West Side Diversion	At headgates					7.83	
27	Westerman Diversion	At headgates					4.21	
27	Long Strip Diversion	At headgates					2.79	
27	Main Canal	Near Barlow Diversion			13.8			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Reeves County Water Improvement District No. 1 Canal System — September 25, 26, 1923

Reach: Canal system from headgates to last diversion, near Balmorhea, Tex.

Date 1923	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Sept. 25	Main Canal	San Solomon Springs at outlet			35.0			
25	Giffin Springs	At outlet				1.75		
25	Main Canal	At Bruces and Stewarts			35.9			
25	Main Canal	At McGarry bridge			34.9			
25	Scherye Biversion						4.54	
26	West Side Delivery	At Koontz corner					12.2	
26	Main Canal	At Scherys and McGarry corner			18.5			
25	S.H.Sharp Delivery						4.72	
25	Grain field delivery						5.26	
25	Main Canal	At Knapp foot bridge			7.56			
25	J. F. Meir Delivery						4.14	
25	Main Canal	In front of Hotel			2.93			
26	West Side Delivery	On Byrd farm ½ mi below headgate					12.6	
26	Sharp Delivery	Bridge at Scherye corner					5.09	
26	Sharp Delivery	At corner of Sharp field					3.99	
26	Saragosa Spring Creek	Near old weir				4.04		

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Reeves County Water Improvement District No. 1 Canal System April 26, 27, 1923

Reach: From Bruces corner to 6th diversion at Blakesley delivery near Balmorhea, Tex.

Date 1923	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Apr. 26	Main Canal	400 ft south of Bruce corner			26.2			
26	1st diversion	C. C. Goss to Carpenter Place					3.05	
27	West Side Delivery	2nd diversion at County corner					6.97	
27	Main Canal	At Town delivery below 4th diversion			8.05			
27	Town delivery						0	
27	Main Canal	At Scherye corner			7.68			
27	Moore diversion	5th diversion					3.77	
27	Main Canal	Below Blakesley delivery			0			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Reeves County Water Improvement District No. 1 Canals near Balmorhea

October 27-November 18, 1931

Reach: Laterals of canal system, near Balmorhea, Tex.

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Oct. 27	Carpenter take-out	At point of diversion	0		2.81			
27	Carpenter take-out	At point of delivery	1.0		2.73			
27	Reservoir take-out	At point of diversion	0		2.83			
27	Reservoir take-out	At confluence with creek	1.0		2.33			
27	Highway ditch	At point of diversion	0		9.32			
27	Mills ditch	At point of diversion	.8				5.91	
27	Highway ditch	Below Mills ditch takeout	.8		3.80			
27	Highway ditch	At point of delivery to Mayer farm	1.3		3.84			
28	Siphon ditch	At point of diversion	0		9.32			
28	Siphon ditch	At point of delivery to Fane Down farm	2.3		6.19			
Nov. 16	Moore canal	300 ft below dam	0		4.29			
16	Moore canal	At P.V.S. Railway crossing	.5		4.35			
16	Saragosa canal	1,000 ft below diversion dam	0		1.97			
16	Saragosa canal	At weir	.5		1.68			
18	Giffin Spring canal	At weir	0		3.80			
18	Giffin Spring canal	At siphon	.8		4.06			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Reeves County Water Improvement
District No. 1 Canal near Balmorhea

October 27, 28, 1931

Reach: Main canal from source to end, near Balmorhea, Tex.

Date 1931	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Oct. 27	Main canal	300 ft below San Solomon Spring	0		32.0			
27	Carpenter takeout	200 ft below weir	.8				2.81	
27	Giffin Spring	At source	1.4			1.34		
27	Reservoir takeout	At point of diversion	1.4				2.83	
27	Henry Jones takeout	At point of diversion	1.4				.40	
27	North canal takeout	At point of diversion	2.2				.27	
27	Gate leakage	Total leakage on Main Canal					.12	
27	Main canal	At Crenshaw garage	4.0		25.3			
27	Walker takeout	At point of diversion	6.0				.61	
27	Gate leakage	Total leakage on Main Canal					.10	
28	Main canal	At highway No. 3 crossing	7.0		21.4			
28	Highway takeout	At point of diversion	7.0				5.94	
28	Sol Mayer takeout	At point of diversion	8.0				5.20	
28	Saragosa canal	At weir inflow point	8.4			1.98		
28	Siphon ditch takeout	At weir	8.4				8.98	
28	Gate leakage	Total leakage on Main Canal					.60	
28	Main canal	150 ft below Siphon ditch takeout	8.4		1.42			
28	Gate leakage	Total leakage on Main Canal					.70	
28	Main canal	½ mi above end of system	11.4		.38			

Reeves County Water Improvement District No. 1 Canal near Balmorhea — January and March 1933

Reach; Main canal from source to end, near Balmorhea, Tex.

Date 1933	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Tributary	Diversion	Remarks
Jan. 11	Main canal	500 ft below Giffin canal	1.8		48.7			
11	North spill	At Knapps corner	3.1				26.3	
11	Main canal	At Balmorhea Hotel	4.7		19.9			
11	Gate leakage	Total of 2 leaks					.1	
11	West Sandia canal	At gage	5.6			1.8		
11	Main canal	At Brogado	6.0		22.2			
11	Lateral diversion	At point of diversion	6.6				.8	
11	Main canal	½ mi above highway crossing	7.1		20.2			
11	Gate leakage	Total of 3 leakr					.2	
11	Main canal	½ mi below highway crossing	8.1		21.0			
12	Siphon ditch	At weir 75 ft below main canal	9.6				1.8	
12	Main canal	Just below Siphon ditch	9.7		17.1			
12	Main canal	Near end of system	11.1		17.4			
Mar. 13	Main canal	500 ft below Giffin canal	1.8		11.3			
13	Main canal	At Wigley road crossing	2.8		11.4			
13	Gate leakage	At Knapps corner	3.1				.1	
13	Main canal	400 ft above Highway Garage	4.7		11.0			
13	West Sandia canal	50 ft above highway	5.6			1.3		
13	Main canal	1 mi below Grogado	6.3		11.9			
13	Main canal	At highway crossing	7.7		11.9			
13	Experiment Farm spill	At highway crossing	8.3			.6		
13	Main canal	Above Saragosa canal	9.6		12.5			
13	Main canal	½ mi below Siphon ditch	10.1		8.3			
13	Main canal	At Saragosa road crossing	11.1		8.8			
14	Main canal	500 ft below Giffin canal	1.8		8.2			
14	Gate leakage		3.0				.1	
14	Gate leakage		3.7				.1	
14	Main canal	400 ft above Highway Garage	4.7		7.8			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Reeves County Water Improvement District No. 1 canal system near Balmorhea — February 6, 7, 1935

Reach: Middle Canal, Main Canal takeout to Balmorhea Reservoir, and Madera Canal, near Balmorhea, Tex.

During the investigation the stage remained constant.

Discharge measurements of laterals of Reeves County Water Improvement District No. 1 from San Solomon Springs to Balmorhea Reservoir, near Balmorhea, Tex., to determine seepage, on San Solomon Springs Middle Canal, Main Canal takeout to Balmorhea Reservoir, and Madera Canal, in February 1935.

Date 1935	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Tributary	Diversion	Remarks
Feb. 6	Middle Canal	.5 mi below San Solomon Springs	.5		34.1			Total flow of springs.
7	Main Canal	Just below check gate 2½ mi above Balmorhea	1.4				2.2	Leakage thru gate.
7	Main Canal takeout to Balmorhea Reservoir	.2 mi below point of diversion	1.6		42.8			Combined flow of San Solomon and Phantom Lake Springs except leakage.
7	Main Canal takeout to Balmorhea Reservoir	.6 mi below point of diversion	2.0		44.0			
7	Madera Canal	Just above Main Canal takeout	2.2			0		
7	Madera Canal	½ mi below Main Canal takeout	2.7		42.0			
7	Madera Canal	300 ft above Balmorhea Reservoir	4.2		37.8			

Reeves County Water Improvement District No. 1 canal system near Balmorhea — July-September 1940

Reach: All lateral canals of system, near Balmorhea, Tex.

A series of discharge measurements was made on each of several laterals in Reeves County Water Improvement District No. 1 in Toyah Creek Basin in the vicinity of Balmorhea, Tex., to determine seepage gains or losses. The investigations were made during periods of constant discharge and the determinations of gain or loss represent normal conditions. All diversions from each lateral were measured.

Date 1940	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
July 2	North lateral	At U. S. Highway290 road crossing	0		0.70			
2	North lateral	At NE corner of sec. 258	.9		.52			
2	North lateral	1 mi NW of Balmorhea	2.2		.50			
2	North lateral	At corner of sec. 39, 51, and 94	2.9		.49			
2	Delivery ditch	60 ft below the above location	2.9				0.1	Estimate.
2	North lateral	1 mi NE of Balmorhea	4.0		.16			
Aug. 28	North lateral	At U. S. Highway 290 road crossing	0		.52			
28	North lateral	At County road crossing NE edge of NW ¼ sec. 258	.4		.45			
28	North lateral	At NE corner of sec. 258	.9		.40			
28	North lateral	In SE ¼ sec. 259 near line between sec. 259 and 260	1.7		.32			
28	North lateral	Just below county road crossing at N corner sec. 260	2.5		.32			
28	Delivery ditch	10 ft below the above location	2.5				.02	Estimate.
28	North lateral	At corner of sec. 39, 51, and 94	2.9		.30			
28	Delivery ditch	4 ft below the above location	2.9				.03	Estimate.
28	North lateral	1 mi NE of Balmorhea	4.0		.21			
28	Humphrey-Mayer lateral	50 ft below headgate	0		3.36			
28	Humphrey-Mayer lateral	20 ft above drainage ditch	.5		2.95			
28	Humphrey-Mayer lateral	50 ft below drainage ditch	.5		3.57			Increase from drainage ditch.
28	Humphrey-Mayer lateral	20 ft above property line of Helms and Mayer	.7		3.48			

Date 1940	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
Aug. 29	Back lateral	50 ft below property line of Pacy and Mott tracts	0		4.34			
29	Back lateral	1,000 ft below SW corner of SE ¼ sec. 117	1.1		4.57			
29	Back lateral	650 ft above SE corner of SW ¼ sec. 128	1.7		4.37			
29	Back lateral	650 ft below SE corner of SW ¼ sec. 128	2.2		4.34			
Sept. 6	Greasy Row lateral	50 ft below headgate	0		.60			
6	Delivery ditch	½ mi below headgate	.5				0.01	
6	Greasy Row lateral	½ mi below headgate	.5		.60			
6	Delivery ditch	1 mi below headgate	1.0				.01	
6	Greasy Row lateral	1½ mi below headgate	1.5		.56			
Aug. 29	Halbert corner lateral	Just below county road crossing	0		4.28			
29	Delivery ditch	30 ft above SW corner of SW ¼ sec. 129	.7				.03	
29	Halbert corner lateral	15 ft below SW corner of SW ¼ sec. 129	.7		4.32			
29	Halbert corner lateral	Near SW corner of NW ¼ sec. 129	1.2		3.82			
29	Delivery ditch	10 ft below the above location	1.2				.03	
29	Delivery ditch	At boundary between Pardoe and Hanaker Estate	1.4				.15	
29	Halbert corner lateral	Near SE corner of NW ¼ sec. 129	1.6		4.22			
29	Ikens Estate lateral	SW corner of SW ¼ sec. 116 Blk 13	0		5.50			
29	Ikens Estate lateral	Boundary between Benham and B. L. Co.	.2		4.54			

Reeves County Water Improvement District No. 1 canal system — July, August 1932 and July 1933

Reach: Reservoir outlet canal from reservoir to main canal, near Balmorhea, Tex.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1932								
July 22	Outlet canal	.1 mi below release gate	.1		52.2			
22	Gate leakage	.3 mi below release gate	.3				0.4	
22	Outlet canal	3.5 mi below release gate	3.5		48.0			
26	Outlet canal	.1 mi below release gate	.1		42.1			
26	Gate leakage	.3 mi below release gate	.3				.3	
26	Outlet canal	.7 mi below release gate	.7		40.9			
26	Outlet canal	1.7 mi below release gate	1.7		41.1			
26	Outlet canal	2.4 mi below release gate	2.4		39.8			
26	Outlet canal	50 ft above main canal	3.5		41.5			
Aug. 17	Outlet canal	.1 mi below release gate	.1		1.8			
17	Outlet canal	.4 mi below release gate	.4		2.1			
17	Outlet canal	2.6 mi below release gate	2.6		1.6			
1933								
July 20	Outlet canal	.2 mi below release gate	.2		14.2			
20	Outlet canal	.4 mi above main canal	3.1		11.6			
26	Outlet canal	.2 mi below release gate	.2		7.2			
26	Outlet canal	.6 mi above main canal	2.9		6.0			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

West Sandia Creek   October 17, 1932

Reach: From a point 4,000 ft above gage to the gaging station near Balmorhea, Tex.

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Oct. 17	West Sandia Creek	300 ft above springs	0		0.2			
17	West Sandia Creek	80 ft below springs	.07		.6			
17	Canal wasteway	500 ft below springs	.15			0.1		
17	West Sandia Creek	At gaging station	.76		2.2			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Cherry Canyon — September 15-October 7, 1932

Reach: From a point 1.5 mi above to 2.5 mi below gage near Toyahvale, Tex.

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs			Remarks
					Main Stream	Tributary	Diversion	
Sept. 15	Cherry Canyon	10 mi above Highway 290 - gaging station	0		13.5			
15	Cherry Canyon	500 ft above Kingston line fence	2.0		0			
21	Cherry Canyon	1.5 mi above gaging station	-1.5		1.2			
21	Cherry Canyon	At gaging station	0		5.0			
Oct. 7	Cherry Canyon	At gaging station	0		31.2			
7	Cherry Canyon	2.5 mi below gaging station	2.5		0			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Limpia Creek — October 1932-August 1933

Reach: From a point 12.3 mi above to 40.2 mi below Fort Davis, Tex.

Date 1932	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Tributary	Diversion	Remarks
Oct. 8	Limpia Creek	.8 mi below Wild Rose Canyon	14.7		31.0			
8	Short Canyon	At mouth	15.8			1.8		
8	Limpia Creek	500 ft below old Limpia post office	18.2		46.0			
8	Limpia Creek	3 mi below old Limpia post office	21.2		41.8			
8	Horse Thief Canyon	At mouth	27.7			1.2		
8	Runey Canyon	At mouth	27.9			1.5		
8	Limpia Creek	At Jeff Ranch house	28.2		65.1			
8	Limpia Creek	9 mi below Jeff Ranch house	37.2		4.2			
8	Limpia Creek	12 mi below Jeff Ranch house	40.2		0			
18	Limpia Creek	12.3 mi above old Fort Davis lane	-12.3		.1			
18	Limpia Creek	12.0 mi above old Fort Davis lane	-12.0		0			
18	Limpia Creek	11.3 mi above old Fort Davis lane	-11.3		.2			
18	Limpia Creek	11.0 mi above old Fort Davis lane	-11.0		0			
18	Limpia Creek	10.3 mi above old Fort Davis lane	-10.3		.5			
18	Limpia Creek	9.8 mi above old Fort Davis lane	- 9.8		0			
18	Limpia Creek	9.7 mi above old Fort Davis lane	- 9.7		.1			
18	Limpia Creek	7.9 mi above old Fort Davis lane	- 7.9		.6			
18	Limpia Creek	6.0 mi above old Fort Davis lane	- 6.0		5.7			
18	Side Canyon	5.9 mi above old Fort Davis lane	- 5.9			.5		
18	Limpia Creek	3.7 mi above old Fort Davis lane	- 3.7		5.7			
18	Limpia Creek	1.3 mi above old Fort Davis lane	- 1.3		5.3			
18	Grayson Canal	At old Fort Davis lane	0				0.5	
18	Limpia Creek	At first Fort Davis-Toyahvale crossing	1.2		3.8			
19	Limpia Creek	At first Fort Davis-Toyahvale crossing	1.2		3.8			
19	Side Canyon	2.1 mi below old Fort Davis lane	2.1			.4		
19	Side Canyon	2.1 mi below old Fort Davis lane	2.1			.2		
19	Limpia Creek	4.2 mi below old Fort Davis lane	4.2		8.0			
19	Side Canyon	4.8 mi below old Fort Davis lane	4.8			.5		
19	Limpia Creek	7.2 mi below old Fort Davis land	7.2		8.8			

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs: Main Stream	Tributary	Diversion	Remarks
1932	From a point 12.3 mi above to 40.2 mi below Fort Davis, continued							
Oct. 19	Limpia Creek	10.2 mi below old Fort Davis lane	10.2		8.4			
19	Frazier Canyon	At mouth	10.3			0.4		
19	Limpia Creek	At upper end of Wild Rose Canyon	11.7		9.4			
19	Limpia Creek	At lower end of Wild Rose Canyon	14.0		12.9			
19	Short Canyon	At mouth	15.8			.1		
19	Limpia Creek	At old Limpia post office	18.2		14.0			
Nov. 1	Limpia Creek	At old Limpia post office	18.2		8.2			
1	Limpia Creek	3 mi below old Limpia post office	21.2		5.4			
1	Limpia Creek	5.9 mi below old Limpia post office	24.1		4.6			
1	Limpia Creek	At Jeff Ranch house	28.2		6.2			
1	Limpia Creek	1 mi below Jeff Ranch house	29.2		0			
21	Limpia Creek	At upper end of Wild Rose Canyon	11.7		4.0			
21	Limpia Creek	At lower end of Wild Rose Canyon	14.0		6.1			
21	Limpia Creek	At old Limpia post office	18.2		4.7			
21	Limpia Creek	3 mi below old Limpia post office	21.2		2.0			
21	Limpia Creek	6 mi below old Limpia post office	24.2		1.1			
21	Limpia Creek	At Jeff Ranch house	28.2		2.4			
21	Limpia Creek	½ mi below Jeff Ranch house	28.7		0			
1933								
Aug. 3	Limpia Creek	75 ft below mouth of Short Canyon	15.8		12.6			
3	Limpia Creek	At old Limpia post office	18.2		4.0			
3	Limpia Creek	½ mi below old Limpia post office	18.7		0			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Toyah Creek   November 1932-July 1933

Reach: From a point 1.2 mi above to a point 8.8 mi below Toyahvale, Tex.

Date	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
1932 Nov. 6	Toyah Creek	At Aloma settlement	1.0		13.6			
6	Project waste	.9 mi above Balmorhea	3.9			0.3		
6	Saragosa Springs Creek	150 ft above mouth	4.7			9.9		
6	Toyah Creek	500 ft below Balmorhea bridge	4.8		29.1			
6	Toyah Creek	500 ft below Moore Dam	5.8		30.7			
6	Toyah Creek	At Saragosa Dam	8.8		29.0			
1933 Jan. 23	Toyah Creek	1.8 mi above Balmorhea bridge	3.0		0			
23	Saragosa Springs Creek	200 ft above mouth	4.7			8.2		
23	Toyah Creek	300 ft below Balmorhea bridge	4.8		12.5			
23	Toyah Creek	300 ft below Moore Dam	5.8		12.8			
23	Toyah Creek	At Saragosa Dam	8.8		10.5			
Mar. 14	Toyah Creek	At U. S. Highway 290 crossing	-1.2		2.5			
14	Toyah Creek	1.8 mi above Balmorhea bridge	3.0		0			
14	Saragosa Springs Creek	200 ft above mouth	4.7			6.7		
14	Toyah Creek	500 ft below Balmorhea bridge	4.8		9.4			
14	Moore Canal	150 ft below headgates	5.8				5.3	
14	Toyah Creek	500 ft below Moore Dam	5.8		4.8			
14	Saragosa Canal	50 ft below headgates	8.8				6.0	
14	Toyah Creek	50 ft below Saragosa Dam	8.8		.2			
May 16	Toyah Creek	1.8 mi above Balmorhea bridge	3.0		0			
16	Saragosa Springs Creek	50 ft above mouth	4.7			6.4		
16	Toyah Creek	500 ft below Balmorhea bridge	4.8		9.2			
16	Moore Canal	2,000 ft below headgates	5.8				7.3	
16	Toyah Creek	500 ft below Moore Dam	5.8		1.6			
16	Saragosa Canal	50 ft below headgates	8.8				4.0	
16	Toyah Creek	50 ft below Saragosa Dam	8.8		0			

Date 1933	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From a point 1.2 mi above to a point 8.8 mi below Toyahvale, continued							
July 11	Toyah Creek	1.8 mi below Balmorhea bridge	3.0		0			
11	Saragosa Springs Creek	200 ft above mouth	4.7			5.6		
11	Toyah Creek	500 ft below Balmorhea bridge	4.8		8.3			
11	Moore Canal	2,000 ft below headgates	5.8				7.0	
11	Toyah Creek	500 ft below Moore Dam	5.8		1.6			
11	Saragosa Canal	125 ft below headgates	8.8				3.5	
11	Toyah Creek	50 ft below Saragosa Dam	8.8		0			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Pecos County Water Improvement District No. 1 canal system at Fort Stockton — November-December 1939

Reach: High line, Seven-D, lateral No. 2, and lateral No. 3 Canals, near Fort Stockton, Tex.

A series of discharge measurements was made on each of several canals and laterals in Pecos County Water Improvement District No. 1 in Comanche Creek Basin in the vicinity of Fort Stockton, Tex., to determine seepage gains or losses. The investigations were made during periods of constant discharge and the determinations of gain or loss represent normal conditions. All diversions from each canal were measured.

Date 1939	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Nov. 24	High line Canal	1.2 mi below headgates	-		28.3			
24	Lateral No. 2	SW corner water tract 25, sec. 8	-				11.1	
24	High line Canal	2.8 mi below headgates	0		12.4			
24	Lateral No. 3	At Grandfalls-Fort Stockton Hwy.	1.1				5.3	
24	High line Canal	At Grandfalls-Fort Stockton Hwy.	1.1		6.8			
24	High line Canal	In water tract 7, sec. 2	3.6		6.7			
24	High line Canal	9.2 mi below headgates at end of concrete	6.4		6.3			
Dec. 14	High line Canal	At headgates	0		41.0			
14	Seven-D Canal	Just above Fort Stockton-Sheffield Hwy.	1.2				13.8	
14	High line Canal	2½ mi below headgates	2.5		27.6			
14	Seven-D Canal	At headgates	0		13.8			
14	Seven-D Canal	Just below siphon under Comanche Creek	.1		13.5			
14	Delivery ditch	In water tract 3, sec. 2	1.4				6.4	
14	Delivery ditch	In water tract 1, sec. 2	1.5		6.4			
14	Lateral No. 2	At headgates	0		12.1			
14	Minear delivery	¼ mi below headgates	.2				5.4	
14	Lateral No. 2	2,000 ft below headgates	.4		6.7			
14	Lateral No. 2	1 mi below headgates	1.0		6.7			
14	Delivery ditch	At Barker House in water tract 63, sec. 10	2.4		6.3			
14	Lateral No. 3	At headgate	0		6.2			
14	Lateral No. 3	At end of concrete sec.	1.8		6.2			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Rio Grande — February 7-20, 1925

Reach: From Lajitas to Del Rio, Tex.

During this series of measurements the river was at a constant stage and the measurements represent natural conditions.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Feb. 7	Rio Grande	At Lajitas	0		1,060			
7	Terlingua Creek	At mouth	16.8			0		
8	Rio Grande	At Sublett, Tex., ½ mi below Grand Canyon of Santa Helena and mouth of Terlingua Creek	17.3		1,040			
9	Rio Grande	Near Mariscal damsite	60.5		1,040			
11	Rio Grande	At Boquillas, Coah.	79.5		1,090			
13	Rio Grande	At Stillwell crossing	94.0		1,120			
15	Rio Grande	At Reagan Canyon	118.9		1,220			
19	Rio Grande	At Langtry	219.8		1,440			
19	Pecos River	Near Comstock - gaging station	240.7			199		From daily records.
20	Devils River	Near Del Rio - gaging station	281.2			378		From daily records.
20	Rio Grande	Near Del Rio	293.1		2,420			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Devils River   January and October 1921

Reach: From a point about 30 mi above to mouth near Del Rio, Tex.

Date 1921	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tribu-tary	Diver-sion	Remarks
Jan. 26	Devils River	At Rubboard Ford	0		283			
26	Smiths Spring	8 mi below Rubboard Ford	8			25		Estimate.
28	Devils River	At Rough Canyon Damsite	20		393			
27	Devils River	At Del Rio-Comstock road crossing	25		417			
27	Devils River	½ mi below Southern Pacific Railroad bridge	27.2		448			Rock channel.
Oct. 6	Devils River	At Rough Canyon Damsite	20		292			
7	Devils River	At Del Rio-Comstock road crossing	25		290			
7	Devils River	At Southern Pacific Railroad bridge	26.8		342			
7	Devils River	At Abandoned gage site at Devils River	27.8		344			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Devils River   August 8-13, 1925

Reach: From Beaver Lake to Del Rio-Comstock highway crossing, Val Verde County, Tex.

During this investigation the stream was at a constant stage and the measurements represent natural conditions.

Date 1925	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Aug. 8	Devils River	Just below Beaver Lake	0		1.6			
8	Devils River	.2 mi below Beaver Lake	.2		0			
8	Juno Springs	At Juno	3.2			5.8		
8	Devils River	1.0 mi below Juno	4.2		0			
8	Devils River	Just above Pecan Springs Creek	13.7		0			
8	Devils River	Just below Pecan Springs Creek	13.8		42.2			
8	Devils River	At first crossing above Bakers Crossing	19.3		78.1			
8	Devils River	At Bakers Crossing - gaging station	22.3		119			
9	Devils River	1½ mi below Bakers Crossing	23.8		122			
9	Devils River	5½ mi below Bakers Crossing	26.6		132			
9	Devils River	7 mi below Bakers Crossing	32.5		148			
10	Devils River	3 mi above Dolan Creek	33.5		165			
10	Dolan Creek	At mouth	36.5			34.2		
10	Devils River	Just below Dolan Creek	36.5		243			Large increase from east side not measurable.
10	Dry Devils River	At mouth	45.4			0		
11	Devils River	½ mi below Dry Devils River	45.9		301			
12	Devils River	4½ mi above Sellers Ranch	56.3		303			
12	Swann-Shelton Springs	½ mi above Sellers Ranch	60.8			44.3		Part of inflow only - not possible to measure total.
13	Devils River	2½ mi below Sellers Ranch	63.3		492			Poor measurement - subject to error.
13	Devils River	At Del Rio-Comstock highway crossing	73.0		473			
13	Devils River	At Devils River - gaging station	76.0		512			Not measured - from recorder record.

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Devils River — February 14-20, 1928 / February 7-11, 1928

Reaches: From Dolans Creek to Smith Ranch about 3 miles below Satan Creek near Comstock, Tex.
From Smith Ranch 3 miles below Satan Creek to a point ½ mile below Southern Pacific Railroad bridge near Del Rio, Tex.

During the investigations the river was at a constant stage, and the measurements represent the natural conditions.

Tributaries not listed were not flowing at the time these investigations were made.

Date 1928	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Dolans Creek to Smith Ranch about 3 mi below Satan Creek							
Feb. 14	Devils River	Just above Dolans Creek	0		118			
15	Dolans Creek	At mouth	.1			17.5		
15	Devils River	Just below Dolans Creek	.1		147			
15	6 springs	On left bank 1.1 mi below Dolans Creek	1.2			2.0		Estimate.
15	Devils River	1.3 mi below Dolans Creek	1.4		149			
15	Spring	On left bank 1.4 mi below Dolans Creek	1.5			.02		Estimate.
15	4 springs	On left bank 1.8 mi below Dolans Creek	1.9			.1		Estimate.
15	Spring	On left bank 2.6 mi below Dolans Creek	2.7			.3		Estimate.
15	Spring	On left bank 2.6 mi below Dolans Creek	2.7			1.0		Estimate.
15	Spring	On left bank 2.6 mi below Dolans Creek	2.7			.1		Estimate.
15	Devils River	3.1 mi below Dolans Creek	3.2		164			
16	Devils River	1,000 ft above Indian Creek	3.8		167			
16	Spring	On left bank 1.5 mi above Dry Devils River	6.5			.1		Estimate.
16	Spring	On right bank 1.5 mi above Dry Devils River	6.5			.1		Estimate.
16	Devils River	1.5 mi above Dry Devils River	6.55		203			
17	Devils River	At mouth of Dry Devils River	8.1		189			
17	Devils River	1.0 mi below Dry Devils River	9.2		189			
18	Devils River	1.5 mi above Deadman Creek	10.8		180			
18	Devils River	1.5 mi below Deadman Creek	13.4		200			

Date 1928	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Dolans Creek to Smith Ranch about 3 mi below Satan Creek, continued							
Feb. 19	Devils River	2-3/4 mi above Satans Creek	16.8		205			
20	Devils River	1.0 mi below Satans Creek	20.7		193			
20	4 springs	On left bank 1.5 mi below Satans Creek	21.3			1.0		Estimate.
20	Swann-Shelton Spring	On left bank 1.5 mi below Satans Creek	21.3			25.7		
20	Spring	On left bank 1.8 mi below Satans Creek	21.5			.5		Estimate.
20	Spring	On left bank 1.8 mi below Satans Creek	21.5			1.5		Estimate.
20	Little Satan Creek	At mouth	22.0			.5		Estimate.
20	Devils River	3/4 mi above Smith Ranch house	22.3		232			
	From Smith Ranch 3 mi below Satan Creek to a point ½ mi below Southern Pacific Railroad bridge							
7	Devils River	3/4 mi above Smith Ranch house	0		242			
7	Unnamed spring	On right bank across from Smith Ranch house	.5			2.69		
7	Unnamed spring	In river channel 600 ft below Smith Ranch house	.6			-		Not measured.
7	12 springs	On left bank just below Smith Ranch house	.6-1.2			1.0		Estimate.
7	Devils River	3/4 mi below Smith Ranch house	1.3		275			
7	5 springs	On right bank .8 mi below Smith Ranch	1.55			1.54		
7	Spring	On right bank 1.1 mi below Smith Ranch	1.70			.2		Estimate.
7	Spring	On right bank 400 ft above Sellers Ranch	1.85			.50		
7	6 springs	On right bank at Sellers Ranch house	2.00			1.0		Estimate.
7	Spring	On right bank ¼ mi below Sellers Ranch house	2.2			.4		Estimate.
8	Lester Spring	On left bank .6 mi below Sellers Ranch house	2.7			.2		Estimate.
8	Spring	On left bank 1.2 mi below Sellers Ranch house	3.45			2.71		
8	Spring	On left bank 1.25 mi below Sellers Ranch house	3.50			.54		
8	Devils River	1½ mi below Sellers Ranch house	3.90		292			

Date 1928	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
	From Smith Ranch 3 mi below Satan Creek to a point 1/3 mi below Southern Pacific Railroad bridge, continued							
Feb. 8	Spring	On left bank 2 mi above Dam #1	5.75			0.1		Estimate.
8	Devils River	1¼ mi above Dam #1	6.5		289			
9	Spring	On left bank 1.2 mi above Dam #1	6.55			.1		Estimate.
9	Spring	On left bank .9 mi above Dam #1	7.0			.53		
9	Spring	On left bank .6 mi above Dam #1	7.20			.8		Estimate.
9	Spring	On left bank .6 mi above Dam #1	7.20			.1		Estimate.
9	Spring	On right bank in Rough Canyon	7.25			1.0		Estimate.
9	5 springs	On left bank .5 mi above Dam #1	7.30			1.5		Estimate.
9	Spring	On left bank 1,000 ft above Dam #1	7.70			.08		
9	Devils River	At mouth of Bluff Creek 1,000 ft below Dam #1	8.00		301			
9	Spring	On left bank .3 mi below Dam #1	8.50			1.0		Estimate.
10	Devils River	1.0 mi below Dam #1	9.20		303			
10	Devils River	At Country Club ¼ mi below Damsite #9	11.8		301			
11	Devils River	At causeway 12 mi above Del Rio	14.0		315			
11	Spring	On right bank opposite gaging station	15.5			10.2		
11	Devils River	Just above Southern Pacific Railroad bridge	15.8		369			
11	Devils River	3,000 ft below Southern Pacific Railroad bridge	16.5		366			

In conjunction with the above investigations temporary gages were installed at five sites described below, each gage being a staff gage from 0 to 3.3 feet. From two to seven measurements were made at each station. On several occasions the stage rose above the gages. At those times daily discharge was not determined (see footnote to table of daily discharge). Records good for stations at Smith ranch and highway bridge; fair for the others.

At Gobbles ranch.-On right bank just below ranch house of M. H. Gobbles, 2½ miles below mouth of Dry Devils River, 25 miles northwest of Del Rio, Val Verde County, and 30 miles above mouth. Period of record: Mar. 22, 1928, to Apr. 27, 1929.

At Carruthers ranch.-On left bank near ranch house of J. W. Carruthers, 22 miles northwest of Del Rio, Val Verde County, and 27 miles above mouth. Period of record: Mar. 5, 1928, to Apr. 30, 1929.

At Smith ranch.-In front of Sam Smith ranch house, on left bank at Slaughter Bend crossing, 18 miles north of Del Rio, Val Verde County, and 18 miles above mouth. Period of record: Mar. 5, 1928, to Apr. 30, 1929.

At country club.-On right bank 500 feet above Devils River Country Club house, 6 miles above mouth, and 10 miles northwest of Del Rio, Val Verde County. Period of record: Mar. 12 to Sept. 21, 1928.

At highway bridge.-On right bank 800 feet above Comstock-Del Rio highway bridge, 5 miles above mouth, and 9 miles northwest of Del Rio, Val Verde County. Period of record: Jan. 1 to Sept. 21, 1928.

Daily discharge records for the above temporary gaging stations are published in Water Supply Paper 688, pages 112-118.

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Rio Grande February 9-March 3, 1926

Reach: From Del Rio to Eagle Pass, Tex.

During this series of measurements the river was at a constant stage, and the measurements represent the natural conditions.

Date 1926	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Feb. 9	Rio Grande	Near Del Rio - gaging station	0		2,730			
Mar. 2	San Felipe Creek	At springs 5 mi above mouth	3			76		
3	Sycamore Creek	2 mi above mouth	12			1		
Feb. 10	Rio Grande	3/4 mi above Bedell-Moore pump	14		2,830			
Mar. 3	Pinto Creek	1 mi above mouth	21			6		
Feb. 11	Rio San Diego	1 mi above mouth	26			77		
Mar. 3	Las Moras Creek	1 mi above mouth	32.5			7		
Feb. 11	Rio San Rodrigo	At mouth	40			27		
12	Rio Grande	3 mi below Jiminez	43		3,060			
12	Rio Grande	At Eagle Pass - gaging station	57		3,040			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Rio Grande February 12-22, 1926

Reach: From Eagle Pass to San Ygnacio, Tex.

During this series of measurements the river was at a constant stage, and the measurements represent the natural conditions.

Date 1926	Stream	Location	River Miles	Water Temp.	Discharge, in cfs Main Stream	Tributary	Diversion	Remarks
Feb. 12	Rio Grande	At Eagle Pass - gaging station	0		3,040			
13	Rio Chico	At mouth	3			71		
13	Rio Grande	1 mi above Rio Santo Domingo	11		2,950			
13	Rio Santo Domingo	At mouth	12			10		Estimate.
14	Rio Grande	At Indio Ranch	19		2,980			
14	Rio Grande	2 mi above long islands and shoals	29		3,000			
15	Rio Grande	At lower end of shoals	41		2,970			
16	Rio Grande	½ mi below San Ambrosia Creek	55		2,870			
16	Rio Grande	At island 2 mi below San Lorenzo Creek	67		2,990			
17	Rio Grande	1 mi below Apache Ranch	77		2,880			
17	Rio Grande	1 mi below Palafox	89		2,970			
18	Rio Grande	At Minerva	99		2,900			
18	Irrigation Pumps	From mile 99 to 111	99-111				5	Estimate.
18	Rio Grande	3 mi SE of Isletas	111		2,910			
19	Rio Grande	2½ mi SE of San Isabel	116.5		2,790			
19	Irrigation Pumps	From mile 111 to Laredo	111-127				5	Estimate.
19	Rio Grande	1½ mi above Laredo - gaging station	127.5		2,760			
20	Irrigation Pumps	From Laredo to mile 139½	127.5-139				15	Estimate.
21	Rio Grande	½ mi below Santa Rosa Ranch	139.5		2,750			
21	Rio Grande	1 mi SE of Los Castros Ranch	146		2,790			
22	Rio Grande	¼ mi below La Perla Creek	157		2,760			
22	Rio Grande	At San Ygnacio	167		2,760			

LOW-FLOW INVESTIGATIONS - RIO GRANDE BASIN

Rio Grande   January 12-April 25, 1928

Reach: From, Near Comal, Tex., half a mile below confluence with Rio San Rodrigo (Mexican tributary) to Laredo, Tex.

Temporary gaging stations were established on the Rio Grande at the following locations, a water-stage recorder being installed at each station. All stations were well rated by current-meter measurements from a boat for range of stage during period. Records excellent.

Near Comal Tex., half a mile below confluence with Rio San Rodrigo (Mexican tributary) and 16 miles northwest of Eagle Pass. Period of record, January 12 to March 18, 1928.

At Eagle Pass, Tex., a temporary gage was installed at the intake for the municipal water plant on January 10, 1928, and was moved 650 feet upstream to a permanent location on April 12, 1928.

At Rosita pumping plant, 9 miles below Eagle Pass. Period of record, February 1 to March 15, 1928.

At Indio ranch, 1 mile above "The Narrows" and 18 miles below Eagle Pass. Period of record, January 11 to April 13, 1928.

At Palafox, Tex. (upper), 1,000 feet above point where road approaches river's edge, 41 miles above Laredo, and 87 miles below Eagle Pass. Two ratings were developed for this station, 300 and 500 feet respectively below the gage, the lower rating giving 60 second-feet the greater discharge. Period of records, February 18 to April 25, 1928.

At Palafox, Tex. (lower). See Palafox upper. Period of record, February 18 to April 25, 1928.

At Darwin Ferry, Tex., 28 miles above Laredo and 100 miles below Eagle Pass. Period of record, April 2-25, 1928.

At Islitas, Tex., 20 miles above Laredo and 108 miles below Eagle Pass. Period of record, February 17 to April 25, 1928.

At Laredo, Tex., 128 miles below Eagle Pass. Period of record, February 21 to April 22, 1928.

The gain in discharge due to visible inflow and the loss due to diversions by a number of small pumping plants for that stretch of river under investigation were a negligible percentage of the total discharge and were considered to approximately balance each other.

Rio Grande January 12-April 25, 1928, continued

Summary of Miscellaneous Discharges, Rio Grande, 1928

Period	Station	River Miles	Mean Discharge, in cfs
Jan. 13 to Mar. 18	Comal	0	2,855
Do	Eagle Pass	16	2,885
Do	Indio ranch	34	2,945
Feb. 2 to Mar. 14	Eagle Pass	0	2,870
Do	Rosita pump	9	2,910
Do	Indio ranch	18	2,925
Jan. 12 to Apr. 12	Eagle Pass	0	2,685
Do	Indio ranch	18	2,740
Feb. 22 to Apr. 12	Eagle Pass	0	2,420
Do	Indio ranch	18	2,455
Do	Palafox (upper)	87	2,445
Do	Palafox (lower)	87	2,505
Do	Islitas	108	2,385
Do	Laredo	128	2,410
Apr. 3 to 22	Eagle Pass	0	2,105
Do	Palafox (upper)	87	2,080
Do	Palafox (lower)	87	2,140
Do	Darwin Ferry	100	2,090
Do	Islitas	108	2,010
Do	Laredo	128	2,030
Feb. 22 to Apr. 22	Eagle Pass	0	2,370
Do	Laredo	128	2,345

Delivery of Water Investigations

DIVERSIONS FROM RED RIVER TO LAKE DALLAS, TEXAS; AND RELATED CHANNEL LOSSES * FEBRUARY AND MARCH 1954

Introduction

As a drought emergency measure the city of Dallas in 1953 constructed a pumping plant on Red River directly north of Gainesville for the purpose of diverting Red River water over the Red-Trinity River divide and into Lake Dallas to supplement its municipal supply. Six electric pumps deliver water from Red River through a concrete pipe line and a cut channel a distance of about 3 miles to the head of Pecan Creek - a tributary of Elm Fork Trinity River. During the investigation from February 10 to March 3 each of the pumps delivered an average of 19 cfs at the lower end of the cut channel just upstream from the uppermost gaging station.

In August 1953 the city of Dallas requested that the Geological Survey and its cooperating agency, the Texas Board of Water Engineers, make an investigation of channel losses during a test run. Due to mechanical difficulties at the pumping plant, the test was delayed until February 1954. On February 10 three temporary recording gages were installed in the reach in addition to the regular gaging station on Elm Fork Trinity River near Sanger. The locations of the gages are shown in figure 7. The lower gage was installed at State Highway 10, northeast of Denton, which is the farthest downstream accessible point above backwater from Lake Dallas.

Results

During the period Feb. 10 to Mar. 3, 1954, the city of Dallas pumped 1,363 acre-feet of water from its Red River plant into Pecan Creek (a tributary of Elm Fork Trinity River) 3.5 miles above Gainesville; 1,272 acre-feet of this diversion reached the head of Lake Dallas. Discharge records were obtained at four points along the channels. This water was transported down the channels of Pecan Creek and Elm Fork Trinity River to Lake Dallas, a distance of about 31 miles. Total flow of pumped water for three of the locations is given in the following tabulation of results.

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* U. S. Geological Survey Open File Report No. 47 by Pat H. Holland

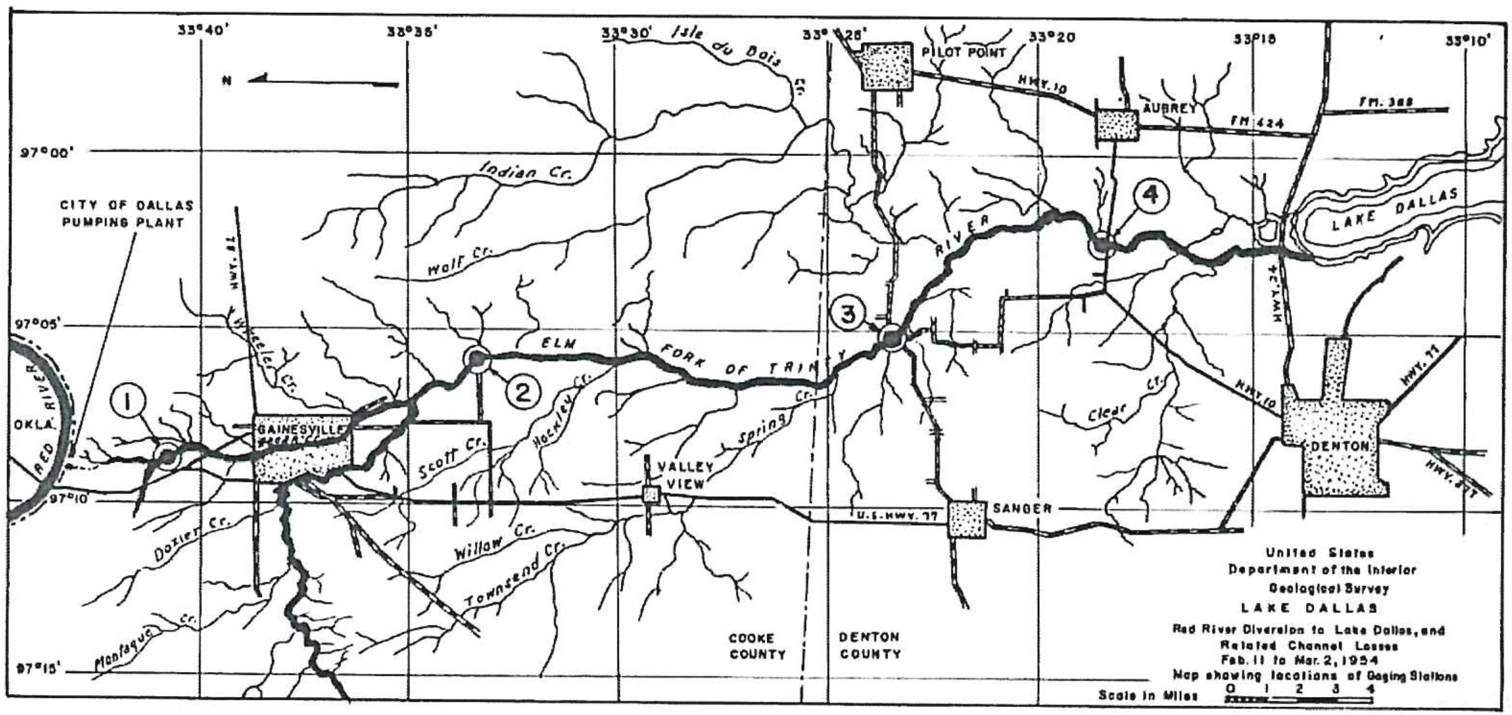


FIGURE 7.- MAP SHOWING LOCATION OF STREAM-GAGING STATIONS, RED RIVER DIVERSIONS TO LAKE DALLAS-1954.

Tabulation of Results

Total acre-feet Feb. 11 to Mar. 3, 1954

	Pecan Creek 3.5 mi. north of Gainesville	Elm Fork Trinity R. 6 mi. south of Gainesville	Elm Fork Trinity R. at Highway 10 northeast of Denton	Loss in Acre-feet	Loss %
Channel Mile from Pumping Plant	3.0	12.6	33.9		
6 Pumps Operating 72 hours	685	683	645	40	5.8
4 Pumps Operating 72 hours	454	421	421	33	7.3
2 Pumps Operating 72 hours	224	220	206	18	8.0
Total Pumpage	1,363	1,324	1,272	91	6.7

Discussion

Prior to the investigation K. F. Hoefle, Superintendent of Dallas Water Department, and Pat H. Holland, Geological Survey engineer-in-charge of field investigations, agreed upon the following method of pump operation:

1. The interval of flow method be used to determine losses, with interval of 72 hours pumping and 72 hours shutdown or recession time between runs.

2. Three rates of flow be investigated - flow from 6, 4, and 2 pumps.

3. 6 pumps be started at noon February 11.

The pumps were started and operated as scheduled with only two interruptions when a single pump was stopped for a short time. The chart records from the continuous recorders were complete and a full range of discharge measurements was obtained. The investigation was completed on March 3 but the recording gages were operated until March 18 and pumping continued after that time.

Prior to the investigation some pump tests had been made. One of these, of 4 days duration, had ended about noon of February 8. A residue of this water was present at all three of the Elm Fork stations when recorders were installed on February 10. Elm Fork Trinity River was flowing 5.0 cfs just above the mouth of Pecan Creek on February 12 and 4.0 cfs on February 19. Pecan Creek was dry above Gainesville and had only slight flow at its mouth. On February 11 all tributaries within the reach were inspected and all flow measured. A total of

2.9 cfs was measured in Isle du Bois, Spring, and Scott Creeks.

Hourly discharges were computed and figure 8 shows actual discharge hydrograph for the three stations and figure 9 shows discharge hydrograph with normal or base flow eliminated. Figure 10 is a time of travel curve between the upper and lower gages.

After careful analysis it was decided that the data obtained at Elm Fork Trinity River near Sanger was not sufficiently accurate to include in this report. The stage-discharge relation for medium and low stages is controlled by a clay and mud bar a short distance downstream from the gage. The highway bridge at this site is too weak to carry heavy equipment and therefore bulldozers and other equipment must be forded. The gage control, being the shallowest point near the bridge, is used as a ford for this equipment and often dirt is pushed into the channel before the vehicles are crossed, thereby changing the stage-discharge relation. During the investigation the control at the Sanger station was disturbed to such an extent that the low and medium records could not be computed to good accuracy.

Minor shifting of the stage-discharge relation occurred at the gage below Gainesville and therefore this record, although good, is not considered as accurate as that at Pecan Creek and Elm Fork Trinity northeast of Denton.

Base data are considered excellent and except for some minor uncertainties in determining the normal flow at the two Elm Fork stations, the results as a whole are considered excellent. There was no normal or base flow at the Pecan Creek station. Accuracy of the interval of flow method depends on an accurate definition of the interval as it progresses downstream. This can be done by sandwiching the foreign water between two troughs that return to the normal flow. Considerable time would be required to allow the troughs or the flow recession to return to absolute base flow. The 72 hour pumping interval proved sufficient to produce desired volumes of flow but the 72 hour shutdown or recession time was not long enough for recession flows to return to normal. Probably twice the allotted recession time would have been enough but 72 hours was the maximum that could be allowed due to the imminence of weather changes. Rainfall of consequence would end this type of study and past history indicates that some rains are almost certain during February in this section of northeast Texas. However, the inaccuracies due to uncertain normal flow are of small consequence owing to the small percentages involved.

The small percentage of loss encountered in delivery of Red River water can be attributed largely to the low seasonal evaporation and transpiration losses and the relatively impervious nature of the streambed material. The geologic formations across which the streams flow are of the Washita group of the Cretaceous age consisting generally of clays and marls with a few thin beds of limestone and sandy clay, all of which are relatively impervious.

The weather was ideal for this type of investigation because no rain fell in the vicinity and the sun was shining much of the time. Evaporation losses, however, might have been higher than the seasonal average because brisk winds blew from the north, south and west with accompanying dust clouds at times from the west and northwest. Conditions were ideal for high evaporation and transpiration for this season of the year and the losses experienced should be near the maximum for a winter season.

Field work and partial computation of data in this report was performed under the direction of R. L. Allen, Area Engineer, Fort Worth Area office.

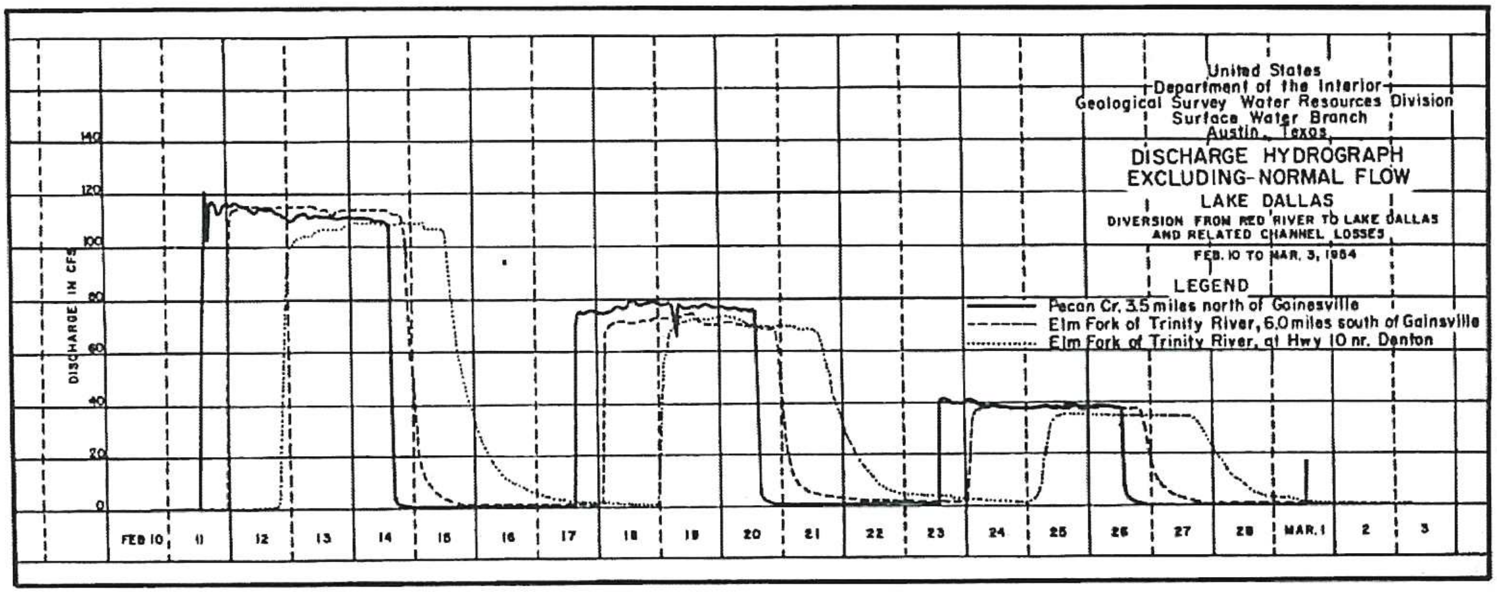
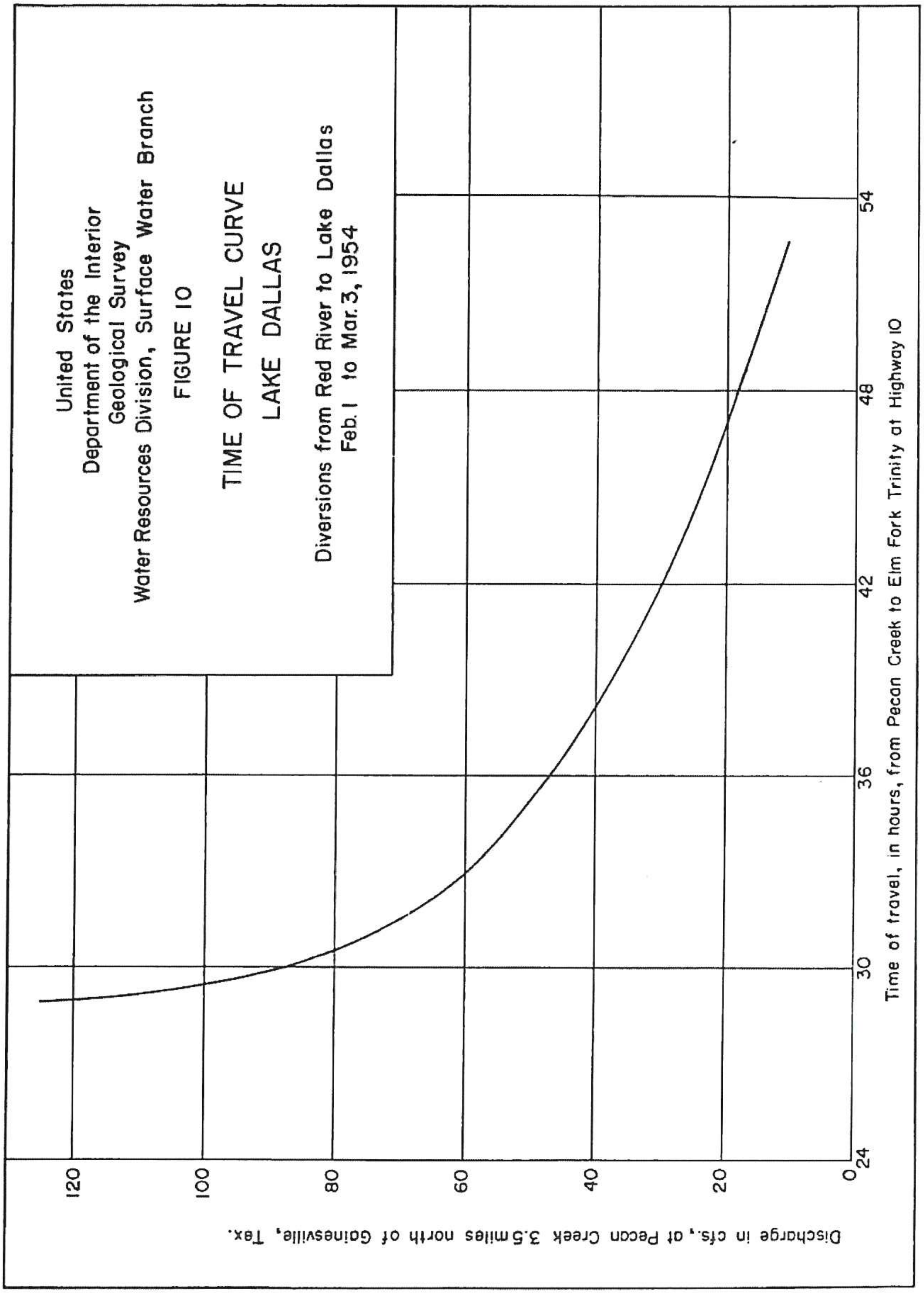


FIGURE 9.- DISCHARGE HYDROGRAPHS EXCLUDING NORMAL FLOW, RED RIVER DIVERSIONS TO LAKE DALLAS-1954.


United States
Department of the Interior
Geological Survey
Water Resources Division, Surface Water Branch
FIGURE 10
TIME OF TRAVEL CURVE
LAKE DALLAS
Diversions from Red River to Lake Dallas
Feb. 1 to Mar. 3, 1954
0
20
40
60
80
100
120
24
30
36
42
48
54
Discharge in cfs., at Pecan Creek 3.5 miles north of Gainesville, Tex.
Time of travel, in hours, from Pecan Creek to Elm Fork Trinity at Highway 10

DELIVERY OF WATER
FROM
POSSUM KINGDOM RESERVOIR TO RICHMOND, TEXAS
VIA BRAZOS RIVER CHANNEL *
AUGUST AND SEPTEMBER 1948

Introduction and Purpose

Unusual drought conditions in the summer of 1948 led the irrigators in the lower Brazos River Valley to request releases from Possum Kingdom Reservoir primarily for the irrigation of rice.

The purpose of this study was to determine the time of travel of released water from Possum Kingdom Reservoir to Richmond, Texas.

Results

An average time of travel graph, showing the time of travel from Possum Kingdom Reservoir to Richmond, Texas, is given in figure 11. The first release of water required 340 hours to travel from Possum Kingdom Reservoir to Richmond, while the second release required 370 hours to travel this distance. Travel time of the third release could not be determined accurately because of flood runoff.

Discussion

The first release is identified as that passing the Palo Pinto stream-gaging station, 20 miles downstream from the reservoir, during the period August 9-16, 1948; the second release is that during the period August 16-30; and the third release is that during the period August 30 to September 6, 1948.

The first release of 11,800 acre-feet, as measured at the Palo Pinto gaging station, could be followed fairly accurately downstream to Richmond. This

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* U. S. Geological Survey Open File Report No. 41 by D. E. Havelka

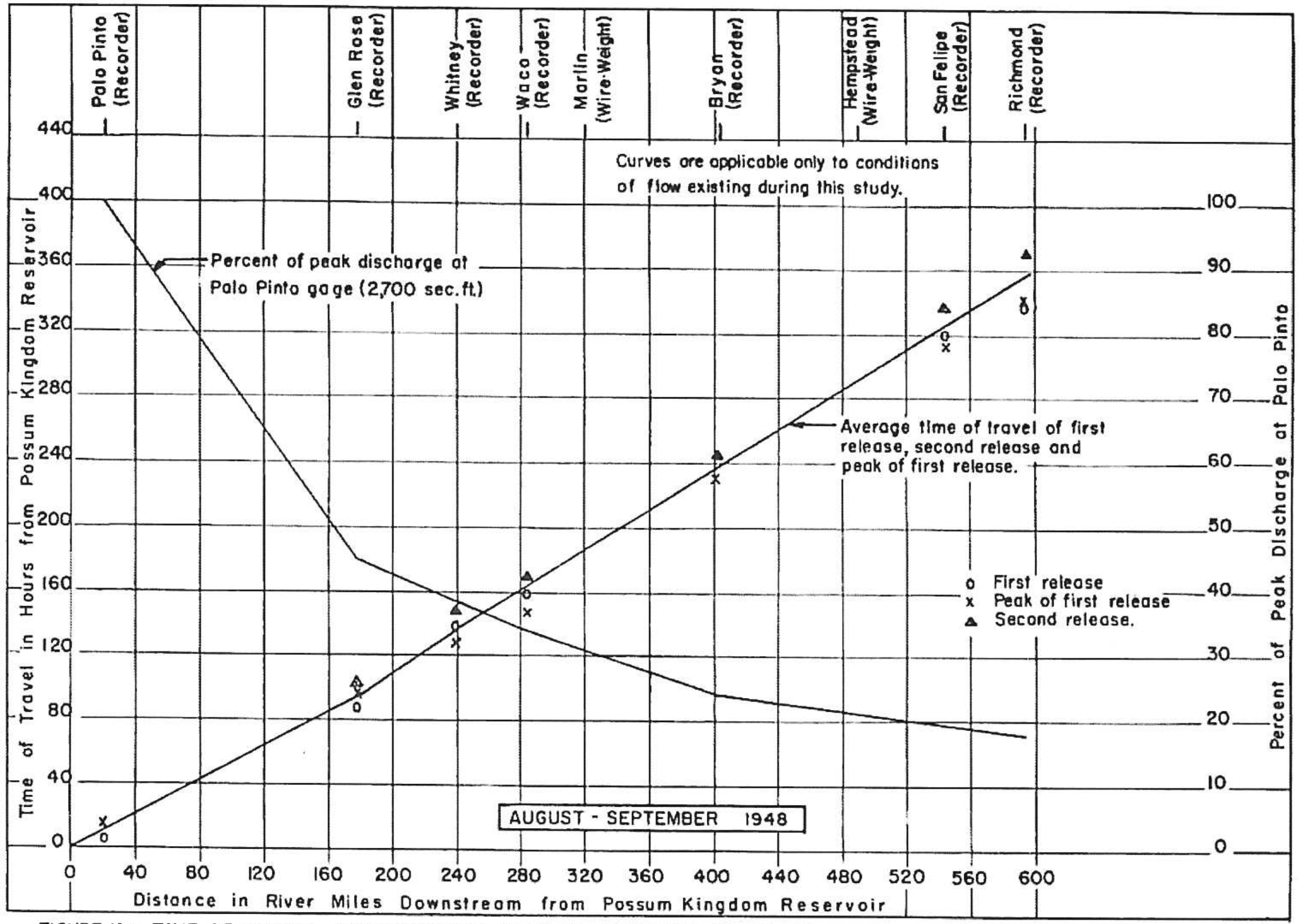
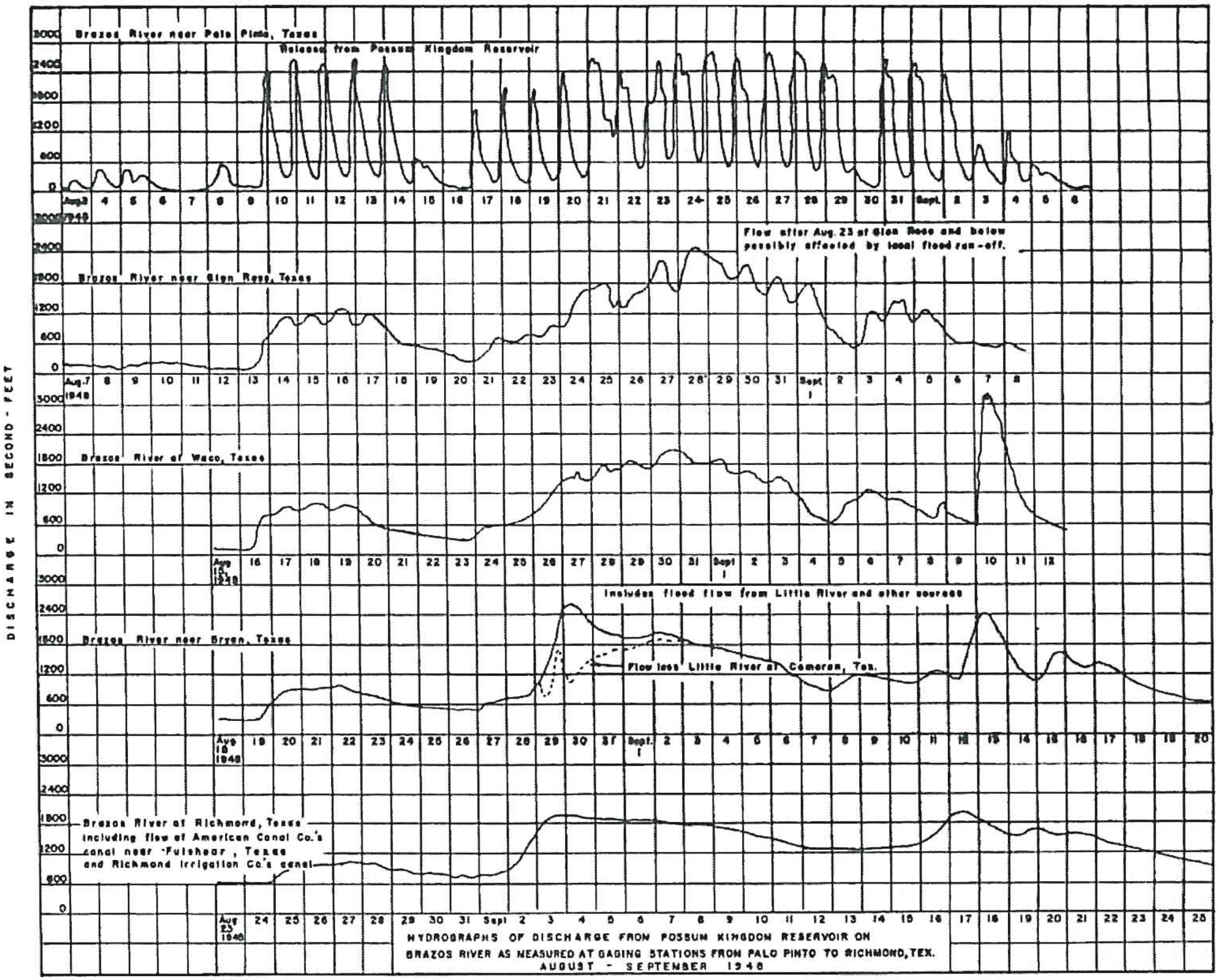


FIGURE 11.- TIME OF TRAVEL AND REDUCTION IN PEAK OF WATER RELEASED FROM POSSUM KINGDOM RESERVOIR

U.S. Geological Survey- Surface Water Branch- Austin, Texas release traveled in a relatively dry channel. The peak discharge at the Palo Pinto gaging station was only 610 cfs (cubic feet per second) during the 9-day period preceding this release and no runoff from rain was indicated during time of travel to Richmond.

A graph showing percent of the momentary peak discharge of the first release of 2,700 cfs at the Palo Pinto gaging station that reached each gaging station is shown in figure 11. Only 18 percent or 490 cfs of this peak reached Richmond. This chart does not include base flow. The peak discharge of the second and third releases were increased by runoff due to rain and a satisfactory determination of peak reduction could not be made.

Discharge hydrographs of gaging stations on the Brazos River near Palo Pinto, near Glen Rose, at Waco, near Bryan and at Richmond, Tex., are shown in figure 12. The hydrograph of flow at Richmond includes the flow of the American Canal Company's Canal near Fulshear, Tex., and Richmond Irrigation Company's Canal near Richmond, Tex., both of which divert water from Brazos River upstream from the Richmond gaging station. In addition to the gaging stations shown in figure 12, those near Whitney and near San Felipe were used in computing time of travel of released water. All of the gaging stations mentioned above were equipped with continuous water-stage recorders.



HYDROGRAPHS OF DISCHARGE FROM POSSUM KINGDOM RESERVOIR ON BRAZOS RIVER AS MEASURED AT GAGING STATIONS FROM PALO PINTO TO RICHMOND, TEX.
AUGUST - SEPTEMBER 1948

FIGURE 12.

DELIVERY OF WATER
WHITNEY RESERVOIR TO RICHMOND, TEXAS
VIA BRAZOS RIVER CHANNEL *
1954

Problem

The problems involved in this study were as follows:

1. To determine the percentage of water released from Whitney Reservoir and transported down the Brazos River channel that would be available near Richmond, Tex.

2. To determine the time of travel from Whitney Reservoir to Richmond.

The gaging station near Whitney, which is the upstream point for measuring released water, is 3 miles downstream from Whitney Reservoir, and the gaging station at Richmond is the downstream point for measuring releases. All determinations in this study were made from the Whitney gage to the Richmond gage or to gages between.

Results

During the period Aug. 1-31, 1954, 47,700 acre-feet of water was released from Whitney Reservoir for the use of irrigators below Richmond, Tex. (See fig. 13) Of this released water, 76 percent (36,200 acre-feet), arrived at Hempstead 243 miles downstream from the Whitney gage, and 69 percent (33,100 acre-feet) arrived at Richmond 346 miles downstream from the Whitney gage. (See figs. 14 and 15.) The time of travel was 137 hours to Hempstead and about 193 hours to Richmond. The river channel was already wet, owing to the presence of residual water from previous releases in the channel and in river sand and gravel beds, and no extra initial loss occurred. About 9,500 acre-feet of the 14,600 acre-feet lost in transit from Whitney to Richmond is attributed to evaporation. These results can be expected only when conditions are similar to those existing during the period of this investigation.

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* U. S. Geological Survey Open File Report No. 53 by Seth D. Breeding and Pat H. Holland

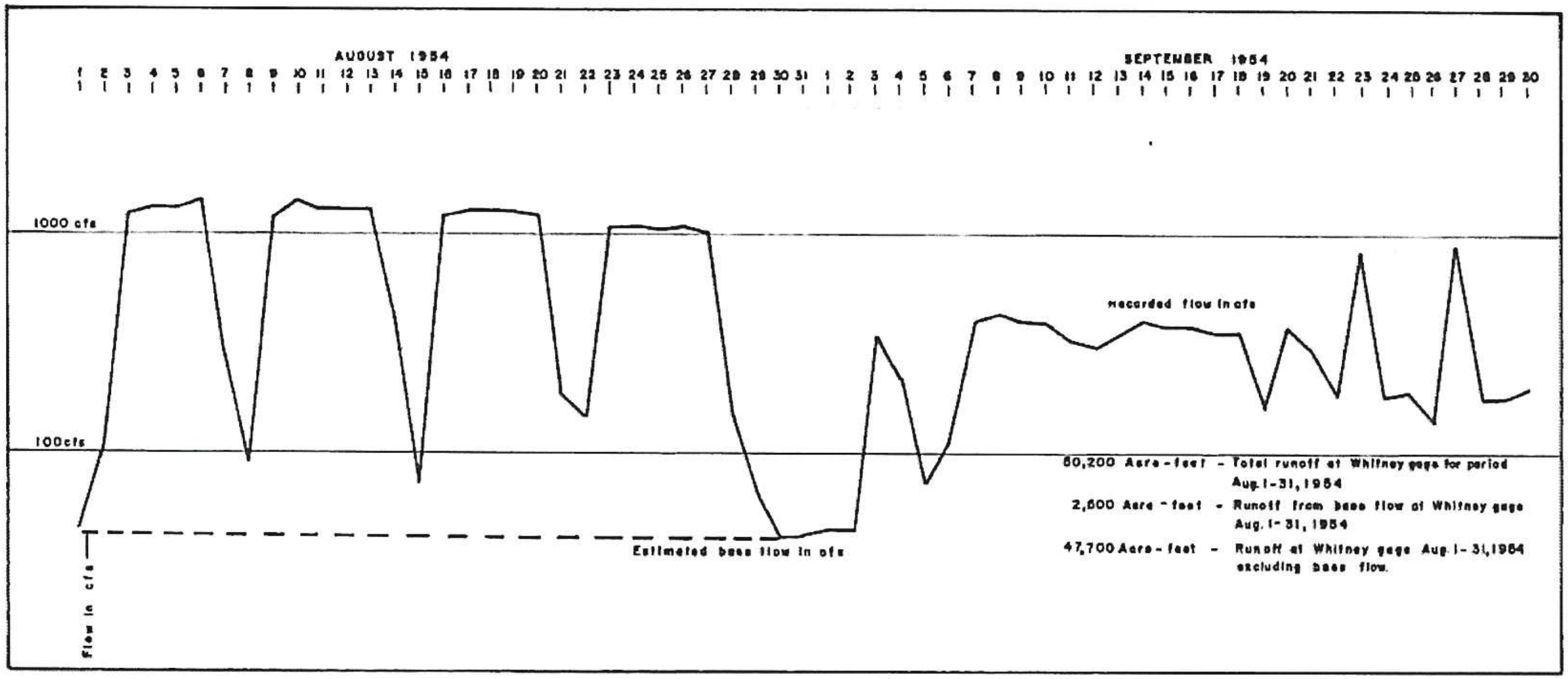

FIGURE 13.- DISCHARGE HYDROGRAPH, BRAZOS RIVER NEAR WHITNEY, TEX.-1954.

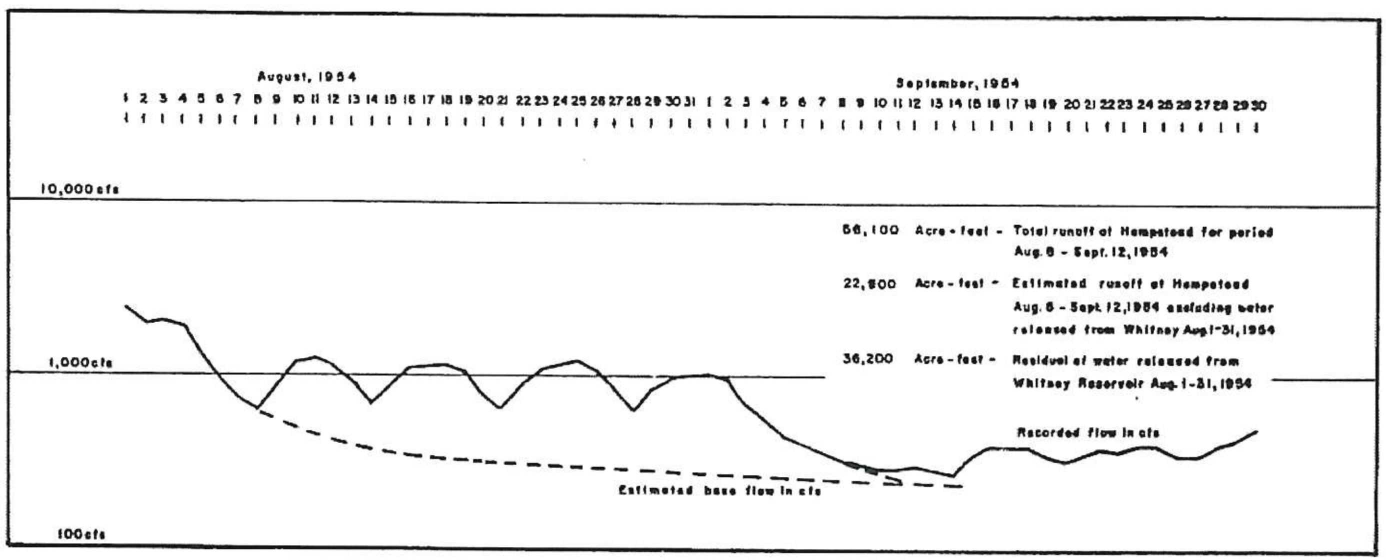

FIGURE 14.-DISCHARGE HYDROGRAPH, BRAZOS RIVER NEAR HEMPSTEAD, TEX.-1954.

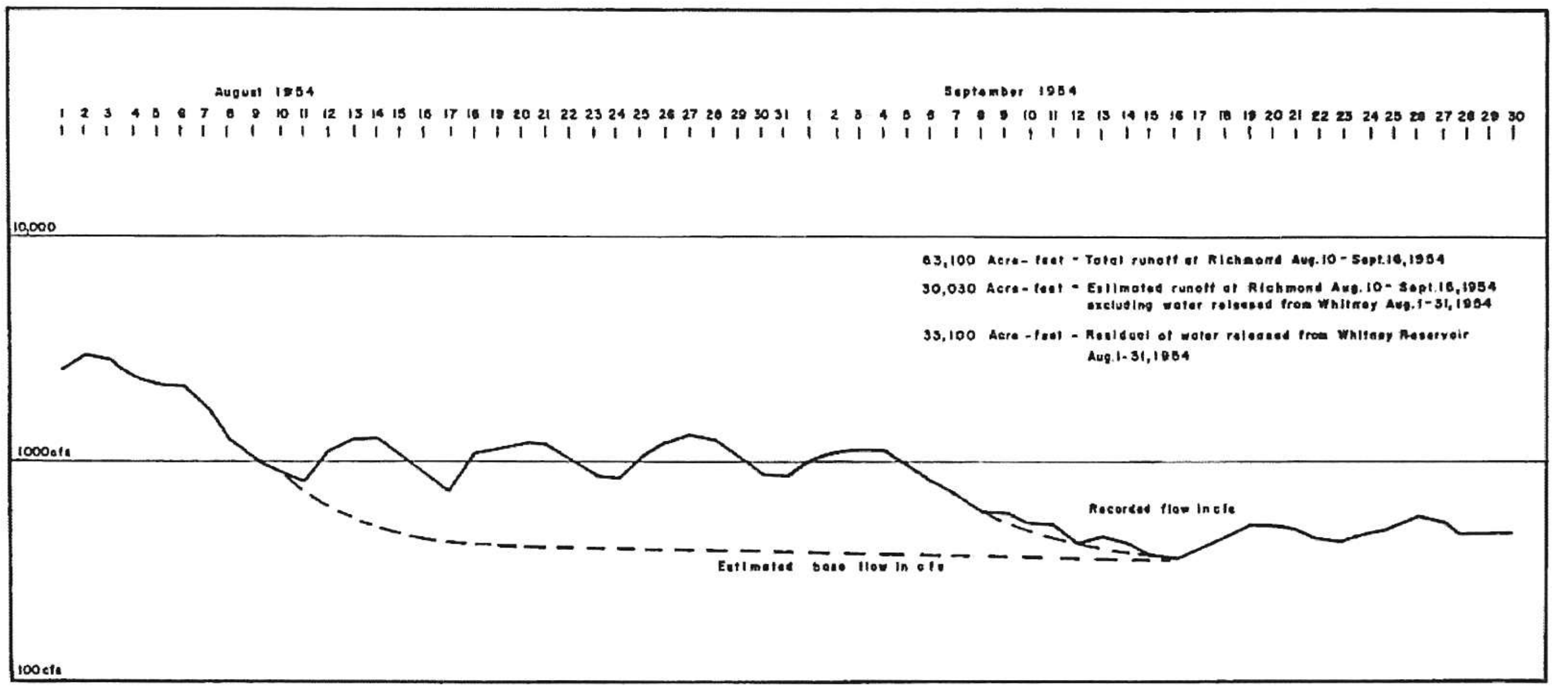

FIGURE 15.- DISCHARGE HYDROGRAPH,

BRAZOS RIVER AT RICHMOND, TEXAS + AMERICAN CANAL + RICHMOND CANAL, AUG.& SEPT.1954

Scope of Study

The river reach concerned is 346 miles between the U. S. Geological Survey-Corps of Engineers, U. S. Army gaging stations near Whitney (3 miles downstream from Whitney Dam and Reservoir) and at Richmond, Tex. Four other gaging stations in the reach are those at Waco, near Bryan, near Hempstead, and near San Felipe, which are located 35, 154, 243, and 297 miles, respectively, downstream from the Whitney gage. Records from the Waco, Bryan, and San Felipe gaging stations are not included in this report. The period August 1-31 was selected for study because there was very little inflow from tributaries and very little runoff from rainfall, and the water released could be clearly identified, owing to periods of low flow at the beginning and at end of month. Also, the river channel was in condition for determining average loss owing to the fact that releases had been made previous to this period and no material initial loss would be involved.

Field Investigation

Recorder charts were removed and discharge measurements were made once a week at each of the gaging stations in the reach.

Office Computations and Discussion

The records were computed weekly and reports were made to the State Board of Water Engineers and other interested organizations.

Discharge hydrographs were plotted for each of the six gaging stations in the reach for the months of August and September. These hydrographs were plotted from mean daily discharges as previously computed except for the Whitney station. The Richmond hydrograph was plotted on basis of the record at Richmond plus records for the Richmond and American Canals. These two canals divert water from the Brazos River between San Felipe and Richmond. For the purpose of this study the daily discharges for August 1-31 at the Whitney gaging station were revised slightly from those published in Water-Supply Paper 1342 on the basis of a reanalysis of the stage-discharge relation. These slightly revised records will be used only in this study and do not supersede the published record. A line showing estimated base flow from antecedent releases was drawn on each graph. The difference between base flow and measured flow is the residual of water released from Whitney Reservoir.

The water was released from Whitney Reservoir through the power plant, which automatically adjusts gate openings to power demand. The low power demand on Saturday and Sunday is the cause of the low discharges on week-ends. These lows, or troughs, on the gage-height charts can be followed downstream to all the gages. The time of the week-end trough was picked from recorder charts and plotted on a graph that shows time of travel to all gages between Whitney and San Felipe. (See fig. 16)

The loss to evaporation was estimated on basis of 346 miles of river having an estimated average width of 300 feet and average evaporation of 9 inches. Records of evaporation for August at Waco (10.8 in.), College Station (8.82 in.) and Prairie View (7.87 in.) were used to determine the average for the reach.

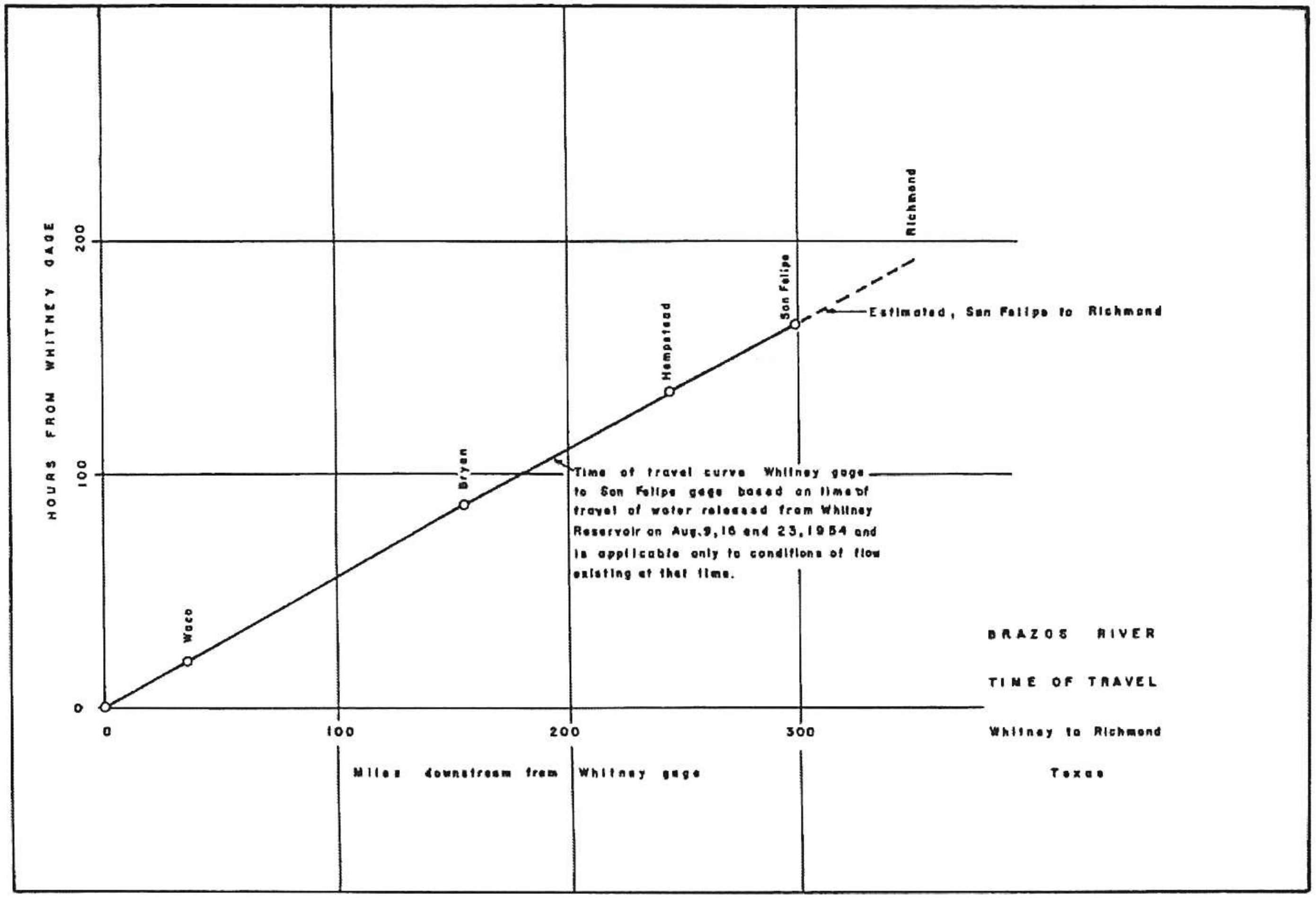

FIGURE 16.-BRAZOS RIVER TIME OF TRAVEL CURVE, WHITNEY TO RICHMOND, TEX.-1954.

DELIVERY OF WATER
WHITNEY RESERVOIR TO RICHMOND, TEXAS
VIA BRAZOS RIVER CHANNEL *
1956

Problem

The problems involved in this study were as follows:

1. To determine losses in transit of water released from Whitney Reservoir and transported down the Brazos River channel to Richmond, Tex.

2. To determine time of travel of released water from Whitney Reservoir to gaging station at Richmond.

The gaging station near Whitney, which is the upstream point for measuring water released from Whitney Reservoir, is 3 miles downstream from Whitney Dam, and the gaging station at Richmond is the downstream point for measuring releases. All determinations in this study were made from the Whitney gage to the Richmond gage or to gages between.

The quantity of flow reaching Juliff gage (located 26 miles downstream from Richmond) could not be determined because of lack of records of diversions between Richmond and Juliff.

Results

During the period July 2 to August 5, 1956, 103,000 acre-feet of water was released from Whitney Reservoir for the use of irrigators below Richmond, Tex. (See fig. 17) Of the released water, 71,300 acre-feet (fig.18), or 69 percent of the total volume arrived at the Richmond gaging station 346 miles downstream. The time of travel of the first water released was about 198 hours. Shown on the following page is a table giving data for each gaging station in the reach from Whitney to Richmond.

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* U. S. Geological Survey Open File Report No. 59 by Pat H. Holland

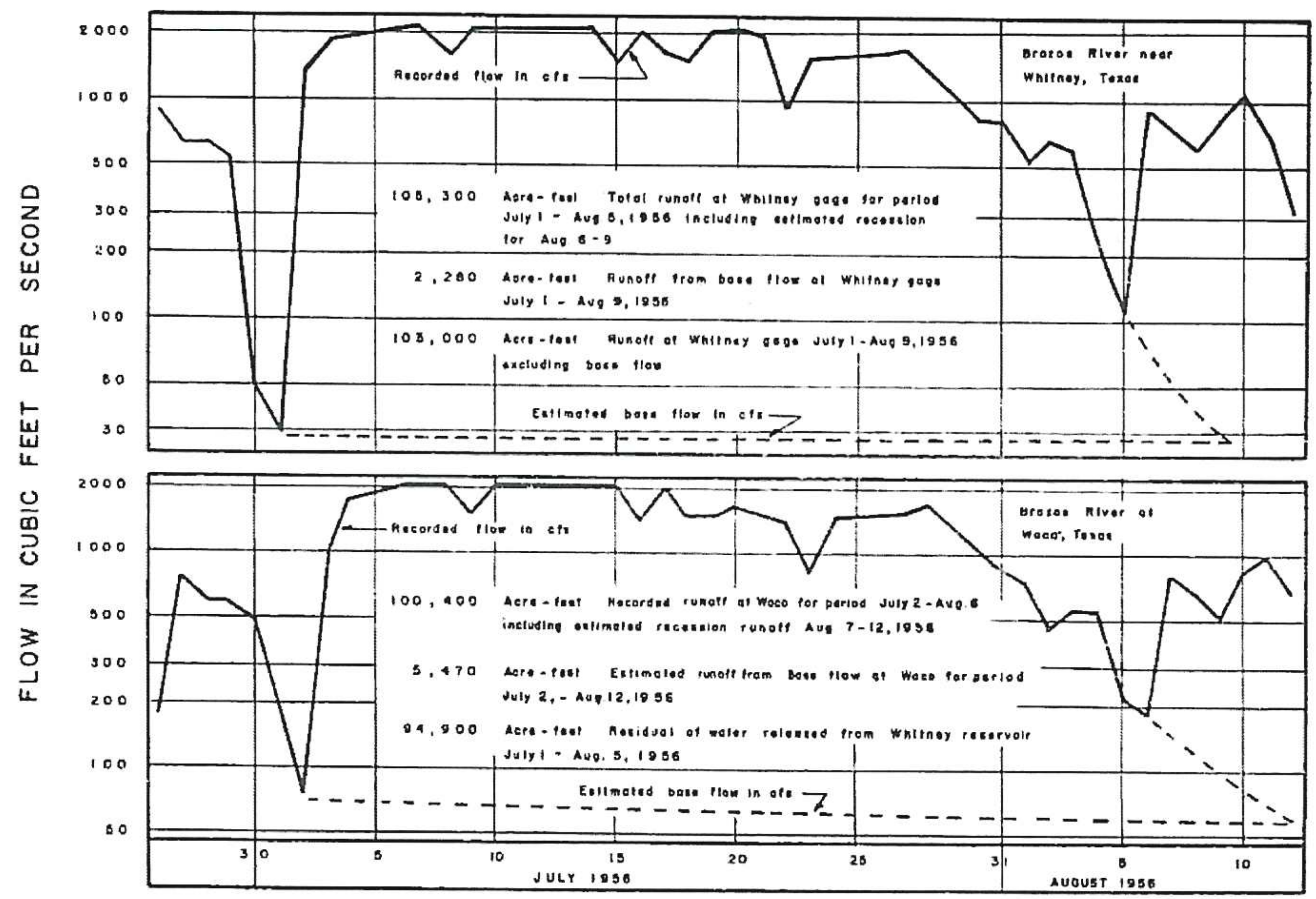

FIGURE 17.-DISCHARGE HYDROGRAPHS, BRAZOS RIVER NEAR WHITNEY AND AT WACO, TEX.-1956.

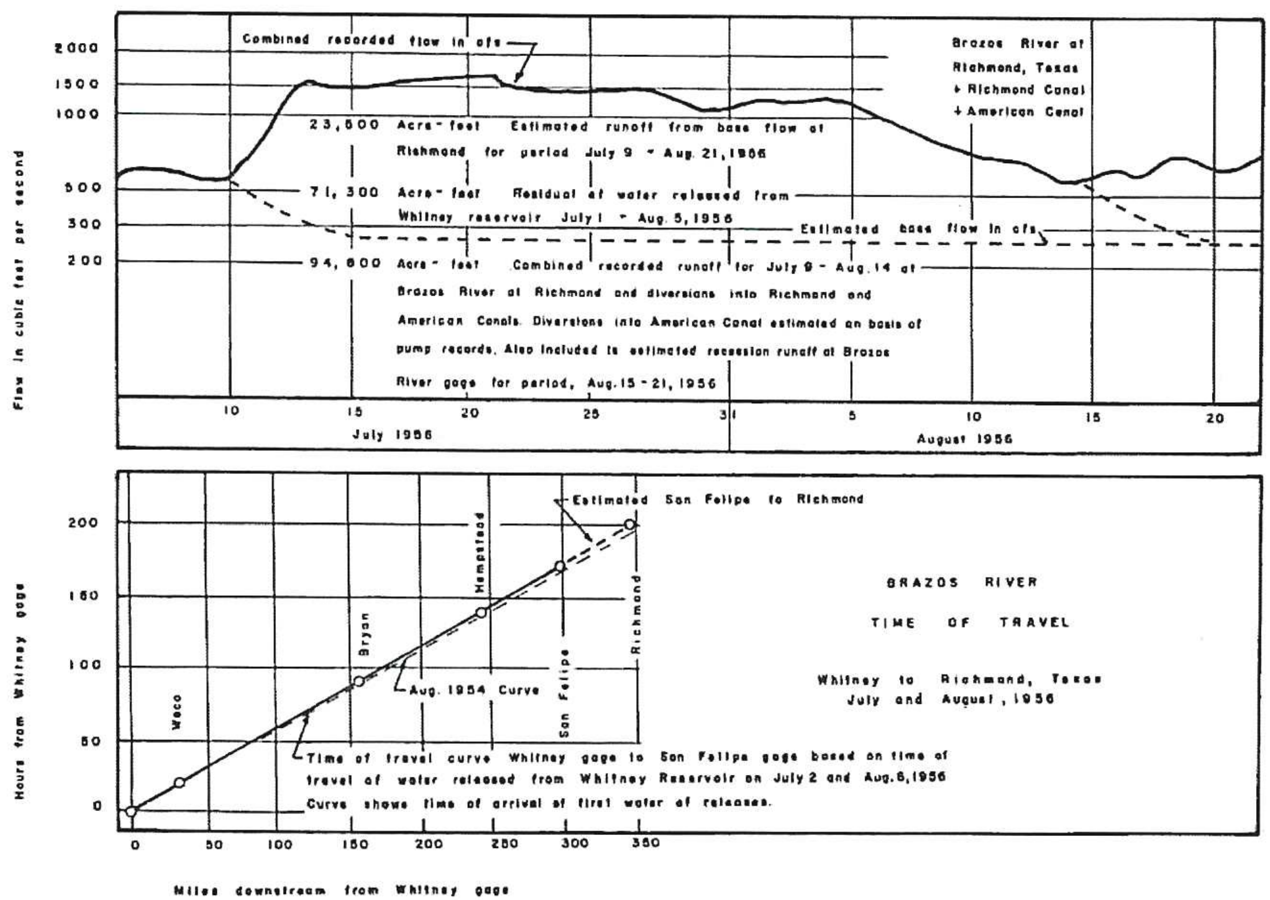

FIGURE 18. DISCHARGE HYDROGRAPH, BRAZOS RIVER AT RICHMOND, TEX.-1956.
TIME OF TRAVEL CURVE, BRAZOS RIVER, WHITNEY TO RICHMOND, TEX.

Tabulation of Results

Gaging station	Amount of water arriving (ac.-ft.)	Percent of released water	Lost in transit (ac.-ft.)	Percent of release lost between gages	Travel time of first water (hours)	Miles below Whitney gaging station
Whitney	103,000	100	--	--	--	--
Waco	94,900	92	8,100	8	18	35
Bryan	79,400	77	15,500	15	90	154
Hempstead	74,500	72	4,900	5	140	243
Richmond	71,300	69	3,200	3	198	346

No initial loss occurred, as previous releases had conditioned the channel and saturated the alluvium beds in the reach.

About 15,000 of the 31,700 acre-feet lost in transit is attributed to evaporation. The above results can be expected to occur only when conditions are similar to those existing during the period of this investigation.

Comparisons of Results with Previous Investigations

During the period Aug. 1-31, 1954, 47,700 acre-feet of water was released from Whitney Reservoir for the use of irrigators below Richmond. Results of that study are contained in Open File Release No. 53, August 1956, "Delivery of Water, Whitney Reservoir to Richmond, Tex. via Brazos River Channel, 1954". Also, Open File Release No. 57, February 1957, "Delivery of Water from Belton Reservoir to the Brazos River Gaging Station at Richmond, Tex., by way of the Leon, Little, and Brazos River Channels, 1956", covers delivery of 73,000 acre-feet of water from Belton Reservoir to industrial users in the vicinity of Freeport, Tex.

The following table contains a comparison of results shown in the three reports.

Comparison of Release to Delivery

Reservoir releasing water	Period of release	Amount of release (acre-feet)	Amount lost in transit (acre-feet)	Percent of released water arriving at Richmond	Distance below reservoir (miles)	Time of travel of first water (hours)
Whitney	Aug. 1-31, 1954	47,700	14,600	69	346	193
Whitney	July 1 to Aug. 5, 1956	103,000	31,700	69	346	198
Belton	Nov. 1 to Dec. 14, 1956	73,000	18,700	74	342	202

Scope of Study

During the period July 9-16, 1956, a special water release was made from Whitney Reservoir for the use of Briscoe Irrigation Company. This water was obtained from the Brazos River Authority, and the Board of Water Engineers granted a permit for its transportation down the Brazos River channel. The Whitney releases were repaid by the Brazos River Authority from Possum Kingdom Reservoir. The Board of Water Engineers requested daily reports during this period at six gaging stations between Whitney Reservoir and Briscoe Irrigation Company, located below Richmond. Several discharge measurements were made and recording gages inspected regularly during the period.

The period July 2 to August 5 was selected for study because it encompasses the period of this special release. It was impossible to study the period July 9-16 because no definition of the interval could be recognized as it progressed downstream. The longer interval was defined by periods of low flow at the beginning and end of the period and could be clearly identified at all gaging stations.

Also during this period inflow from tributaries was at a minimum and rainfall was either lacking or very scant.

The river reach concerned is 346 miles between the gaging stations near Whitney (3 miles downstream from Whitney Dam and Reservoir) and at Richmond, Tex. Other gaging stations in the reach are at Waco, near Bryan, near Hempstead, and near San Felipe, which are located 35, 154, 243, and 297 miles, respectively, downstream from the Whitney gage. Records for the San Felipe gaging station are not included in this report.

The river channel was in a favorable condition for determining average loss, owing to the fact that releases had been made previous to this period and no material initial loss was involved.

Field Investigation

During the period July 9-16, 1956 gaging stations were vistied frequently and several discharge measurements were made at each gage to better define the stage-discharge relation.

Discharge measurements were made at Whitney on July 9, 10, 16, 30 and Aug. 15; at Waco, June 21, July 9, 10, 16, 30 and Aug. 30; near Bryan, June 11, July 9, 10, 16, 30 and Aug. 13; near Hempstead, July 2, 9, 10, 16, Aug. 4, 10, 13 and 20; and at Richmond, July 5, 9, 10, 11, 16, Aug. 6, 10, 13 and 20.

Office Computations and Discussion

Daily reports of flow were made to the Board of Water Engineers during the period of the special release, July 9-16, 1956, on the basis of special measurements listed above.

No work was done on this report until the 1956 water year computations were completed for the stations included. From these records discharge hydrographs were plotted (figs. 17 to 19) using mean daily discharge as published in Water-Supply Paper 1442, except for the station at Richmond. The Richmond hydrograph was plotted on basis of the Brazos River record at Richmond plus record of diversions into Richmond Canal and estimated diversions into American Canal. The American Canal diverts from the left bank of Brazos River 18 miles upstream from Richmond, and Richmond Canal diverts from right bank 6 miles upstream from Richmond. The American Canal record was estimated on basis of total daily pumpage as reported by the Canal Company.

The discharge hydrographs also show a line representing estimated base flow, some of which is from antecedent releases at Whitney Reservoir. Information on base flow in the reach is very sketchy due to release procedure and operation of a hydroelectric power plant at Whitney Dam. The operation schedule of the power plant does not allow sufficient drain-down time for the river to return to base flow conditions at stations below Waco.

The periods of low flow prior to and following the period of the investigation facilitated the computation of time of travel of the first water. The instant of first rise was picked from recorder charts at each station and the information used to plot a time-of-travel curve. (See fig. 18) Although only about half as much water was released during the investigation of Aug. 1-31, 1954, the time of travel agreed very closely with that determined for the current investigation. For comparison, the information from the 1954 investigation was plotted on the time-of-travel curve.

The loss to evaporation was estimated on basis of 346 miles of river having an estimated width of 325 feet and average evaporation of 11.32 inches. Records of evaporation for July and August at Waco (Riesel), 12.00 and 11.21 inches, College Station, 13.34 and 11.89 inches, and Prairie View, 10.39 and 9.10 inches, were used to determine the average evaporation of 11.32 inches for an average period of 1.2 months.

Accuracy of Results

The time-of-travel curve, based on time of appearance of the first water, is considered excellent, as it agrees closely with previous determinations of time-of-travel.

The daily discharges at gaging stations are good to excellent, due to the numerous discharge measurements for better definition of the stage-discharge relation at each station. All gage-height records were complete and no estimates were necessary except to determine base flow at each station and diversions into American Canal. The Hempstead gage is non-recording and the record is based on twice daily readings of wire-weight gage by an observer. The observer's readings were complete and numerous additional readings were made by engineers while making discharge measurements.

The estimates of base flow at Whitney and Waco are considered good. Those at the other stations are poor due to lack of definition on gage-height charts or lack of discharge measurements of base flow. Base flows at Bryan, Hempstead, and Richmond were based on poorly defined curves of increases in daily discharge between stations during short periods of relatively constant flow. The recessions at beginning and end of the base flow periods were estimated by comparison with at least one normal recession that was undisturbed by inflow.

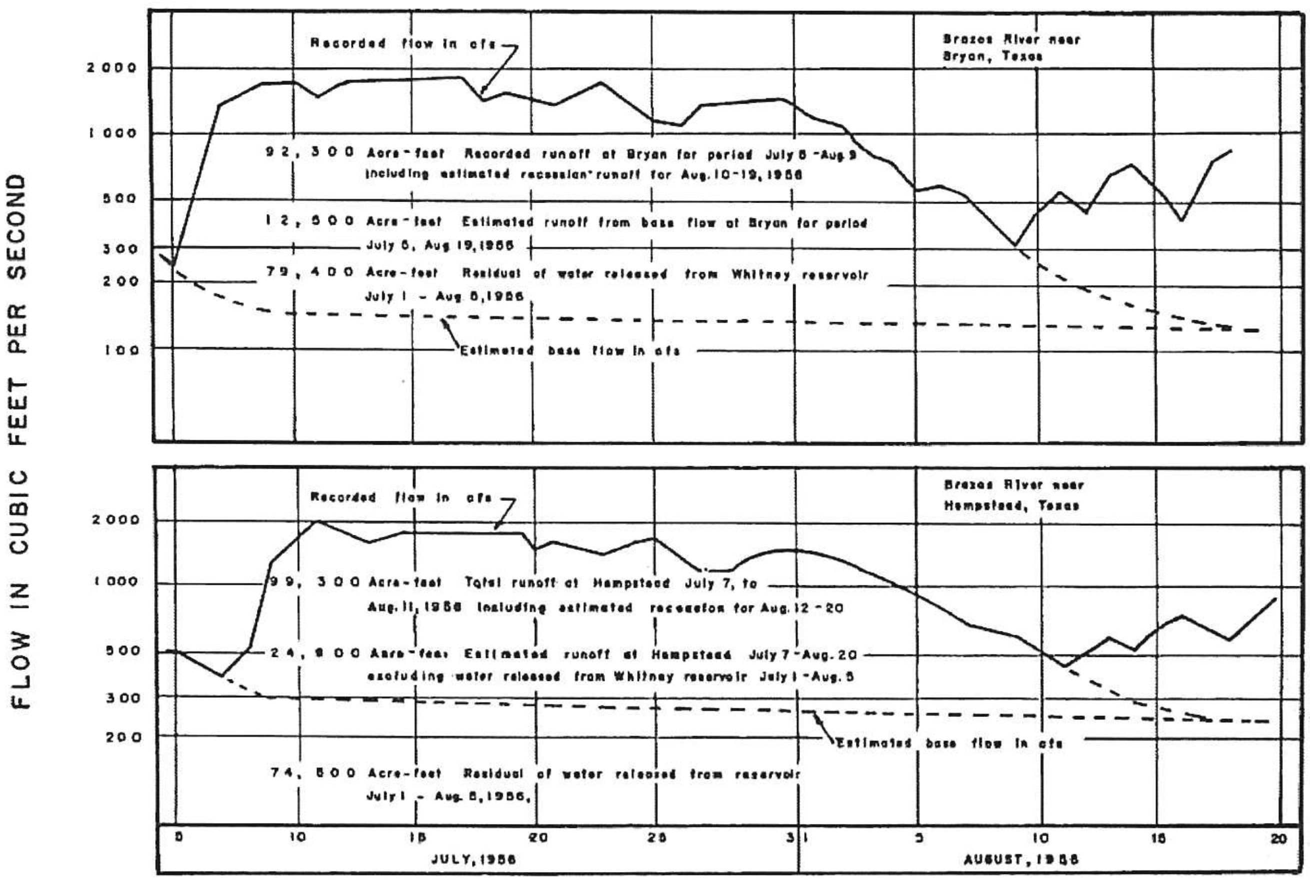

FIGURE 19.- DISCHARGE HYDROGRAPHS, BRAZOS RIVER NEAR BRYAN AND NEAR HEMPSTEAD, TEX. - 1956.

Rainfall was very light during this period. The main tributaries on which gaging stations are located indicated contributions as follows: Above Waco the gages on North Bosque at Clifton and Aquilla Creek near Aquilla recorded zero flow for both July and August; Little River at Cameron had a maximum day of 3.4 cfs and contributed 120 acre-feet for the complete period; Navasota River near Bryan had a maximum day of 4.6 cfs and contributed a total of 33 acre-feet for the period; and Yegua Creek near Somerville recorded zero flow for July and August.

DELIVERY OF WATER FROM BELTON RESERVOIR TO THE BRAZOS RIVER GAGING STATION AT RICHMOND, TEXAS, BY WAY OF THE LEON, LITTLE AND BRAZOS RIVER CHANNELS *
1956

Introduction

Beginning Nov. 1, 1956 and ending Dec. 14, 1956, the Corps of Engineers, in cooperation with the Brazos River Authority, released 73,000 acre-feet of water (as measured at the gaging station on Leon River near Belton) from the Belton Reservoir for industrial use in the vicinity of Freeport, Tex. (See fig. 20) The need for this water at Freeport came as a result of the prolonged drought conditions causing flows in the Brazos River in the vicinity of Freeport to be insufficient to satisfy the industrial and other uses of vital importance.

Purpose

The purpose of this report is to show the quantity of water released from the Belton Reservoir, the time of its travel downstream to Richmond, and the quantity of released water reaching the gaging station on Brazos River at Richmond, Tex.

The reservoir water traversed 342 miles of river channel before it reached the Richmond gaging station. Analysis of the streamflow records shows that about 54,300 acre-feet of the released water reached Richmond. The quantity of water reaching the Juliff station and other points downstream from Richmond could not be determined because of the lack of records of diversion and other basic data between Richmond and Juliff, essential for a complete analysis.

The gaging stations, operated cooperatively by the Geological Survey, the Brazos River Authority, the Corps of Engineers, U. S. Army, and the Board of Water Engineers, recorded the flow as the water was released from Belton Reservoir and also when it passed gaging stations on Little River at Cameron and on the Brazos River near Bryan, near San Felipe, at Richmond, and near Juliff. The study of this flow was complicated by rises resulting from rainfall occurring at the beginning and end of the period of release; consequently,

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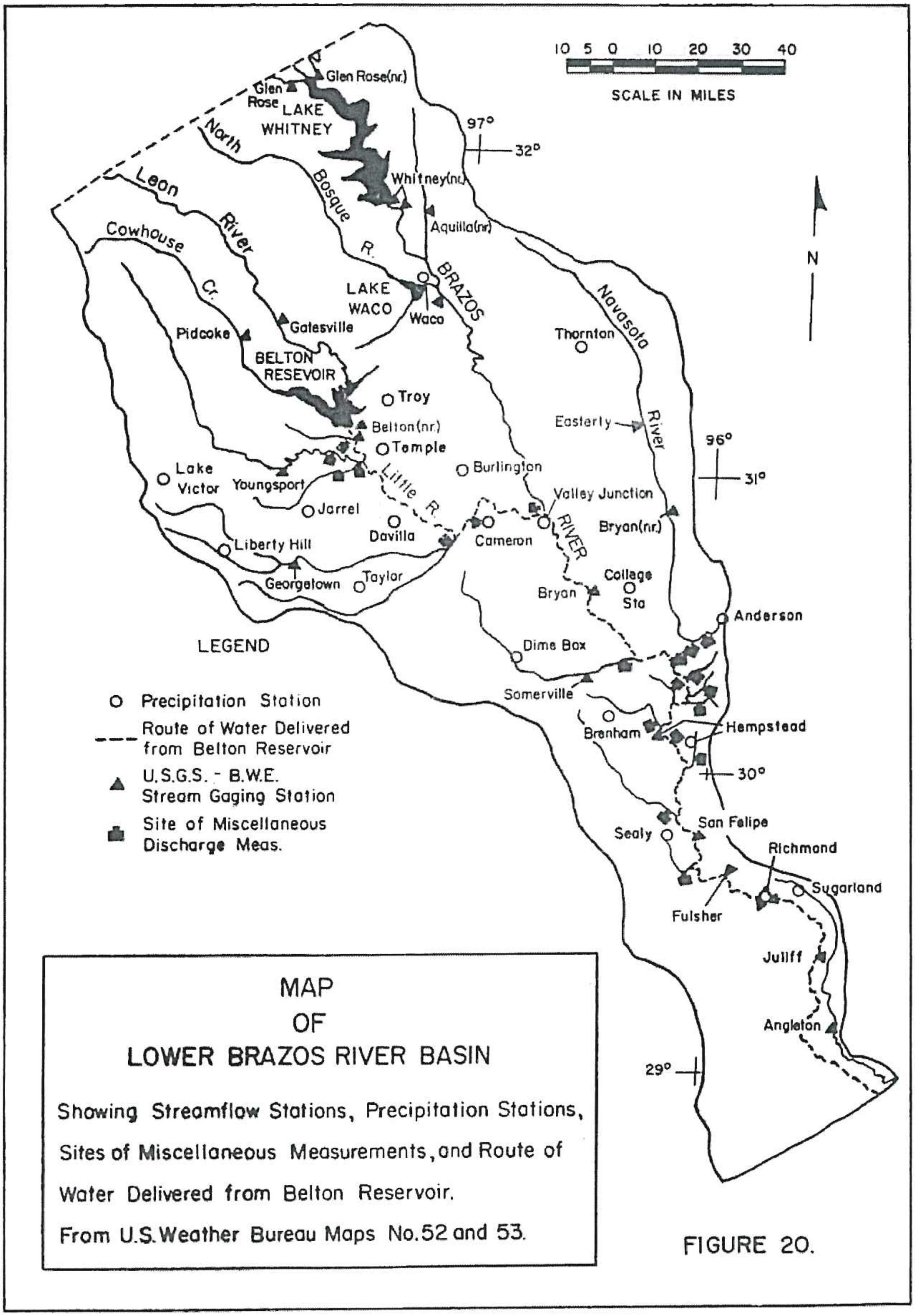
* U. S. Geological Survey Open File Report No. 57 by D. E. Havelka and E. M. Parten



MAP
OF
LOWER BRAZOS RIVER BASIN

Showing Streamflow Stations, Precipitation Stations, Sites of Miscellaneous Measurements, and Route of Water Delivered from Belton Reservoir.

From U.S. Weather Bureau Maps No. 52 and 53.

FIGURE 20.

records of discharge during periods of steady flow of the water released at Belton were used when possible as basic data in the study.

Records for the Brazos River gaging station near Juliff, which is 26 river miles downstream from the gaging station at Richmond, were omitted from this study because the amount of diversions was unknown between the Richmond and Juliff gaging stations. Streamflow data used in this study were analyzed to determine the following:

1. Quantity of water released from Belton Reservoir.

2. Quantity of water released from Belton Reservoir which reached the gaging station on the Brazos River at Richmond.

3. Travel time required for discharges occurring during the delivery.

Scope of Study

The reaches of the river directly involved in this study, in downstreams order, are: Leon River from the gaging station near Belton to its confluence with Little River; Little River from the mouth of Leon River to its confluence with the Brazos River; and the Brazos River from the mouth of Little River to the gaging station near Juliff. Indirectly involved are the reach of the Brazos River from Waco to the mouth of Little River, and all tributaries adding appreciable inflow to the streams named above during the period of delivery.

From a hydrologic standpoint, the losses and rates of travel determined in this study may be expected only for conditions such as those existing during the period under study, with emphasis placed on season of the year, climatic conditions, and channel conditions.

Field Work

Frequent current-meter measurements of discharge were made at each gaging station to maintain an accurate stage-discharge relation for computing the flow. Miscellaneous discharge measurements were made on the Brazos River just upstream from the mouth of Little River, and on all Brazos River tributaries contributing appreciable inflow to the reach under study. The miscellaneous measurement sites are indicated on figure 20, and the location and results of the miscellaneous measurements are shown in the following table.

Miscellaneous discharge measurements on streams contributing appreciable inflow to the released water.

Measurement Site	Location	Date of measurement	Discharge (cfs)
Nolan Creek at Belton at E. Central Ave. crossing	Lat 31°03' Long 97°28'	Dec. 6, 1956	3.18
Lampasas River 30 feet below mouth of Salado Creek	Lat 29°59' Long 97°25'	Dec. 7, 1956	15.1

(Continued on next page)

Miscellaneous discharge measurements on streams contributing appreciable inflow to the released water. (Continued)

Measurement Site	Location	Date of measurement	Discharge (cfs)
San Gabriel River 5 mi NW of Rockdale, at FR 487	Lat 30°44' Long 97°03'	Dec. 5, 1956	0.43
Elm Creek near Cameron at State Hwy 77 & US Hwy 190	Lat 30°54' Long 96°59'	Dec. 4, 1956	0.83
Brazos River above Hwy 190 above Little River nr. Hearne	Lat 30°52' Long 96°42'	Dec. 27, 1956	108
Brazos River nr. Hearne, at US Hwy 190 & above Little R.	Lat 30°52' Long 96°42'	Dec. 4, 1956	87
Yegua Creek near Clay, at FR 50	Lat 30°22' Long 96°21'	Dec. 3, 1956	No flow
Navasota River nr. Hwy 6 near Navasota	Lat 30°25' Long 96°06'	Dec. 3, 1956	6.76
Navasota River nr. Hwy 6 near Navasota	Lat 30°25' Long 96°06'	Dec. 23, 1956	22.7
Walker Creek near Washington	Lat 30°17' Long 96°05'	Nov. 27, 1956	No flow
Doe Run near Washington	Lat 30°13' Long 96°09'	Nov. 27, 1956	do
Jackson Creek near Hempstead	Lat 30°12' Long 96°10'	Nov. 27, 1956	do
New Year Creek near Chapel Hill	Lat 30°08' Long 96°12'	Nov. 27, 1956	do
Caney Creek near Hempstead	Lat 30°04' Long 96°09'	Nov. 28, 1956	do
Piney Creek near Sunnyside	Lat 29°57' Long 96°09'	Nov. 28, 1956	do
Eight Mile Creek near Sealy	Lat 29°40' Long 96°03'	Nov. 28, 1956	do
Big Creek near Lochridge	Lat 29°23' Long 95°35'	Nov. 28, 1956	do

Other small creeks with no names shown on figure 20 were investigated and found to have no flow.

Weekly visits were made to each regular gaging station involved and water-stage recorder charts were removed for use in preparing weekly reports furnished to cooperating agencies.

In general, the field work was coordinated so as to obtain regular and miscellaneous discharge measurements at the same time the water-stage recorder charts were removed. After the water release was stopped and base-flow conditions were resumed, the water-stage recorder charts were removed and low-flow measurements were made at all gaging stations to determine base flow at each station. Local gage observers reported daily gage heights at all stations.

Rainfall

As mentioned above, the basic records used in this report were considerably complicated by inflow from rainfall at the beginning and end of the period of release. The table following shows the significant rainfall occuring during November and December 1956 on watersheds within the area of this report.

Rainfall in inches at selected stations from Climatological
Data published by the U. S. Weather Bureau.

Precipitation Station	November 1956						December 1956					
	2	3	4	5	6	15	18	19	20	21	22	23
Little River basin below Belton Reservoir												
Temple	0.24	0.29	1.22	0.53			0.41	1.29	0.51			
Davilla	1.42	0.40	0.65				0.37	1.79	0.45			
Troy	0.56	0.50	0.85				1.40	0.70		0.15		
Burlington		0.75	1.65	0.22				1.10	0.36			
Cameron	0.69	0.20	0.95	0.15			1.30	0.22				
Lake Victor							2.00	0.25		0.20		
Liberty Hill												
Taylor	0.10	0.50	0.24				0.16	1.98	0.44			
Jarrell	0.65	0.20	2.15	0.55	0.10		0.20	1.07	0.58			0.10
Brazos River basin above Little River												
Waco, WB-AP	0.54	1.02	0.77				0.83	1.03				
Brazos River basin below Little River												
Valley Junction		0.59	0.30	0.70			0.43	0.90	0.19			
Brenham		0.62	0.70	0.23			2.15	0.68	0.20		0.22	1.83
Hempstead		0.25	2.44	0.22			1.45	0.27			0.53	0.91
Sealy		0.52	0.23	0.10			2.92	0.16		0.88	0.43	
Richmond		0.37	0.17				1.92	0.74			1.09	
Sugarland		0.29				0.75	1.45	0.33			1.10	
Dime Box	0.20	0.52	0.48				1.90			0.35	0.38	0.13
Thornton		1.09	0.80	0.85	0.12			1.14	0.18			
College Station	1.03	0.38	0.30	0.12			1.15	0.11		0.15	0.30	
Anderson	0.43	1.58	0.48	0.12			1.73			0.22	2.23	
Brenham		0.62	0.70	0.23		0.15	2.15	0.68	0.20		0.22	1.83
Sealy		0.52	0.23	0.10			2.92	0.16		0.88	0.43	

The rises from rainfall shown in the table above unfortunately arrived at the gaging stations when water released from Belton Reservoir was passing with the exception of the Cameron station, where the release water preceded the rise resulting from rainfall by about one day. (See fig. 21) This fact, combined with very good discharge measuring conditions at the Cameron station, greatly facilitated the separation of the released water from flood water, as well as the determination of the time of travel for all types of flow involved.

Daily and Weekly Reports During Period of Water Release

A daily report of flow at each station was compiled from previously defined stage-discharge relation curves and from once-daily gage readings received from local observers by long-distance telephone. This information (subject to later revision) was furnished immediately to cooperating agencies. In addition, a summary of daily flow at all gaging stations was furnished to cooperating agencies at the end of each week. These data were used by the Corps of Engineers and the Brazos River Authority to regulate the amounts of water released to conform with water losses and variations in travel time of water.

After the release had been completed a final summary of daily discharge

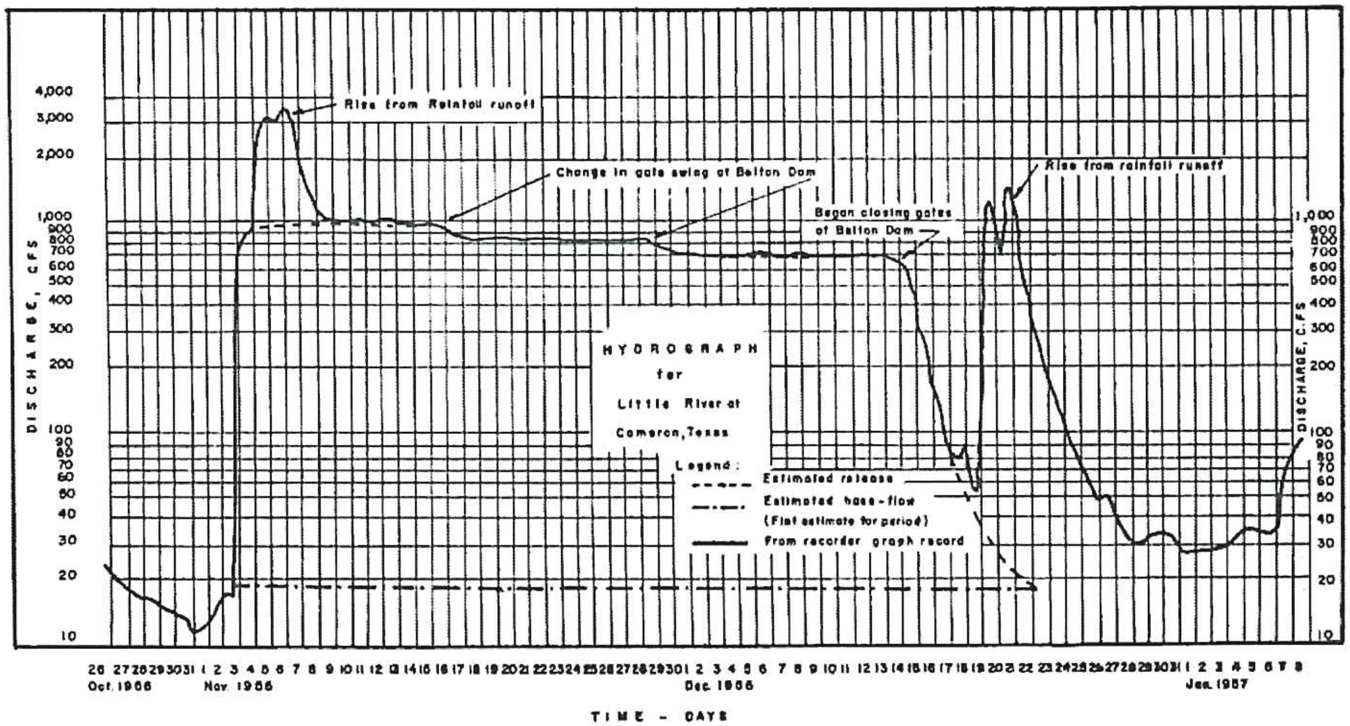


FIGURE 21.-DISCHARGE HYDROGRAPH, LITTLE RIVER AT CAMERON, TEX.-1956.

(USGS form 9-192a) was prepared for each gaging station covering the entire period of the release. These summaries, combined with actual current-meter measurements, were the basic data used in this study.

Discussion

Very early in the study of this flow-routing investigation, it became obvious that this, and probably most other similar flow-routing investigations, must be treated as special cases with emphasis placed on the following prime factors:

1. Current season of the year
   a. Regarding growth period of phreatophytes
   b. Regarding ground-water conditions affecting base flow.
   c. Regarding inflow from rainfall

2. Condition of river channels
   a. Regarding the flow existing in the channels before and during the period of the routing
   b. Regarding existing river-bed characteristics

This investigation was complicated by a considerable amount of flood inflow resulting from rains soon after release of water began, as well as at the end of the release period, and by some diversions between the stations near San Felipe and at Richmond. Also, during the time this release was in progress, other small intermittent releases were being made from Lake Whitney on the Brazos River upstream from Waco. (See fig. 23) It may be noted by inspecting the discharge hydrographs (fig. 21-26) that periods of low flow existed prior to and following the period of release, and that several long periods of steady flow existed at all gaging stations during the release. These steady-flow periods provided important data for determining water losses between Belton Reservoir and the gaging station on Brazos River at Richmond.

The typical discharge recession curve for Richmond (fig. 27) was based partly on rises following the release and partly on previous rises of a comparable magnitude for the same season of the year, and was used to define the flood-flow recession hydrograph comprising the upper limits of base flow for rises which were partly obscured by the release water. The lower limits of base flow for each station were determined from a study of low-flow records for each station prior to and following the release.

An account of inflow from Brazos River tributaries contributing appreciable amounts of water was obtained by miscellaneous discharge measurements.

Although no seepage investigation has been made on the Brazos River reach considered in this report, the following statement from the Austin, Tex. office of the Ground Water Branch of the U. S. Geological Survey is an indication of the inflow from ground water affecting base flow for this reach of the Brazos River.

> "We have made no detailed studies along the Brazos River, but based on general knowledge of hydrologic conditions in the area, we can make the following general statements:

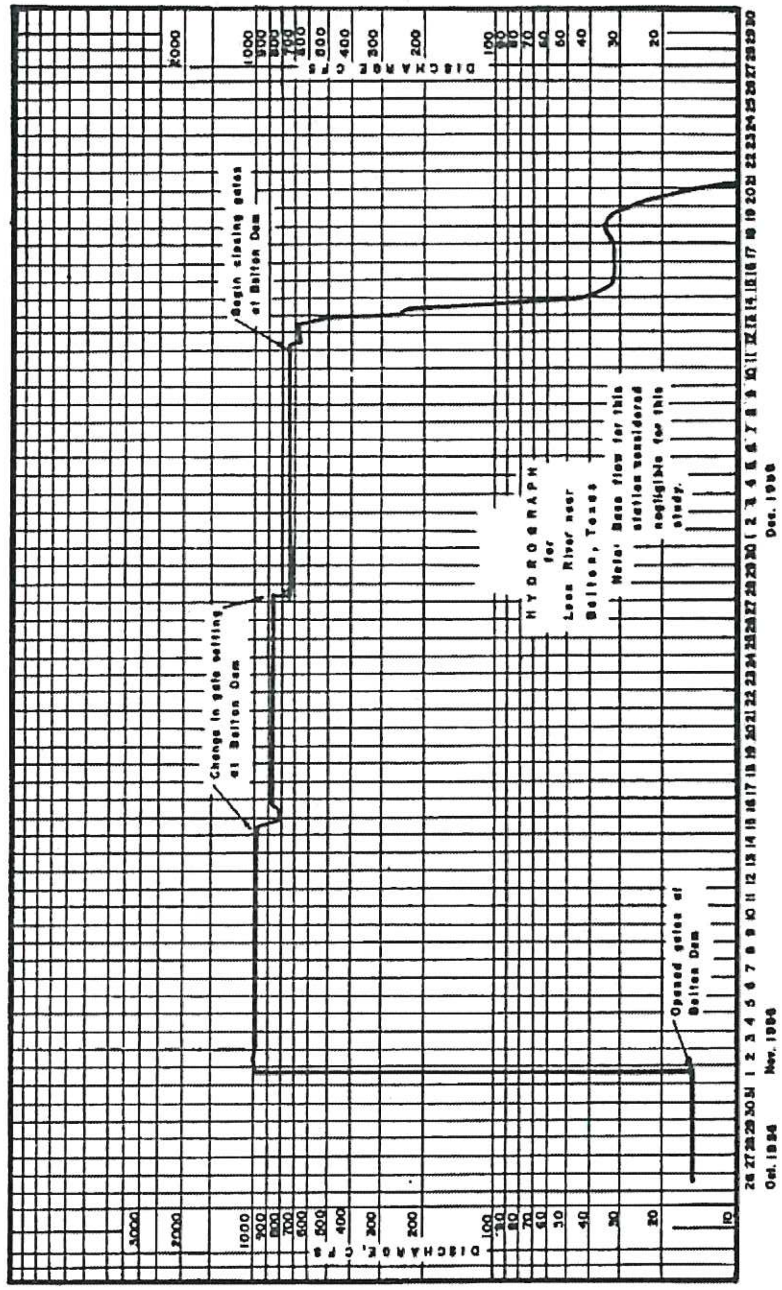


FIGURE 22.-DISCHARGE HYDROGRAPH, LEON RIVER NEAR BELTON, TEX.-1956.

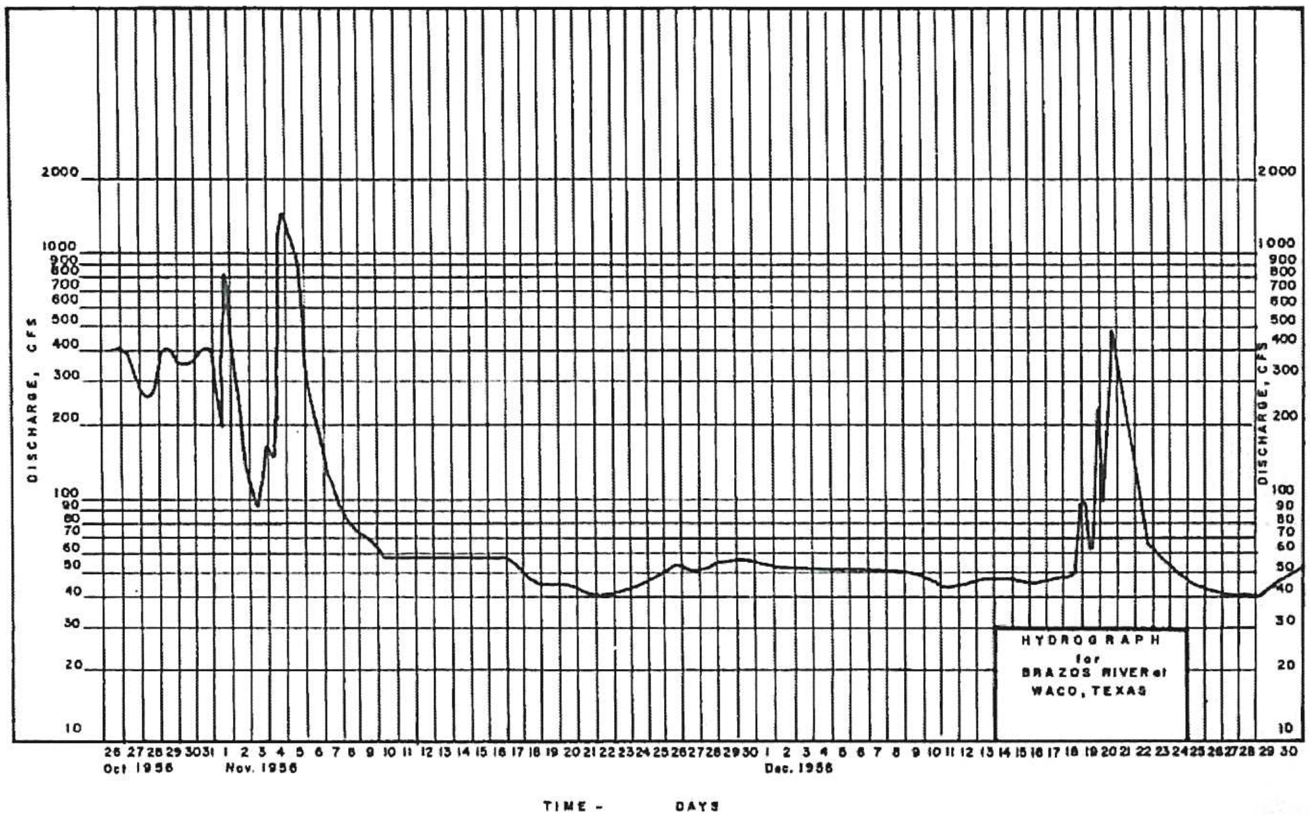


FIGURE 23.- DISCHARGE HYDROGRAPH, BRAZOS RIVER AT WACO, TEX.-1956.

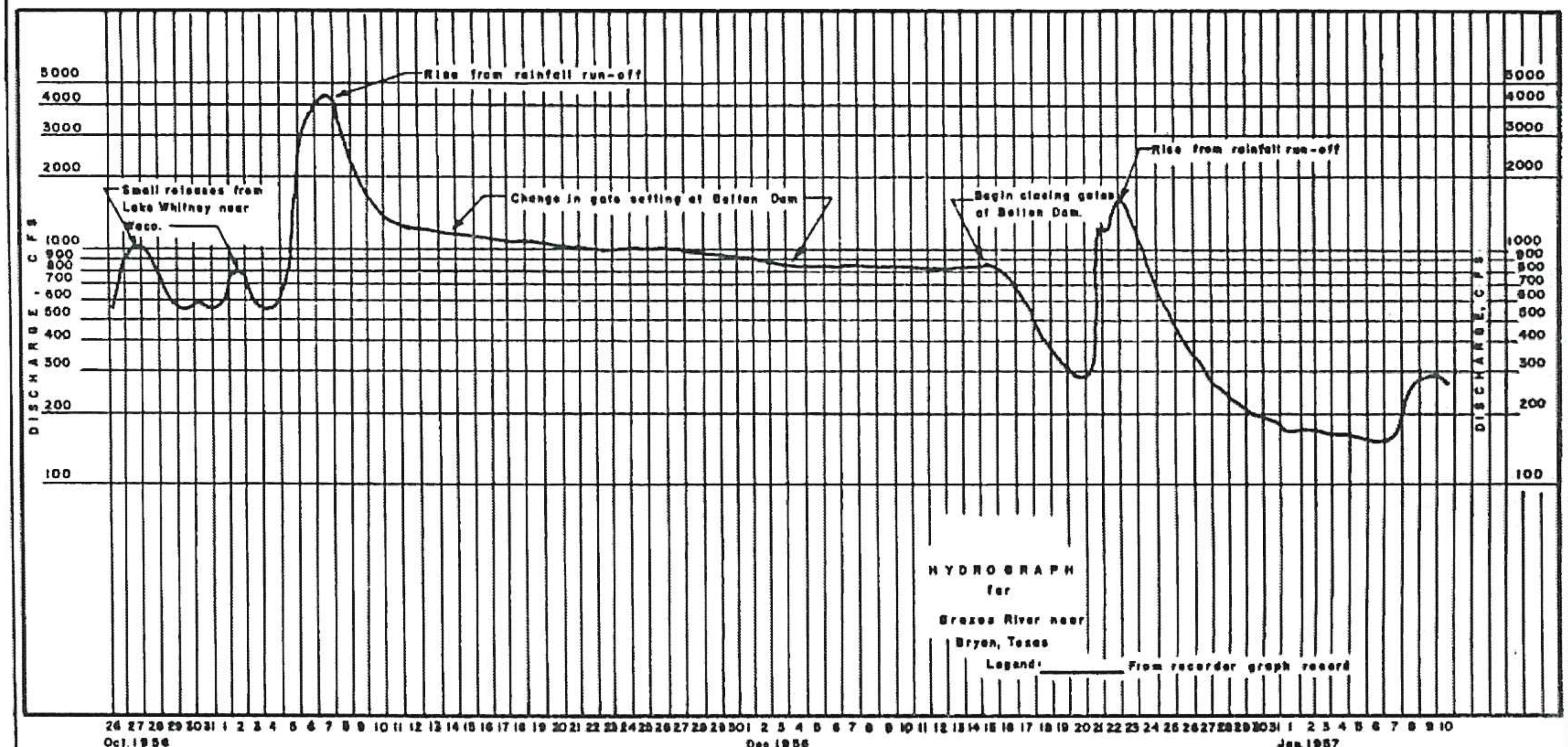


FIGURE 24.-DISCHARGE HYDROGRAPH, BRAZOS RIVER NEAR BRYAN, TEX.-1956.

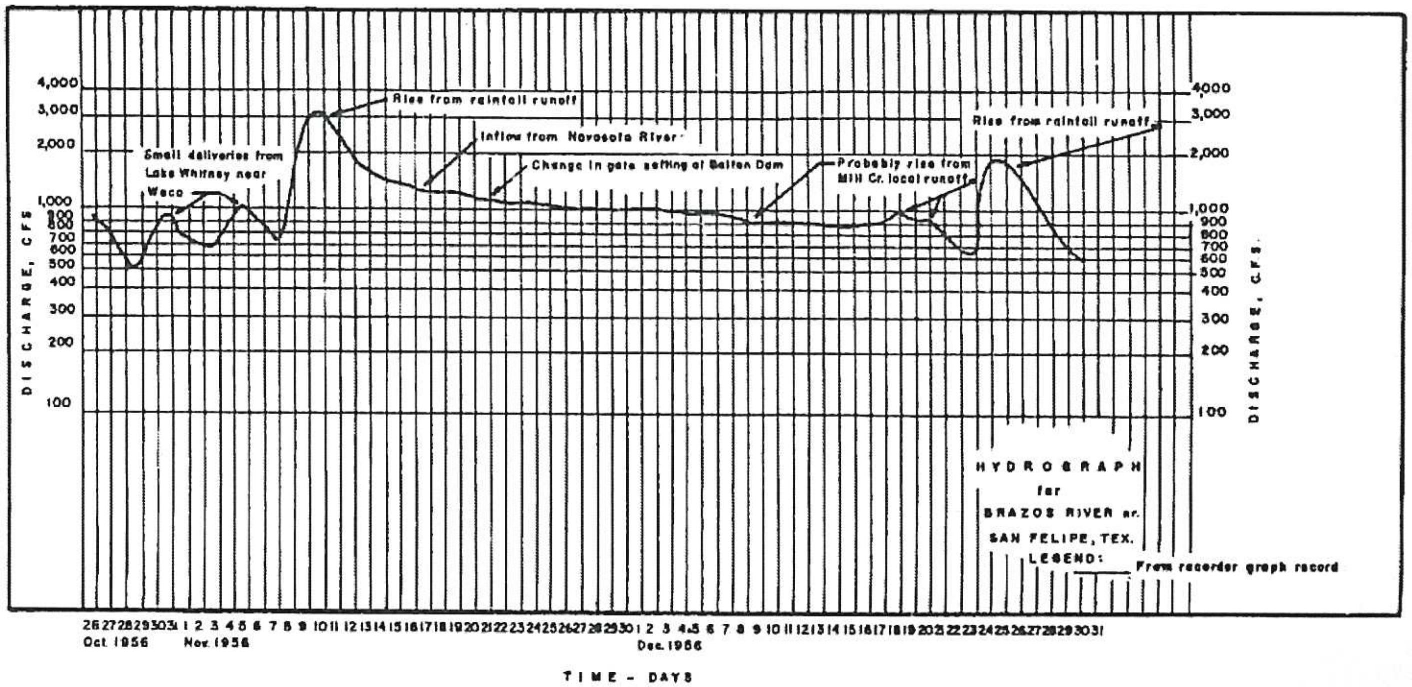


FIGURE 25.-DISCHARGE HYDROGRAPH, BRAZOS RIVER NEAR SAN FELIPE, TEX.- 1956.

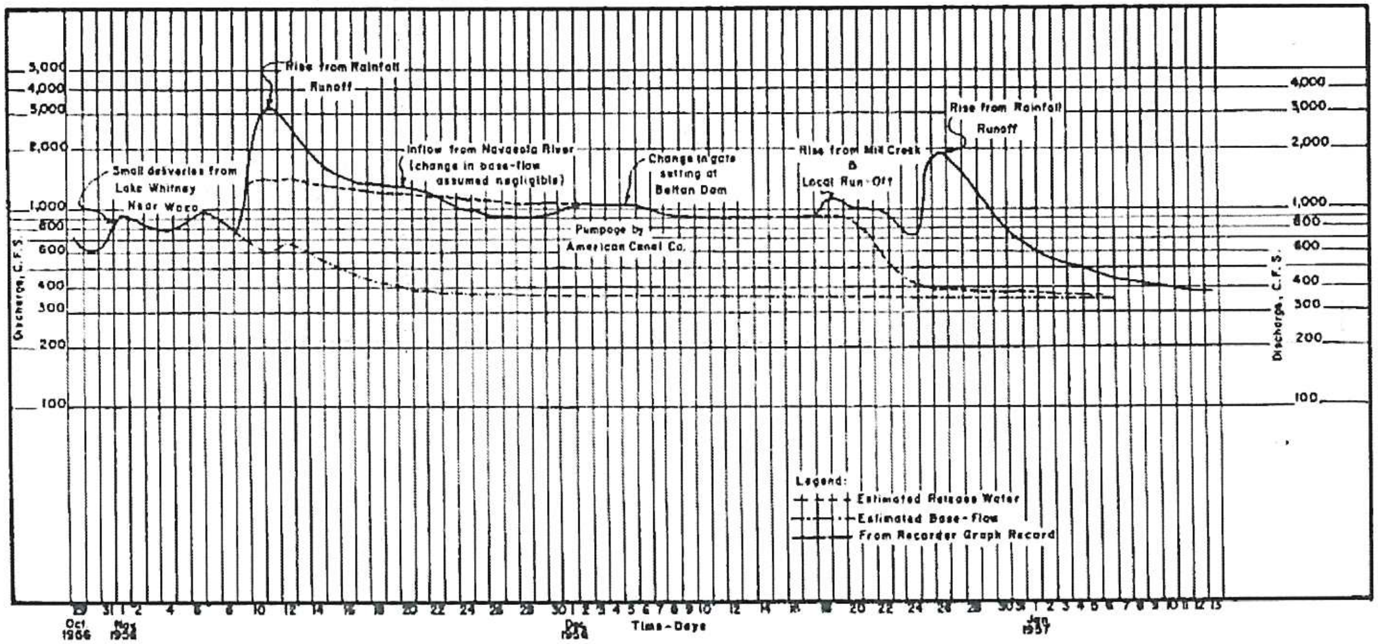


FIGURE 26.- DISCHARGE HYDROGRAPH, BRAZOS RIVER AT RICHMOND, TEX.-1956-57.

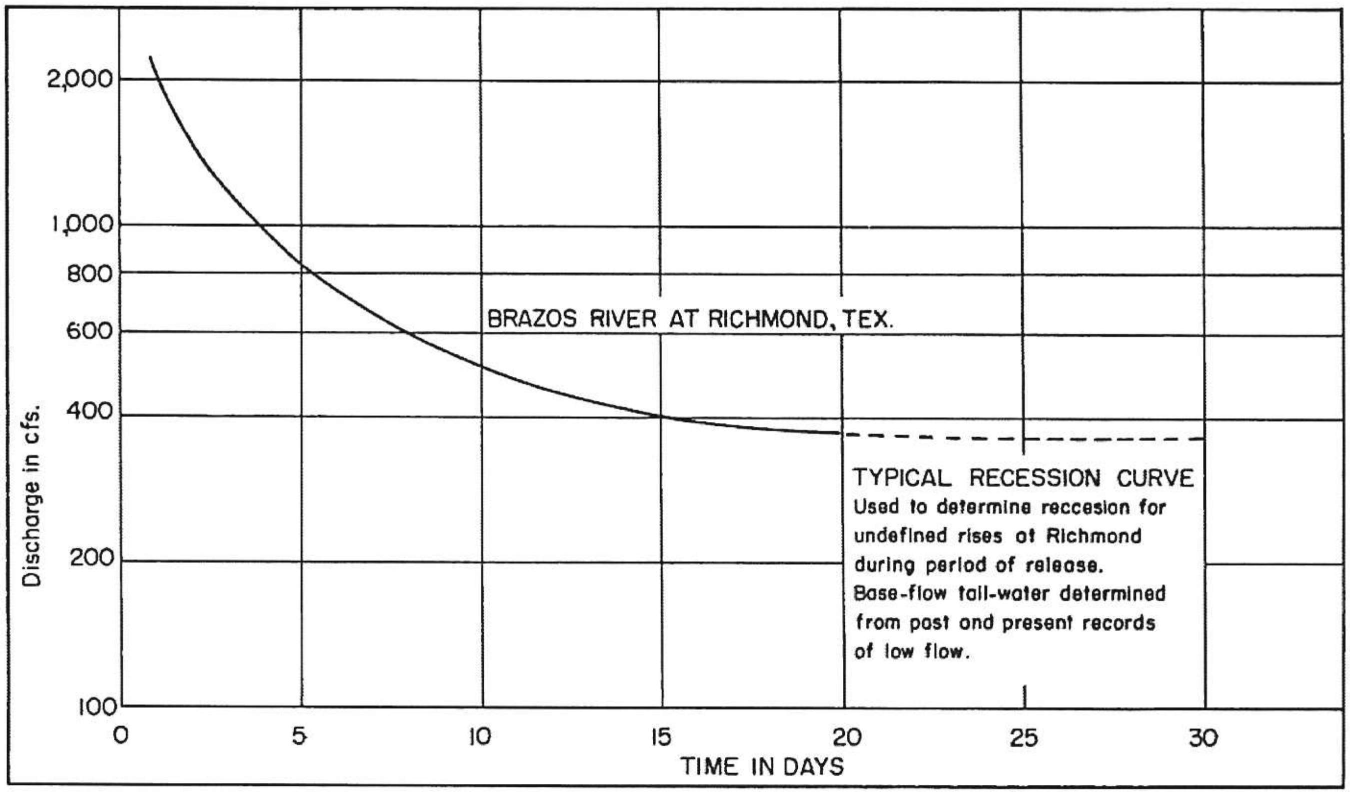


FIGURE 27.- TYPICAL RECESSION CURVE, BRAZOS RIVER AT RICHMOND, TEX.

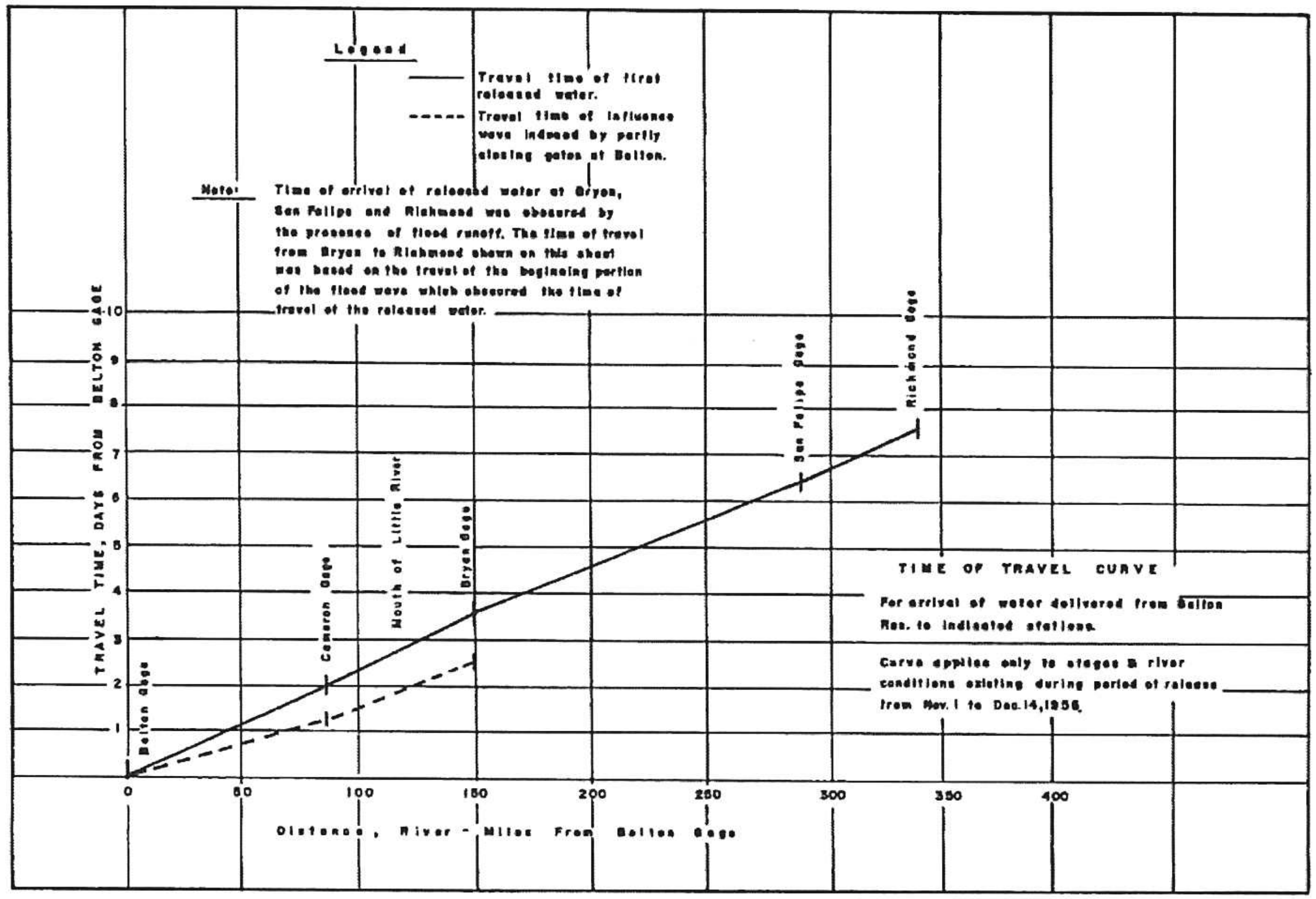


FIGURE 28.- TIME OF TRAVEL CURVE, BELTON TO RICHMOND, TEX.-1956.

connected with delivering water through the reaches of the above-named river channels. The results of each phase of the water-separation study were combined to form a simple graphic analysis of the flow involved. The net accumulated losses from Belton to the Richmond station were obtained by separating the basic types of flow, namely, release, base flow, pumpage, and rainfall-runoff, into their proper category by comparing their respective ordinates on the hydrograph for each day throughout the period of release. (See fig. 29)

Conclusions

Upon the completion of this study of the water released from Belton Reservoir from Nov. 1 to Dec. 14, 1956 the following conclusions were drawn:

1. Each flow-routing investigation must be treated as a special case with emphasis placed on the prime factors as mentioned in first paragraph of Discussion.

2. The time of travel of the first portion of a flood wave is considerably more in many cases than that required for an influence wave as defined in this report.

3. The quantity of water released from Belton Reservoir and reaching the gaging station on Little River and on the Brazos River near Richmond is shown in the following table.

Quantity of water released from Belton Reservoir reaching streamflow stations as indicated

Station	Period of flow 1956	Belton Res. release water reaching indicated station	Percent of release water reaching indicated station
Leon River nr. Belton	Nov. 1 to Dec. 15	72,800 acre-ft.	100
Little River nr. Cameron	Nov. 3 to Dec. 19	69,900 do	96
Brazos River nr. Richmond	Nov. 19 to Dec. 30	54,300 do	74

Accuracy of Field Data and Computed Results

Application of records - The computation of quantities of released water reaching the Richmond gaging station was made complex because an estimate of base flow and flood inflow had to be made. The accuracy of these estimates is classified as "fair", or they are subject to errors of 15 percent or more.

Basic records - The basic records or total flow at all gaging stations and the miscellaneous measurements of flow of tributaries have an accuracy rating of "excellent", or the error in the total runoff past each gaging station is believed to be within 5 percent.

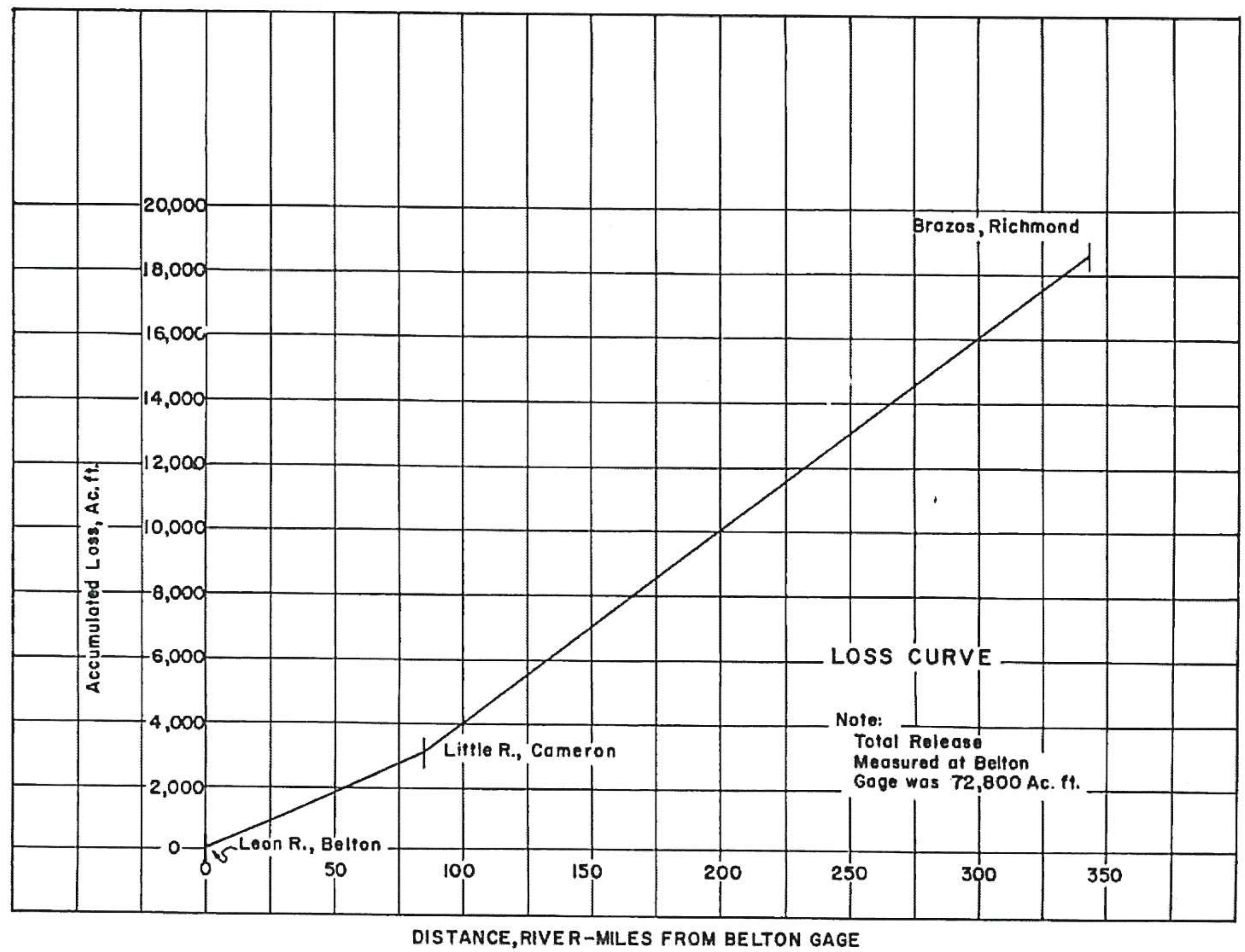


FIGURE 29.- LOSS CURVE, BELTON TO RICHMOND, TEX.-1956.

DELIVERY OF WATER FROM BROWNWOOD RESERVOIR TO WHARTON, TEXAS * JUNE AND JULY 1934

Introduction

The Bay City Water Company entered into an agreement with Brown County Water Improvement District No. 1 for the release of water from Brownwood Reservoir on Pecan Bayou ten miles upstream from Brownwood, Tex., for the purpose of irrigating rice along the Colorado River near Bay City, Tex. The first water was released on June 27, 1934.

Purpose

The purpose of this report is to show the quantity of water released from Brownwood Reservoir, the time of its travel downstream to Wharton, and the quantity of released water reaching Wharton.

Scope of Study

The reaches of the streams directly involved in this study are along Pecan Bayou from the stream-gaging station at Brownwood to its mouth, thence along the Colorado River from the mouth of Pecan Bayou to the temporary stream-gaging station at Wharton; a total distance of 458 river miles.

In addition to the gaging station at Brownwood, the U. S. Geological Survey in cooperation with the Texas Board of Water Engineers maintained during this period regular gaging stations on the Colorado River near San Saba, near Tow, at Austin, at Smithville, and near Eagle Lake. For the special study of this released water, temporary gages were established on the Colorado River at Columbus, Garwood, and Wharton. All gages were equipped with continuous water-stage recorders. The gages at Garwood and Wharton were discontinued on July 16 and at Columbus on July 17. The records at the temporary gages were used only for a study of time intervals and losses for the first part of the water released. The

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* From an unpublished report by Seth D. Breeding, Hydraulic Engineer, U. S. Geological Survey, 1934.

discharge records at the stations near San Saba and at Smithville were not used in a study of losses as they appeared to be somewhat in error.

Results

Fifty-six percent of the first 10,600 acre-feet of released water was lost between Brownwood and Eagle Lake, and 70 percent was lost between Brownwood and Wharton. Thirty-three percent of the first 65,900 acre-feet of released water was lost between Brownwood and Eagle Lake. Study of the time interval table in connection with the hydrograph for Pecan Bayou at Brownwood will indicate a number of conditions affecting the rate of water travel.

The accompanying table and hydrographs (figs. 30 and 31) show in considerable detail the losses and time intervals of various portions of the released water. In determining the loss for the first 10,600 acre-feet released, it was necessary to estimate the latter part of the graph at Columbus and below as the second water released began to overtake the first. Also, it was necessary to estimate the ordinary flow at each station during the period of study of losses. No large error is considered to have been introduced by these estimates.

Discussion

During the period June 27 to July 2, 10,600 acre-feet of water was released. On July 2 the flow had been reduced to 30 cfs (cubic feet per second) at the Brownwood gaging station. The reservoir gates were opened again on July 3 to release another increment of the purchased water and, due to an accident to their mechanism, the gates could not be closed. This permitted all of the stored water, 71,800 acre-feet as measured at the Brownwood gaging station, to drain from reservoir. The rate of released varied as numerous attempts were made to close the gates. The amount and rate of release is best shown by the accompanying hydrograph which was obtained from record of discharge at the gaging station on Pecan Bayou at Brownwood, ten miles below Brownwood Reservoir.

The only diversions of consequence between the point the water was released and the point it was to be used below Wharton are four pumping plants - Lakeside Irrigation Company near Eagle Lake, Garwood Irrigation Company at Garwood, Wilson Bros. Pumping Plant 10 or 12 miles below Garwood, and Pierce Estate Pumping Plant 3 miles above Wharton. These plants continued to divert the same quantity of water after the released water arrived as had been diverted prior to the arrival of that water until the increased flow due to the jamming of the reservoir gates had arrived. The plants were then permitted to divert to capacity.

A number of small diversions, including that of the city of Austin, were also being made during this time. These diversions were probably a constant amount both before and during the period of flow of the released water and are, therefore, taken care of as the ordinary flow at each station is eliminated.

During the period under study, regular gaging stations were also maintained on Colorado River near Milburn, San Saba River at San Saba, Llano River near Castell, and Pedernales River near Spicewood. Neither the discharge records at these stations nor the available rainfall records indicate that there was any

STATION	LOSSES: Period of Flow Studied	LOSSES: A/V Volume in Acre-ft	LOSSES: Percent Lost	LOSSES: Period of Flow Studied	LOSSES: A/V Volume in Acre-ft	LOSSES: Percent Lost	TIME INTERVALS: Distance Downstream	Fall in feet per mile	Travel of first water released (1): Time interval between stations	Travel of first water released (1): Time interval from Brownwood	Travel of first water released (1): Ordinary flow in Cfs	Travel of first peak (2): Time interval between stations	Travel of first peak (2): Time interval from Brownwood	Travel of first peak (2): Flow at peak in Cfs	Travel of second water released (3): Time interval between stations	Travel of second water released (3): Time interval from Brownwood	Travel of second water released (3): Flow at arrival of water in Cfs	Travel of second peak (4): Time interval between stations	Travel of second peak (4): Time interval from Brownwood	Travel of second peak (4): Flow at peak in Cfs	Travel of third peak (5): Time interval between stations	Travel of third peak (5): Time interval from Brownwood	Travel of third peak (5): Flow at peak in Cfs	Travel of fourth peak (6): Time interval between stations	Travel of fourth peak (6): Time interval from Brownwood	Travel of fourth peak (6): Flow at peak in Cfs
Pecan Bayou at Brownwood, Tex.	June 27 to July 2	10,600	0	June 27 to July 20	63,900	0	0 mi			0	0		0	3,590		0	30		0	2,470		0	3,420		0	3,280
								3.15	36 hrs			33 hrs.			36 hrs.			35 hrs			34 hrs.			31 hrs.		
Colorado River near San Saba, Tex.							70 mi			36 hrs	70		33 hrs	2,580		36 hrs	95		35 hrs	2,380		34 hrs	2,640		31 hrs.	3,100
									18 hrs			16 hrs			22 hrs			13 hrs			14 hrs			11 hrs.		
Colorado River near Tow, Tex.				June 30 to July 22	61,800	6.2	114 mi	3.65		54 hrs	100		49 hrs	2,330		58 hrs	142		48 hrs	2,250		48 hrs	2,840		42 hrs	3,300
									77 hrs			90 hrs.			62 hrs			69 hrs			56 hrs			50 hrs		
Colorado River at Austin, Tex.				July 3-25	54,100	18	255.5 mi			131 hrs	148		139 hrs	1,360		120 hrs	330		117 hrs	1,660		104 hrs.	2,320		92 hrs.	3,190
								2.06	53 hrs			54 hrs			45 hrs			50 hrs						35 hrs.		
Colorado River at Smithville, Tex.							328.5 mi			184 hrs	195		193 hrs.	1,160		165 hrs	442		167 hrs.	1,540					127 hrs	2,960
								1.62	51 hrs			57 hrs			46 hrs											
Colorado River at Columbus, Tex.	July 7-16	5,100	52				400.5 mi			235 hrs	255		250 hrs.	902		211 hrs	516							47 hrs		
									13 hrs			18 hrs			10 hrs											
Colorado River near Eagle Lake, Tex.	July 8-15	4,620	56	July 8-30	44,000	33	418.5 mi.			248 hrs	20		268 hrs	896		221 hrs	585								174 hrs.	2,890
								1.53	18 hrs			8 hrs			8 hrs											
Colorado River at Garwood, Tex.	July 8-17	3,990	62			'	430.5 mi			266 hrs	4		276 hrs.	512		229 hrs	223									
									30 hrs			15 hrs			22 hrs											
Colorado River at Wharton, Tex.	July 10-19	3,130	70				457.5 mi			296 hrs	4		291 hrs	358		251 hrs.	184									

A/V- Ordinary flow at each station has been eliminated.

STUDY OF WATER RELEASED FROM BROWNWOOD RESERVOIR ON PECAN BAYOU DURING JUNE & JULY 1934, AS IT TRAVELED DOWN PECAN BAYOU & COLORADO RIVER TO WHARTON, TEXAS

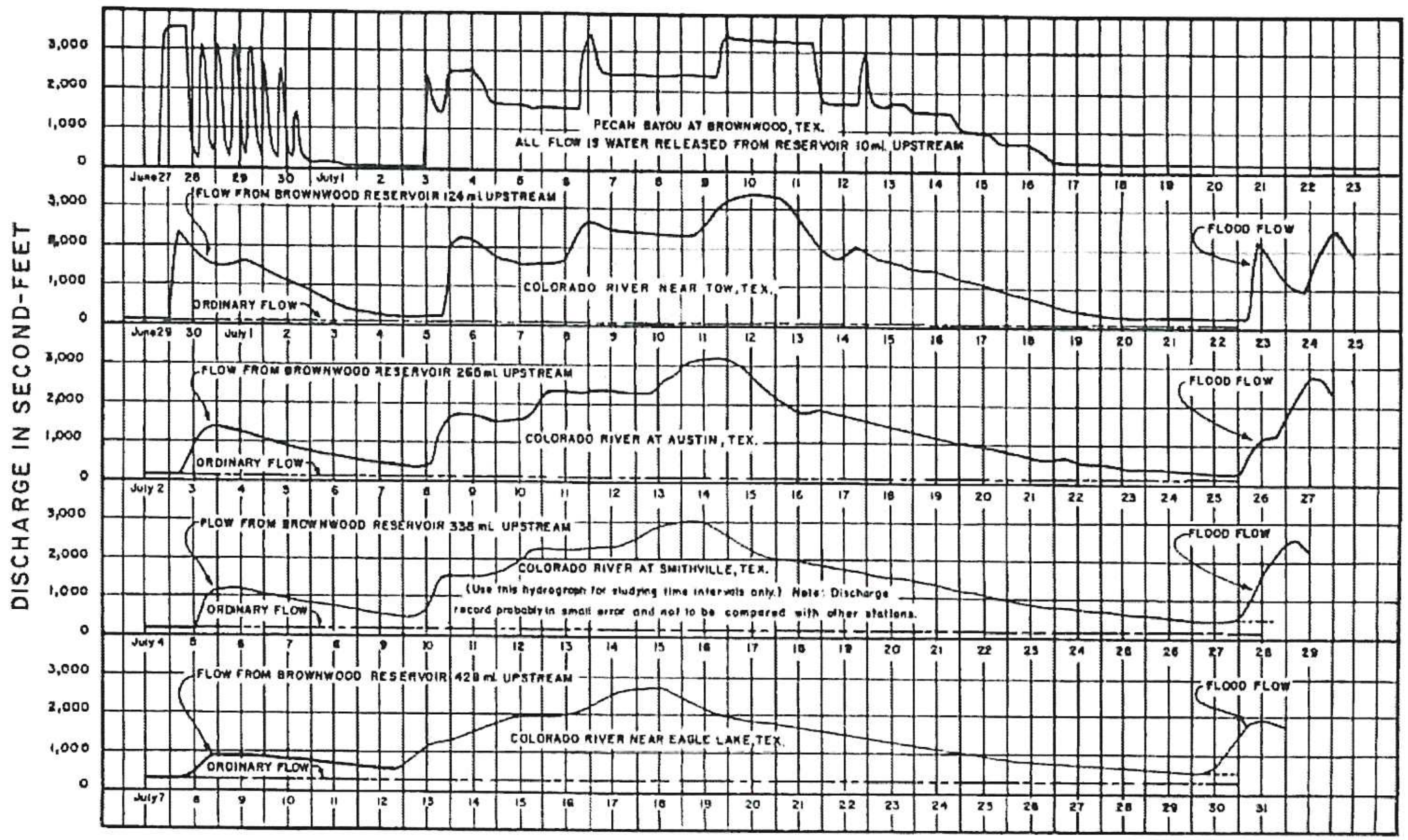

FIGURE 30. - HYDROGRAPHS: Showing Flow of Water Released From Brownwood Reservoir on Pecan Bayou During June and July, 1934.

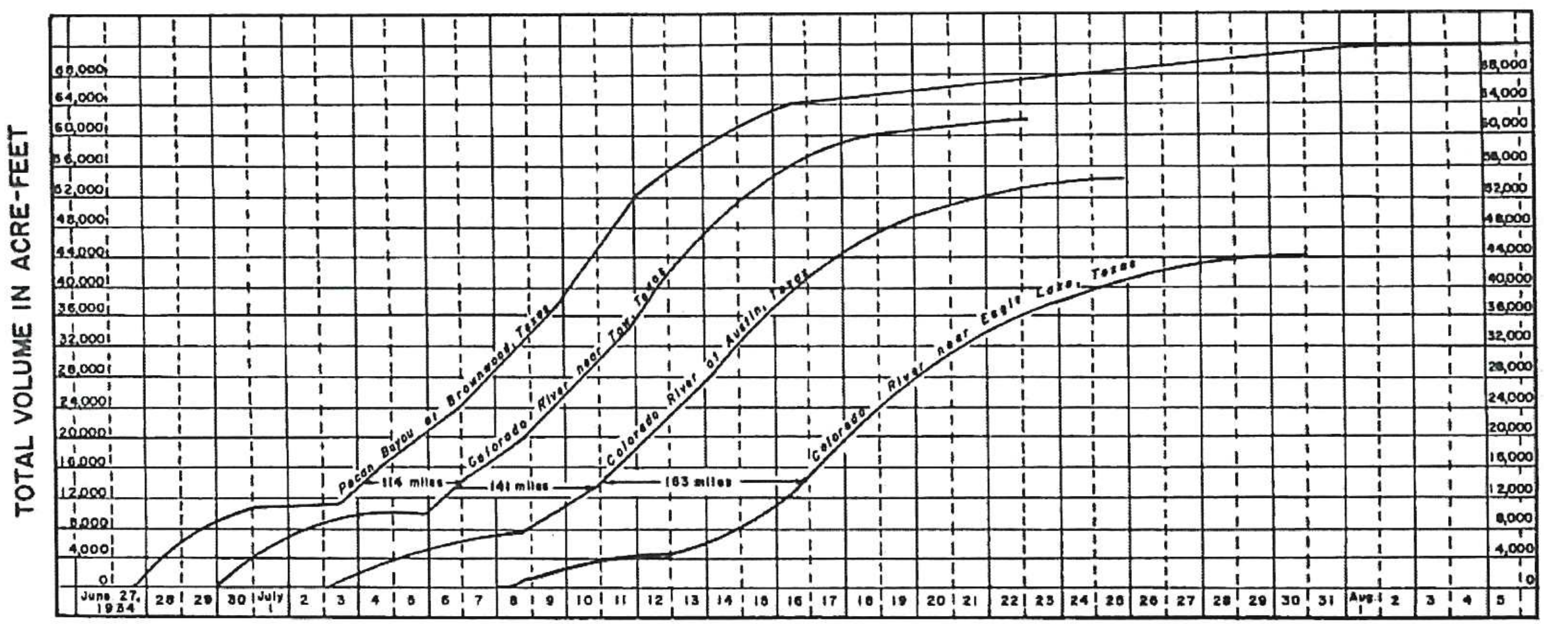

FIGURE 31. - MASS CURVES OF WATER RELEASED FROM BROWNWOOD RESERVOIR WITH NORMAL FLOW ELIMINATED

surfact runoff prior to July 22, that would interfere with a study of the losses in the released water. For over a month prior to the release of the water there was no rain nor rise of any great amount in any part of the stream between Brownwood and Wharton.

The appearance of floodwater in the Colorado River at the San Saba gaging station on July 22 and at later dates downstream made the study of loss in the total water released impossible. However, it was considered that the water released during the period June 27 to July 20, amounting to 65,900 acre-feet, could be followed through to Eagle Lake with fair accuracy.

DELIVERY OF WATER FROM LAKE AUSTIN TO BAY CITY, TEXAS VIA COLORADO RIVER CHANNEL * JULY 1918

Introduction and Purpose

The water stored in Lake Austin on the Colorado River just upstream from Austin, Tex., was sold through order of the Federal Cort to the Markham Irrigation Co., and J. C. Carlson, et al,, Trustees, and release of the water was ordered the first week in July 1918. The purchasers requested that the Texas Board of Water Engineers use its statutory authority to the end that the released water be allowed to flow undisturbed through the natural course of the Colorado River from Lake Austin to the purchasers just below Bay City, Tex. An engineer was sent to the lower Colorado River basin for the purpose of determining the amount of water which reached the purchasers.

Results

Data obtained during this investigation show that of 25,300 acre-feet of water released from Lake Austin, 19,000 acre-feet, or 75 percent passed Columbus (145 miles downstream) and 15,100 acre-feet, or 60 percent passed Wharton (202 miles downstream). The total quantity received by the purchaser (227 miles below Austin) was probably slightly less than that which passed Wharton, due to losses in "The Raft" and to a loss of about 9 cfs (cubic feet per second) which flowed through the "East Channel" of the river at Bay City and could not be recovered. The time of travel of first water was about five days to Columbus and seven days to Wharton.

Discussion

A falling stage had existed on the Colorado River at Austin for several days prior to the time stored water was released. The base flow of the river was determined by interpolation between discharge measurements made before the stored water was released and again after the supply in the reservoir had been exhausted and base-flow conditions were reached.

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* From an unpublished report by Glen A. Gray, District Engineer, U. S. Geological Survey, 1918.

The base flow of the Colorado River as determined at the stream-gaging station at the Congress Avenue viaduct in Austin, about three miles below the Austin Dam, was estimated as 200 cfs on July 5 before the gates of the reservoir were opened. Release of the water impounded by the Austin Dam was begun on the evening of July 5; the supply of stored water in the lake was exhausted at 3:30 p.m., July 24, On July 6, a flow of 786 cfs was measured at the Austin gaging station. This quantity, minus the estimated base flow of the river, gave 601 cfs of released water on July 6.

Discharge measurements were made at Columbus and Wharton to determine the rating curves for these stations. The daily gage heights were ascertained from the mean of two gage readings made each day by local observers. Although some error no doubt was introduced by taking the mean of two gage readings as the mean gage height for the day, the error in this case was not large, as the water was being released from the lake at a uniform rate. Thus, three base gaging stations - Austin, Columbus, and Wharton - were maintained to provide a check on the quantity of water as it progressed from Lake Austin to Bay City.

The records at Columbus and Wharton show that the first of the released water reached Columbus July 10, or five days after it had passed Austin, and that it reached Wharton two days later on July 12.

During the week ending July 13, a representative of the Texas Board of Water Engineers visited the pumping plants of the Lakeside Irrigation Company near Eagle Lake, The Garwood Irrigation Company at Garwood, The A. P. Borden Company above Wharton, and The Southern Irrigation Company at Lane City. Before the water which was released from Lake Austin arrived at these points, discharge measurements were made to determine the amount of water that each plant was diverting. It was impossible to reach the Lane City plant before the river began to rise. At the Lakeside plant it was found that preparations were being made to start operation of a new pumping unit capable of diverting 111 cfs. At first, it was thought that the operation of this new unit would divert the water released from Lake Austin, but it subsequently developed that the new plant was not completed until after the released water had passed Eagle Lake.

The various pumping plants above those which purchased the water were revisited after the rise in the river had reached them. In every case it was found that the plants were not diverting in excess of what had been diverted previously.

On July 9, previous to the arrival of the released water, the Lakeside Irrigation Company was diverting 90.1 cfs. On July 20 when the stage of the river at Lakeside plant had increased one foot, the amount of water diverted was measured and found to be 87.0 cfs.

The A. P. Borden system is equipped with a weir on its canal, and a staff gage and Bristol recorder are installed just above the weir. On July 11, a measurement was made on the crest of the weir at a stage of $16\frac{1}{2}$ inches, and it was found that 51.6 cfs was being diverted. Records kept by the engineer of this pumping plant show that the head over the weir was not increased above $16\frac{1}{2}$ inches during the period of the rise due to releasing of stored water.

On July 10, the Garwood plant was visited and a discharge measurement made of the amount of water diverted. The measurement showed that 112 cfs was being diverted at this plant through the operation of two pumps. This plant was again visited on July 17, and it was found that one pump was in operation. A third visit was made to this plant on July 20, and it was found that the operation of the plant was stopped for repairs during the morning of July 19, and according to the best estimate of the engineer-in-charge, the plant would not be operated until July 23 or 24.

On July 15, the Southern Irrigation Company plant at Lane City was visited, and a discharge measurement made of water being diverted. At that time 210 cfs was being diverted by means of two pumps. This was after the released water had reached Lane City, and the owners of the plant claimed that the quantity being pumped was less than they had previously pumped. This plant was again visited on July 18, and at this time the smaller of the two pumps had been shut down, and as indicated by the level of the water in the flume, the plant was diverting only about two-thirds of the quantity of water which was being diverted on July 15.

Between Lane City and Bay City the flow is obstructed by what is known locally as "The Raft". This obstruction held the released water to such an extent that the time which elapsed before it reached the purchasers at Bay City was longer than anticipated. On July 16, measurements were made of the two pumping plants of the Markham Irrigation Company. The measurements indicated that 294 cfs was being diverted by these two plants. It was somewhat uncertain how much of this flow was base flow of the river, and how much was flow from Lake Austin release. The manager of the company was of the opinion that the flow of 118 cfs in the Markham Canal about represented the water which was being received from Lake Austin.

The Carlson pumping plant was not receiving any appreciable amount of the Lake Austin water at this time, due to the fact that the river did not rise sufficiently below "The Raft" to cause a flow into Blue Creek on which their plant is located. For this reason the Carlson Company decided to complete a canal which would carry water from the Colorado River above "The Raft" to Blue Creek. Water was first turned through this canal on July 24, and it was estimated that 11 cfs was flowing in the canal on July 25. Work of widening and deepening the canal was continued, and a measurement on July 26 indicated a flow of 31 cfs. It was believed that with one or two more days of work on the canal, the flow would be approximately doubled, provided the river above "The Raft" remained at the stage of July 26.

On July 18, measurements were again made on the Markham Canals and they were found to be diverting 307 cfs. Shortly after these measurements were made, the Markham plant increased its diversion to the full capacity of the pumps. A measurement on one Markham Canal on July 26 showed a flow of 197 cfs. Assuming the same flow in the "Northern" Canals as measured on July 18 when the Northern pumps were operating to capacity, a total diversion of 392 cfs is shown for the Markham Company. This represented at least 223 cfs in excess of the base flow of the river. In fact, it is doubtful whether the base flow at this point would have maintained a flow of 169 cfs.

The following tables show the estimated amounts of water released from Lake Austin which passed the base stations.

Colorado River at Austin, Texas

Date 1918	Mean daily discharge of Colorado River at Congress Avenue bridge in cfs	Estimated base flow of Colorado River at Congress Avenue bridge in cfs	Estimated amount of water released from Austin reservoir in cfs	Volume released from Austin reservoir in acre-feet
July 5	220	200	20	40
" 6	786	185	601	1,192
" 7	912	165	747	1,482
" 8	896	150	746	1,480
" 9	928	135	793	1,573
" 10	864	120	744	1,476
" 11	832	110	722	1,432
" 12	730	90	640	1,269
" 13	674	80	594	1,178
" 14	648	70	578	1,146
" 15	688	60	628	1,246
" 16	688	55	633	1,256
" 17	636	50	586	1,162
" 18	648	45	603	1,196
" 19	832	40	792	1,571
" 20	1,010	40	970	1,924
" 21	744	40	704	1,396
" 22	588	40	548	1,087
" 23	716	40	676	1,341
" 24	410	40	370	734
" 25	74	40	34	67
" 26	63	40	23	46
" 27	52	40	12	24
" 28	45	40	5	10
TOTAL				25,328

Colorado River at Columbus, Texas

Date 1918	Mean daily discharge of Colorado River at Columbus in cfs	Estimated base flow of Colorado River at Columbus in cfs	Estimated amount of water released from Austin reservoir which passed Columbus in cfs	Volume released from Austin reservoir which passed Columbus in acre-feet
July 8	450	450	0	0
" 9	400	400	0	0
" 10	540	410	130	258
" 11	842	400	442	877
" 12	824	390	434	861
" 13	860	375	485	962
" 14	836	365	471	934
" 15	824	355	469	930
" 16	715	345	370	734
" 17	670	335	335	664
" 18	680	320	360	714
" 19	715	315	400	793
" 20	725	300	425	843
" 21	720	290	430	853
" 22	720	280	440	873
" 23	926	270	656	1,301
" 24	1,030	260	770	1,527
" 25	824	255	569	1,129
" 26	735	250	485	962
" 27	800	240	560	1,111
" 28	660	230	430	853
" 29	530	220	310	615
" 30	388	215	173	343
" 31	332	210	122	242
Aug. 1	328	205	123	244
" 2	282	200	82	163
" 3	260	190	70	139
" 4	220	185	35	69
" 5	195	180	15	30
" 6	185	180	5	10
TOTAL				19,034

Colorado River at Wharton, Texas

Date 1918	Mean daily discharge of Colorado River at Wharton in cfs	Estimated base flow of Colorado River at Wharton in cfs	Estimated amount of water released from Austin reservoir which passed Wharton in cfs	Volume released from Austin reservoir which passed Wharton in acre-feet
July 11	238	238	0	0
" 12	409	230	179	355
" 13	630	220	410	813
" 14	640	210	430	853
" 15	650	205	445	882
" 16	605	200	405	803
" 17	533	190	343	680
" 18	502	185	317	629
" 19	497	180	317	629
" 20	546	170	376	746
" 21	560	165	395	783
" 22	515	160	355	704
" 23	470	155	315	625
" 24	452	150	302	599
" 25	625	145	480	952
" 26	670	140	530	1,051
" 27	524	135	389	771
" 28	595	130	465	922
" 29	528	125	403	799
" 30	425	125	300	595
" 31	277	120	157	311
Aug. 1	240	120	120	238
" 2	200	115	85	169
" 3	165	115	50	99
" 4	135	110	25	50
" 5	125	105	20	40
" 6	115	105	10	20
" 7	100	100	0	0
TOTAL				15,118

References

(Not fully credited elsewhere)

Holland, Pat H., 1953, Seepage Investigation Lower Trinity River of Texas, October and November 1952: U. S. Geological Survey Open-File Report No. 44.

Holland, Pat H. and Lee, Frank C., 1956, Low-Flow Investigation of the Pedernales River, Texas, January 1956: U. S. Geological Survey Open-File Report No. 54.

Holland, Pat H. and Irelan, Burdge, 1955, Guadalupe and Blanco Rivers, Texas Seepage Investigations, 1955: U. S. Geological Survey Open-File Report No. 52.

Holland, Pat H., 1951 Investigations of Seepage Gains and Losses in the Atascosa, Frio, and Nueces Rivers from Poteet, Tex. to Mikeska, Tex., during January, April, August, and September 1951: U. S. Geological Survey Open-File Report No. 42.

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Protecting Texas by Reducing and Preventing Pollution

November 16, 2018

Mr. Ed McCarthy, Jr.
McCarthy & McCarthy, LLP
1122 Colorado Street, Suite 2399
Austin, Texas 78701

CERTIFIED MAIL

Re: San Antonio River Authority
WRPERM 13515
CN600790620, RN110465085
Application No. 13515 for a Water Use Permit
Texas Water Code § 11.042, Limited Mailed Notice Required
Martinez and Cibolo Creeks, San Antonio River Basin
Bexar and Wilson Counties

Dear Mr. McCarthy:

This acknowledges receipt, on July 30, 2018, of the referenced application and fees in the amount of $125.00 (Receipt No. M828523, copy enclosed).

Additional information and fees are required before the application can be declared administratively complete.

1. Confirm the location of the requested diversion point. Commission records indicate that the authorized diversion point in Water Use Permit No. 5611 is located on the east bank of Cibolo Creek and located at Latitude 29.094963°N, Longitude 97.970915°W. The map provided with the application shows the diversion point as being on the west bank of Cibolo Creek.

2. Clarify the combined diversion rate. Staff notes the application indicates a combined rate of 2.76 cfs. However, Water Use Permit No. 5611 is authorized for 1.56 cfs and page 13 of 23 indicates a rate of 1.16 cfs, which staff calculates is a combined rate of 2.72 cfs.

3. Provide an assessment of the adequacy of the quantity and quality of the flows remaining after the proposed diversion to meet instream flow needs and bay and estuary freshwater inflow needs.

4. Confirm that any discharge of return flows under WQ0010749007 commenced after July 31, 2018.

5. Provide an additional explanation of the 78% loss provided on WORKSHEET 4.0. Staff recognizes the application states that this value was calculated using TWDB methodology; however, additional detail would be needed for staff to perform a technical review of the application.

6. Remit fees in the amount of **$67.62** as described below. Please make checks payable to the TCEQ or Texas Commission on Environmental Quality.

Filing Fee	$ 100.00
Recording Fee	$ 25.00
Notice Fee ($2.94 x 23 WR Holders)	$ 67.62
Total Fees	$ 192.62
Fees Received	$ 125.00
Fees Due	$ 67.62

Please submit the requested information and fees by **December 17, 2018** or the application may be returned pursuant to Title 30 Texas Administrative Code § 281.18.

If you have any questions concerning this matter please contact me via email at sarah.henderson@tceq.texas.gov or by telephone at (512) 239-2535.

Sincerely,

Sarah Henderson, Project Manager
Water Rights Permitting Team
Water Rights Permitting and Availability Section

Enclosure

LAW OFFICES OF

McCARTHY & McCARTHY, L.L.P.

1122 COLORADO STREET, SUITE 2399
AUSTIN, TEXAS 78701
(512) 904-2310
(512) 692-2826 (FAX)

July 27, 2018

RECEIVED
JUL 30 2018
Water Availability Division

Ms. Kim Wilson
Director, Water Availability Division
Texas Commission on Environmental Quality
12100 Park 35 Circle, Bldg. F
3rd Floor – Rm 3101
Austin, Texas 78753

Re: Application of the San Antonio River Authority for Authorization to use the Bed and Banks of a State Water Course Pursuant to Section 11.042(b), Texas Water Code, to transport groundwater-based treated wastewater use downstream for diversion and beneficial reuse

Dear Kim:

Enclosed please find the original and six copies of the San Antonio River Authority's (SARA) Application for Authorization to use the Bed and Banks of a State Water Course Pursuant to Section 11.042(b), Texas Water Code, to transport groundwater-based treated wastewater use downstream for diversion and beneficial reuse. Included in the Application are the Commission's prescribed Application Form Nos. TCEQ-10214B and TCEQ-10214C, together with my Firm's Check No. 1081 payable to the TCEQ in the amount of $125.00 to cover the initial estimated filing fees.

At the convenience of yourself and your Staff, I would appreciate the opportunity to review and discuss the Application, and provide any needed additional information. As always, I look forward to working with you and your Staff, and Iliana Delgado, South Texas Watermaster, on these Applications.

By copy of this letter, I am forwarding a copy of the Application to Sarah Henderson who regularly handles SARA water rights matters, and to Iliana.

Best wishes.

Sincerely,

Edmond R. McCarthy, Jr.

Encl.

cc: San Antonio River Authority
Ms. Sarah Henderson, TCEQ Water Rights Team
Ms. Iliana Delgado, South Texas Watermaster

SAN ANTONIO RIVER AUTHORITY

APPLICATION FOR A BED AND BANKS AUTHORIZATION TO DISCHARGE GROUNDWATER BASED EFFLUENT FOR BENEFICIAL REUSE PURSUANT TO SECTION 11.042(b), TEXAS WATER CODE

RECEIVED
JUL 30 2018
Water Availability Division

Edmond R. McCarthy, Jr.
McCarthy & McCarthy LLP
1122 Colorado St., Suite 2399
Austin, Texas 78701
(512) 904-2313
[redacted]

TABLE OF CONTENTS

I

Introduction

I. INTRODUCTION

San Antonio River Authority ("SARA") seeks authorization pursuant to Section 11.042 (b) of the Texas Water Code, to divert and reuse return flows derived from privately owned groundwater to be discharged by SARA pursuant to TPDES Permit No. WG0010749007 (the "TPDES Permit").[1] SARA owns and operates a facility known as the "Graytown Road Wastewater Treatment Facility" located at 1961 North Graytown Rd. in Bexar County, Texas (the "Martinez Creek Plant"). Beginning on or about August 1, 2018, SARA will commence discharging treated wastewater effluent pursuant to the terms of the TPDES Permit into Martinez Creek. The effluent will flow from Martinez Creek into the lower Cibolo Creek (Segment No. 1902 of the San Antonio River) in the San Antonio River Basin.

SARA seeks the bed and banks authorization to transport its groundwater based effluent, less transportation losses, from the existing point of discharge authorized by its TPDES Permit for diversion at a downstream diversion point for beneficial reuse. SARA's proposed downstream point of diversion is also an existing diversion point under a water right held by SARA designated as water use permit No. 5611 located in Wilson County. By instrument entitled "Conveyance of Water Rights" dated December 1, 2010, and recorded in Book 957, Page 83 of the Official Public Records of Wilson County, SARA obtained ownership of 173 acre-feet of water for irrigation purposes out of 175 acre-feet of water.[2] The existing authorized point of diversion is identified as being on the east bank of Cibolo Creek at latitude 29.0951° N., longitude 97.97146 ° W., bearing S. 40 ° W., 1056 feet from the N.E. corner of the Caballerias Survey in Wilson County. Maps identifying SARA's proposed points of discharge and diversion associated with the requested Bed and Banks Authorization are included with the Application.

SARA historically has not discharged any portion of the treated effluent it seeks authorization to transport downstream and divert for subsequent beneficial reuse. As noted, SARA will commence discharge of the effluent on or about August 1, 2018. Accordingly, neither the environment, nor any downstream water right or water right holder, has relied upon any historic discharges made by SARA from the Martinez Creek Plant.

Included with this application are SARA's Administrative Information and Technical Information Reports utilizing TCEQ forms 10214B and 10214C, including responses to the Marshall Criteria (Worksheet 1.2).

SARA's application is executed by its General Manager, Ms. Suzanne Scott. Ms. Scott has been SARA's General Manager since 2007. In her capacity as General Manager, Ms. Scott is authorized to execute such applications on behalf of SARA as evidenced by SARA's enabling legislation and its Bylaws.[3] Specifically, Section 14 of SARA's enabling legislation and Article II, §§ 1, 3 and Article XV, §1, evidence the General Manager's authority to sign, file and prosecute applications to the TCEQ for water related matters similar to this application for a Bed

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[1] A copy of SARA's TPDES Permit is included with this Application as Appendix "A."

[2] A copy of Permit No. 5611, and the TCEQ internal Change of Ownership Memorandum is included with this Application as Appendix "B."

[3] Copies of SARA's enabling legislation and Bylaws evidencing Ms. Scott's authority to execute the application on behalf of SARA are attached hereto, respectively, as Appendices "C" and "D." Attached hereto as Appendix "E" is a press release dated August 15, 2007, announcing Ms. Scotts appointment as SARA's General Manager.

and Banks Authorization.

To cover the cost of initial filing fees for SARA's Application for the Bed and Banks Authorization, enclosed please find a check, payable to TCEQ in the amount of $125.00 (Check No. 1081) attached hereto.[4] If additional fees are required for processing of this Application, please provide notice of the amount due so that it can be promptly remitted.

SARA's Contact Information is as follows:

Name: San Antonio River Authority
Address: P.O. Box 839980 San Antonio, Texas 78283
Telephone: (210) 302-3611
Federal ID. No.: 74-6011311

Additional information and/or questions about SARA's Application can be addressed to SARA's special water counsel, Ed McCarthy, as follows:

Ed McCarthy
McCarthy & McCarthy LLP
1122 Colorado, Suite 2399
Austin, Texas 78701
(512) 904-2313
[redacted]

[4] A copy of this Firm's Check No. 1081 payable to the TCEQ in the amount of $125.00 is included with this application as Appendix "F."

II

Applicant's Administrative Information Report
(TCEQ Form No. 10214B)

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

TCEQ WATER RIGHTS PERMITTING APPLICATION

ADMINISTRATIVE INFORMATION CHECKLIST

Complete and submit this checklist for each application. See Instructions Page. 5.

APPLICANT(S): SAN ANTONIO RIVER AUTHORITY (SARA)

Indicate whether the following items are included in your application by writing either Y (for yes) or N (for no) next to each item (all items are not required for every application).

Y/N	
X	**Administrative Information Report**
	Additional Co-Applicant Information
	Additional Co-Applicant Signature Pages
X	Written Evidence of Signature Authority
X	**Technical Information Report**
	USGS Map (or equivalent)
	Map Showing Project Details
	Original Photographs
	Water Availability Analysis
X	**Worksheet 1.0**
	Recorded Deeds for Irrigated Land
	Consent For Irrigation Land
	Worksheet 1.1
	Addendum to Worksheet 1.1
X	**Worksheet 1.2**
X	Addendum to Worksheet 1.2
	Worksheet 2.0
	Additional W.S 2.0 for Each Reservoir
	Dam Safety Documents
	Notice(s) to Governing Bodies
	Recorded Deeds for Inundated Land
	Consent For Inundation Land

Y/N	
X	**Worksheet 3.0**
	Additional W.S 3.0 for each Point
	Recorded Deeds for Diversion Points
	Consent For Diversion Access
X	**Worksheet 4.0**
X	TPDES Permit(s)
	WWTP Discharge Data
	24-hour Pump Test
	Groundwater Well Permit
	Signed Water Supply Contract
X	**Worksheet 4.1**
X	**Worksheet 5.0**
	Addendum to Worksheet 5.0
X	**Worksheet 6.0**
X	Water Conservation Plan(s)
X	Drought Contingency Plan(s)
X	Documentation of Adoption
	Worksheet 7.0
	Accounting Plan
X	**Worksheet 8.0**
X	Fees

For Commission Use Only:
Proposed/Current Water Right Number: ____________
Basin: ____________________ Watermaster area Y/N: ___________

ADMINISTRATIVE INFORMATION REPORT

The following information **is required** for **all** new applications and amendments.

****Applicants are strongly encouraged to schedule a pre-application meeting with TCEQ Staff to discuss Applicant's needs prior to submitting an application. Call the Water Rights Permitting Team to schedule a meeting at* (512) 239-4691.

1. TYPE OF APPLICATION (Instructions, Page. 6)

Indicate, by marking X, next to the following authorizations you are seeking.

_____New Appropriation of State Water

_____Amendment to a Water Right *

XX Bed and Banks

If you are seeking an amendment to an existing water rights authorization, you must be the owner of record of the authorization. If the name of the Applicant in Section 2, does not match the name of the current owner(s) of record for the permit or certificate or if any of the co-owners is not included as an applicant in this amendment request, your application could be returned. If you or a co-applicant are a new owner, but ownership is not reflected in the records of the TCEQ, submit a change of ownership request (Form TCEQ-10204) prior to submitting the application for an amendment. See Instructions page. 6. Please note that an amendment application may be returned, and the Applicant may resubmit once the change of ownership is complete.

Please summarize the authorizations or amendments you are seeking in the space below or attach a narrative description entitled "Summary of Request."

SARA seeks a new bed and banks permit to use future discharges from a new wastewater treatment plant (Martinez IV - TPDES Permit No. WQ-0010749007) to offset water needs from municipal, agricultural, and industrial/mining needs from the Region L Water Plan. SARA also seeks to use future discharges for environmental flows and recreational purposes.

2. APPLICANT INFORMATION (Instructions, Page. 6)

a. Applicant

Indicate the number of Applicants/Co-Applicants 1
(Include a copy of this section for each Co-Applicant, if any)

What is the Full Legal Name of the individual or entity (applicant) applying for this permit?
San Antonio River Authority

(If the Applicant is an entity, the legal name must be spelled exactly as filed with the Texas Secretary of State, County, or in the legal documents forming the entity.)

If the applicant is currently a customer with the TCEQ, what is the Customer Number (CN)? You may search for your CN on the TCEQ website at http://www15.tceq.texas.gov/crpub/index.cfm?fuseaction=cust.CustSearch

CN :__________(leave blank if you do not yet have a CN).

What is the name and title of the person or persons signing the application? Unless an application is signed by an individual applicant, the person or persons must submit written evidence that they meet the signatory requirements in *30 TAC § 295.14*.

First/Last Name: Suzanne B. Scott

Title: General Manager

Have you provided written evidence meeting the signatory requirements in 30 TAC § 295.14, as an attachment to this application? Yes

What is the applicant's mailing address as recognized by the US Postal Service (USPS)? You may verify the address on the USPS website at https://tools.usps.com/go/ZipLookupAction!input.action.

Name: San Antonio River Authority

Mailing Address: 100 E. Guenther

City: San Antonio State: Texas ZIP Code: 78204

Indicate an X next to the type of Applicant:

__Individual	__Sole Proprietorship-D.B.A.
__Partnership	__Corporation
__Trust	__Estate
__Federal Government	__State Government
__County Government	__City Government
XX Other Government	XX Other River Authority

For Corporations or Limited Partnerships, provide:
State Franchise Tax ID Number: N/A SOS Charter (filing) Number: N/A

3. APPLICATION CONTACT INFORMATION (Instructions, Page. 9)

If the TCEQ needs additional information during the review of the application, who should be contacted? Applicant may submit their own contact information if Applicant wishes to be the point of contact.

First and Last Name: Ed McCarthy

Title: Attorney

Organization Name: McCarthy & McCarthy LLP

Mailing Address: 1122 Colorado, Suite 2399

City: Austin State: Texas ZIP Code: 78701

Phone No.: 512-904-2313 Extension: N/A

Fax No.: 512-692-2826 E-mail Address: [redacted]

4. WATER RIGHT CONSOLIDATED CONTACT INFORMATION (Instructions, Page. 9)

This section applies only if there are multiple Owners of the same authorization. Unless otherwise requested, Co-Owners will each receive future correspondence from the Commission regarding this water right (after a permit has been issued), such as notices and water use reports. Multiple copies will be sent to the same address if Co-Owners share the same address. Complete this section if there will be multiple owners and **all** owners agree to let one owner receive correspondence from the Commission. Leave this section blank if you would like all future notices to be sent to the address of each of the applicants listed in section 2 above.

I/We authorize all future notices be received on my/our behalf at the following:

First and Last Name: N/A

Title: N/A

Organization Name: N/A

Mailing Address: N/A

City: N/A State: N/A ZIP Code: N/A

Phone No.: N/A Extension: N/A

Fax No.: N/A E-mail Address: N/A

5. MISCELLANEOUS INFORMATION (Instructions, Page. 9)

a. The application will not be processed unless all delinquent fees and/or penalties owed to the TCEQ or the Office of the Attorney General on behalf of the TCEQ are paid in accordance with the Delinquent Fee and Penalty Protocol by all applicants/co-applicants. If you need assistance determining whether you owe delinquent penalties or fees, please call the Water Rights Permitting Team at (512) 239-4691, prior to submitting your application.

1. Does Applicant or Co-Applicant owe any fees to the TCEQ? **Yes / No** XX

   If **yes**, provide the following information:
   Account number: N/A Amount past due: N/A

2. Does Applicant or Co-Applicant owe any penalties to the TCEQ? **Yes / No** No

   If **yes**, please provide the following information:
   Enforcement order number: N/A Amount past due: N/A

b. If the Applicant is a taxable entity (corporation or limited partnership), the Applicant must be in good standing with the Comptroller or the right of the entity to transact business in the State may be forfeited. See Texas Tax Code, Subchapter F. Applicant's may check their status with the Comptroller at https://mycpa.cpa.state.tx.us/coa/

   Is the Applicant or Co-Applicant in good standing with the Comptroller? **Yes / No** Yes

c. The commission will not grant an application for a water right unless the applicant has submitted all Texas Water Development Board (TWDB) surveys of groundwater and surface water use – if required. See TWC §16.012(m) and 30 TAC § 297.41(a)(5).

Applicant has submitted all required TWDB surveys of groundwater and surface water? **Yes / No** Yes

6. SIGNATURE PAGE (Instructions, Page. 11)

Applicant:

I, Suzanne B. Scott General Manager

(Typed or printed name) (Title)

certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

I further certify that I am authorized under Title 30 Texas Administrative Code §295.14 to sign and submit this document and I have submitted written evidence of my signature authority.

Signature: Suzanne B Scott Date: 7/5/18

(Use blue ink)

Subscribed and Sworn to before me by the said

on this fifth day of July, 20 18.

My commission expires on the 17th day of March, 20 21.

Notary Public

MELVA L. RAMIREZ
Notary Public, State of Texas
Comm. Expires 03-17-2021
Notary ID 128557480

[SEAL]

County, Texas

If the Application includes Co-Applicants, each Applicant and Co-Applicant must submit an original, separate signature page

III

Applicant's Technical Information Report
(TCEQ Form No. 10214C)

TECHNICAL INFORMATION REPORT
WATER RIGHTS PERMITTING

This Report is required for applications for new or amended water rights. Based on the Applicant's responses below, Applicants are directed to submit additional Worksheets (provided herein). A completed Administrative Information Report is also required for each application.

Applicants are strongly encouraged to schedule a pre-application meeting with TCEQ Permitting Staff to discuss Applicant's needs and to confirm information necessary for an application prior to submitting such application. Please call Water Availability Division at (512) 239-4691 to schedule a meeting. Applicant attended a pre-application meeting with TCEQ Staff for this Application? **Y / N** N (If yes, date :________________).

1. New or Additional Appropriations of State Water, Texas Water Code (TWC) § 11.121 (Instructions, Page. 12)

State Water is: *The water of the ordinary flow, underflow, and tides of every flowing river, natural stream, and lake, and of every bay or arm of the Gulf of Mexico, and the storm water, floodwater, and rainwater of every river, natural stream, canyon, ravine, depression, and watershed in the state. TWC § 11.021.*

a. Applicant requests a new appropriation (diversion or impoundment) of State Water? **Y / N** Y

b. Applicant requests an amendment to an existing water right requesting an increase in the appropriation of State Water or an increase of the overall or maximum combined diversion rate? **Y / N** N (If yes, indicate the Certificate or Permit number:_______)

If Applicant answered yes to (a) or (b) above, does Applicant also wish to be considered for a term permit pursuant to TWC § 11.1381? N **Y / N**

c. Applicant requests to extend an existing Term authorization or to make the right permanent? **Y / N** N (If yes, indicate the Term Certificate or Permit number:_________________)

If Applicant answered yes to (a), (b) or (c), the following worksheets and documents are required:

- **Worksheet 1.0 – Quantity, Purpose, and Place of Use Information Worksheet**
- **Worksheet 2.0 - Impoundment/Dam Information Worksheet** (submit one worksheet for each impoundment or reservoir requested in the application)
- **Worksheet 3.0 - Diversion Point Information Worksheet** (submit one worksheet for each diversion point and/or one worksheet for the upstream limit and one worksheet for the downstream limit of each diversion reach requested in the application)
- **Worksheet 5.0 – Environmental Information Worksheet**
- **Worksheet 6.0 – Water Conservation Information Worksheet**
- **Worksheet 7.0 – Accounting Plan Information Worksheet**
- **Worksheet 8.0 – Calculation of Fees**
- **Fees calculated on Worksheet 8.0** – see instructions **Page. 34.**
- **Maps** – See instructions **Page. 15.**
- **Photographs** - See instructions **Page. 30.**

Additionally, if Applicant wishes to submit an alternate source of water for the project/authorization, see Section 3, Page 3 for Bed and Banks Authorizations (Alternate sources may include groundwater, imported water, contract water or other sources).

Additional Documents and Worksheets may be required (see within).

2. Amendments to Water Rights. TWC § 11.122 (Instructions, Page. 12)

This section should be completed if Applicant owns an existing water right and Applicant requests to amend the water right. ***If Applicant is not currently the Owner of Record in the TCEQ Records, Applicant must submit a Change of Ownership Application (TCEQ-10204) prior to submitting the amendment Application or provide consent from the current owner to make the requested amendment.*** **See instructions page. 6.**

Water Right (Certificate or Permit) number you are requesting to amend: ____________________

Applicant requests to sever and combine existing water rights from one or more Permits or Certificates into another Permit or Certificate? Y / N (if yes, complete chart below):

List of water rights to sever	Combine into this ONE water right

a. Applicant requests an amendment to an existing water right to increase the amount of the appropriation of State Water (diversion and/or impoundment)? Y / N

If yes, application is a new appropriation for the increased amount, complete ***Section 1 of this Report (PAGE. 1) regarding New or Additional Appropriations of State Water.***

b. Applicant requests to amend existing Term authorization to extend the term or make the water right permanent (remove conditions restricting water right to a term of years)? Y / N

If yes, application is a new appropriation for the entire amount, complete ***Section 1 of this Report (PAGE. 1) regarding New or Additional Appropriations of State Water.***

c. Applicant requests an amendment to change the purpose or place of use or to add an additional purpose or place of use to an existing Permit or Certificate? Y / N
If yes, submit:

- **Worksheet 1.0 – Quantity, Purpose, and Place of Use Information Worksheet**
- **Worksheet 1.2 - Notice: "Marshall Criteria"**

d. Applicant requests to change: diversion point(s); or reach(es); or diversion rate? Y / N

If yes, submit: **Worksheet 3.0 - Diversion Point Information Worksheet** (submit one worksheet for each diversion point or one worksheet for the upstream limit and one worksheet for the downstream limit of each diversion reach)

e. Applicant requests amendment to add or modify an impoundment, reservoir, or dam? Y / N

If yes, submit: **Worksheet 2.0 - Impoundment/Dam Information Worksheet** (submit one worksheet for each impoundment or reservoir)

f. Other - Applicant requests to change any provision of an authorization not mentioned above?Y / N *If yes, call the Water Availability Division at (512) 239-4691 to discuss.*

Additionally, all amendments require:

- **Worksheet 8.0 – Calculation of Fees; and Fees calculated – see instructions Page.34**
- **Maps – See instructions Page. 15.**
- **Additional Documents and Worksheets may be required (see within).**

3. Bed and Banks. TWC § 11.042 (Instructions, Page 13)

a. Pursuant to contract, Applicant requests authorization to convey, stored or conserved water to the place of use or diversion point of purchaser(s) using the bed and banks of a watercourse? TWC § 11.042(a). **Y/N** N

If yes, submit a signed copy of the Water Supply Contract pursuant to 30 TAC §§ 295.101 and 297.101. Further, if the underlying Permit or Authorization upon which the Contract is based does not authorize Purchaser's requested Quantity, Purpose or Place of Use, or Purchaser's diversion point(s), then either:

1. *Purchaser must submit the worksheets required under Section 1 above with the Contract Water identified as an alternate source; or*
2. *Seller must amend its underlying water right under Section 2.*

b. Applicant requests to convey water imported into the state from a source located wholly outside the state using the bed and banks of a watercourse? TWC § 11.042(a-1). **Y / N** N

If yes, submit: worksheets 1.0, 2.0, 3.0, 4.0, 5.0, 7.0, 8.0, Maps and fees from the list below.

c. Applicant requests to convey Applicant's own return flows derived from privately owned groundwater using the bed and banks of a watercourse? TWC § 11.042(b). **Y / N** Y

If yes, submit: worksheets 1.0, 2.0, 3.0, 4.0, 5.0, 7.0, 8.0, Maps, and fees from the list below.

d. Applicant requests to convey Applicant's own return flows derived from surface water using the bed and banks of a watercourse? TWC § 11.042(c). **Y / N** N

If yes, submit: worksheets 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, Maps, and fees from the list below.

Please note, if Applicant requests the reuse of return flows belonging to others, the Applicant will need to submit the worksheets and documents under Section 1 above, as the application will be treated as a new appropriation subject to termination upon direct or indirect reuse by the return flow discharger/owner.

e. Applicant requests to convey water from any other source, other than (a)-(d) above, using the bed and banks of a watercourse? TWC § 11.042(c). **Y / N** N

If yes, submit: worksheets 1.0, 2.0, 3.0, 4.0, 5.0, 7.0, 8.0, Maps, and fees from the list below.

Worksheets and information:

- **Worksheet 1.0 – Quantity, Purpose, and Place of Use Information Worksheet**
- **Worksheet 2.0 - Impoundment/Dam Information Worksheet** (submit one worksheet for each impoundment or reservoir owned by the applicant through which water will be conveyed or diverted)
- **Worksheet 3.0 - Diversion Point Information Worksheet** (submit one worksheet for the downstream limit of each diversion reach for the proposed conveyances)
- **Worksheet 4.0 – Discharge Information Worksheet** (for each discharge point)
- **Worksheet 5.0 – Environmental Information Worksheet**
- **Worksheet 6.0 – Water Conservation Information Worksheet**
- **Worksheet 7.0 – Accounting Plan Information Worksheet**
- **Worksheet 8.0 – Calculation of Fees; and Fees calculated – see instructions Page. 34**
- **Maps** – See instructions Page. 15.
- **Additional Documents and Worksheets may be required (see within).**

4. General Information, Response Required for all Water Right Applications (Instructions, Page 15)

a. Provide information describing how this application addresses a water supply need in a manner that is consistent with the state water plan or the applicable approved regional water plan for any area in which the proposed appropriation is located or, in the alternative, describe conditions that warrant a waiver of this requirement (*not required for applications to use groundwater-based return flows*). Include citations or page numbers for the State and Regional Water Plans, if applicable. Provide the information in the space below or submit a supplemental sheet entitled "Addendum Regarding the State and Regional Water Plans":

SARA seeks to use future discharges from new wastewater treatment plant to offset water needs from municipal, agricultural, and industrial needs from the Region L Water Plan. SARA also seeks to use future discharges for environmental flows and recreational purposes.

b. Did the Applicant perform its own Water Availability Analysis? Y / N N

If the Applicant performed its own Water Availability Analysis, provide electronic copies of any modeling files and reports.

c. Does the application include required Maps? (Instructions Page. 15) Y / N Y

WORKSHEET 1.0
Quantity, Purpose and Place of Use

1. New Authorizations (Instructions, Page. 16)

Submit the following information regarding quantity, purpose and place of use for requests for new or additional appropriations of State Water or Bed and Banks authorizations:

Quantity (acre-feet) *(Include losses for Bed and Banks)*	State Water Source (River Basin) or Alternate Source *each *alternate source (and new appropriation based on return flows of others) also requires completion of Worksheet 4.0*	Purpose(s) of Use	Place(s) of Use **requests to move state water out of basin also require completion of Worksheet 1.1 Interbasin Transfer*
560	San Antonio	municipal, agricultural, industrial	in SAR Basin
		recreational, environmental	

560 Total amount of water (in acre-feet) to be used annually (*include losses for Bed and Banks applications*)

If the Purpose of Use is Agricultural/Irrigation for any amount of water, provide:

1. Location Information Regarding the Lands to be Irrigated
   i) Applicant proposes to irrigate a total of ________acres in any one year. This acreage is all of or part of a larger tract(s) which is described in a supplement attached to this application and contains a total of ___________ acres in ________________County, TX.
   ii) Location of land to be irrigated: In the __________________Original Survey No. ________, Abstract No.______________.
   A copy of the deed(s) or other acceptable instrument describing the overall tract(s) with the recording information from the county records must be submitted. Applicant's name must match deeds.
   If the Applicant is not currently the sole owner of the lands to be irrigated, Applicant must submit documentation evidencing consent or other documentation supporting Applicant's right to use the land described.

   Water Rights for Irrigation may be appurtenant to the land irrigated and convey with the land unless reserved in the conveyance. 30 TAC § 297.81.

2. Amendments - Purpose or Place of Use (Instructions, Page. 12)

a. Complete this section for each requested amendment changing, adding, or removing Purpose(s) or Place(s) of Use, complete the following:

Quantity (acre-feet)	Existing Purpose(s) of Use	Proposed Purpose(s) of Use*	Existing Place(s) of Use	Proposed Place(s) of Use**

**If the request is to add additional purpose(s) of use, include the existing and new purposes of use under "Proposed Purpose(s) of Use."*

***If the request is to add additional place(s) of use, include the existing and new places of use under "Proposed Place(s) of Use."*

Changes to the purpose of use in the Rio Grande Basin may require conversion. 30 TAC § 303.43.

b. For any request which adds Agricultural purpose of use or changes the place of use for Agricultural rights, provide the following location information regarding the lands to be irrigated:

i) Applicant proposes to irrigate a total of ________acres in any one year. This acreage is all of or part of a larger tract(s) which is described in a supplement attached to this application and contains a total of ___________ acres in______________________ County, TX.

ii) Location of land to be irrigated: In the ________________Original Survey No. ________, Abstract No.______________.

A copy of the deed(s) describing the overall tract(s) with the recording information from the county records must be submitted. Applicant's name must match deeds. If the Applicant is not currently the sole owner of the lands to be irrigated, Applicant must submit documentation evidencing consent or other legal right for Applicant to use the land described.

Water Rights for Irrigation may be appurtenant to the land irrigated and convey with the land unless reserved in the conveyance. 30 TAC § 297.81.

c. Submit Worksheet 1.1, Interbasin Transfers, for any request to change the place of use which moves State Water to another river basin.

d. See Worksheet 1.2, Marshall Criteria, and submit if required.

e. See Worksheet 6.0, Water Conservation/Drought Contingency, and submit if required.

WORKSHEET 1.1
INTERBASIN TRANSFERS, TWC § 11.085

Submit this worksheet for an application for a new or amended water right which requests to transfer State Water from its river basin of origin to use in a different river basin. A river basin is defined and designated by the Texas Water Development Board by rule pursuant to TWC § 16.051.

Applicant requests to transfer State Water to another river basin within the State? Y / N

1. Interbasin Transfer Request (Instructions, Page. 20)

a. Provide the Basin of Origin.________________________________

b. Provide the quantity of water to be transferred (acre-feet).________________

c. Provide the Basin(s) and count(y/ies) where use will occur in the space below:

____

2. Exemptions (Instructions, Page. 20), TWC § 11.085(v)

Certain interbasin transfers are exempt from further requirements. Answer the following:

a. The proposed transfer, which in combination with any existing transfers, totals less than 3,000 acre-feet of water per annum from the same water right. Y/N

b. The proposed transfer is from a basin to an adjoining coastal basin? Y/N

c. The proposed transfer from the part of the geographic area of a county or municipality, or the part of the retail service area of a retail public utility as defined by Section 13.002, that is within the basin of origin for use in that part of the geographic area of the county or municipality, or that contiguous part of the retail service area of the utility, not within the basin of origin? Y/N

d. The proposed transfer is for water that is imported from a source located wholly outside the boundaries of Texas, except water that is imported from a source located in the United Mexican States? Y/N

3. Interbasin Transfer Requirements (Instructions, Page. 20)

For each Interbasin Transfer request that is not exempt under any of the exemptions listed above Section 2, provide the following information in a supplemental attachment titled "Addendum to Worksheet 1.1, Interbasin Transfer":

a. the contract price of the water to be transferred (if applicable) (also include a copy of the contract or adopted rate for contract water);

b. a statement of each general category of proposed use of the water to be transferred and a detailed description of the proposed uses and users under each category;

c. the cost of diverting, conveying, distributing, and supplying the water to, and treating the water for, the proposed users (example - expert plans and/or reports documents may be provided to show the cost);

d. describe the need for the water in the basin of origin and in the proposed receiving basin based on the period for which the water supply is requested, but not to exceed 50 years (the need can be identified in the most recently approved regional water plans. The state and regional water plans are available for download at this website: (http://www.twdb.texas.gov/waterplanning/swp/index.asp);

e. address the factors identified in the applicable most recently approved regional water plans which address the following:

   (i) the availability of feasible and practicable alternative supplies in the receiving basin to the water proposed for transfer;

   (ii) the amount and purposes of use in the receiving basin for which water is needed;

   (iii) proposed methods and efforts by the receiving basin to avoid waste and implement water conservation and drought contingency measures;

   (iv) proposed methods and efforts by the receiving basin to put the water proposed for transfer to beneficial use;

   (v) the projected economic impact that is reasonably expected to occur in each basin as a result of the transfer; and

   (vi) the projected impacts of the proposed transfer that are reasonably expected to occur on existing water rights, instream uses, water quality, aquatic and riparian habitat, and bays and estuaries that must be assessed under Sections 11.147, 11.150, and 11.152 in each basin *(if applicable)*. If the water sought to be transferred is currently authorized to be used under an existing permit, certified filing, or certificate of adjudication, such impacts shall only be considered in relation to that portion of the permit, certified filing, or certificate of adjudication proposed for transfer and shall be based on historical uses of the permit, certified filing, or certificate of adjudication for which amendment is sought;

(f) proposed mitigation or compensation, if any, to the basin of origin by the applicant; and

(g) the continued need to use the water for the purposes authorized under the existing Permit, Certified Filing, or Certificate of Adjudication, if an amendment to an existing water right is sought.

WORKSHEET 1.2
NOTICE. "THE MARSHALL CRITERIA"

This worksheet assists the Commission in determining notice required for certain **amendments** that do not already have a specific notice requirement in a rule for that type of amendment, and *that do not change the amount of water to be taken or the diversion rate.* The worksheet provides information that Applicant **is required** to submit for such amendments which include changes in use, changes in place of use, or other non-substantive changes in a water right (such as certain amendments to special conditions or changes to off-channel storage). These criteria address whether the proposed amendment will impact other water right holders or the on-stream environment beyond and irrespective of the fact that the water right can be used to its full authorized amount.

*This worksheet is **not required for Applications in the Rio Grande Basin** requesting changes in the purpose of use, rate of diversion, point of diversion, and place of use for water rights held in and transferred within and between the mainstems of the Lower Rio Grande, Middle Rio Grande, and Amistad Reservoir. See 30 TAC § 303.42.*

*This worksheet is **not required for amendments which are only changing or adding diversion points, or request only a bed and banks authorization or an IBT authorization.** However, Applicants may wish to submit the Marshall Criteria to ensure that the administrative record includes information supporting each of these criteria*

1. The "Marshall Criteria" (Instructions, Page. 21)

Submit responses on a supplemental attachment titled "Marshall Criteria" in a manner that conforms to the paragraphs (a) - (g) below:

a. Administrative Requirements and Fees. Confirm whether application meets the administrative requirements for an amendment to a water use permit pursuant to TWC Chapter 11 and Title 30 Texas Administrative Code (TAC) Chapters 281, 295, and 297. An amendment application should include, but is not limited to, a sworn application, maps, completed conservation plan, fees, etc.

b. Beneficial Use. Discuss how proposed amendment is a beneficial use of the water as defined in TWC § 11.002 and listed in TWC § 11.023. Identify the specific proposed use of the water (e.g., road construction, hydrostatic testing, etc.) for which the amendment is requested.

c. Public Welfare. Explain how proposed amendment is not detrimental to the public welfare. Consider any public welfare matters that might be relevant to a decision on the application. Examples could include concerns related to the well-being of humans and the environment.

d. Groundwater Effects. Discuss effects of proposed amendment on groundwater or groundwater recharge.

e. State Water Plan. Describe how proposed amendment addresses a water supply need in a manner that is consistent with the state water plan or the applicable approved regional water plan for any area in which the proposed appropriation is located or, in the alternative, describe conditions that warrant a waiver of this requirement. The state and regional water plans are available for download at: http://www.twdb.texas.gov/waterplanning/swp/index.asp.

f. Waste Avoidance. Provide evidence that reasonable diligence will be used to avoid waste and achieve water conservation as defined in TWC § 11.002. Examples of evidence could include, but are not limited to, a water conservation plan or, if required, a drought contingency plan, meeting the requirements of 30 TAC Chapter 288.

g. Impacts on Water Rights or On-stream Environment. Explain how proposed amendment will not impact other water right holders or the on-stream environment beyond and irrespective of the fact that the water right can be used to its full authorized amount.

WORKSHEET 1.2

MARSHALL CRITERIA

This is an application for authorization to use the bed and banks of portions of the water courses in the San Antonio River Basin, the majority of which have been conveyed by the Texas Legislature to SARA pursuant to its enabling legislation.

a. **Administrative Requirements and Fees.** Confirm whether application meets the administrative requirements for an amendment to a water use permit pursuant to TWC Chapter 11 and Title 30 Texas Administrative Code (TAC) Chapters 281, 295, and 297. An amendment application should include, but is not limited to, a sworn application, maps, completed conservation plan, fees, etc.

   RESPONSE: Based upon a review of the completed responses to the application for a bed and banks authorization prepared by SARA, including a review of the requirements of Chapter 11, Texas Water Code, and Chapters 281, 295 and 297 of Title 30 of the Texas Administrative Code, SARA believes its application to be complete. SARA believes its application includes all of the required documentation including maps and appropriate fees, as well as evidence of the authority of SARA's General Manager to execute the same.

b. **Beneficial Use.** Discuss how proposed bed and banks authorization is a beneficial use of the water as defined in TWC § 11.002 and listed in TWC § 11.023. Identify the specific proposed use of the water (e.g., road construction, hydrostatic testing, etc.) for which the bed and banks authorization is requested.

   RESPONSE: Authorization to use the bed and banks of state water courses to transport its treated effluent for beneficial use downstream will facilitate SARA's ability to make the water available for multiple beneficial uses including municipal, agricultural and industrial/mining needs within Region L. The treated effluent to be transported through the state's bed and banks will also be available for environmental flows and recreational purposes. As the treated effluent is groundwater based, it is not an appropriation of state water and is not subject to the restrictions or limitations on the first time permitting of state water for environmental purposes.

c. **Public Welfare.** Explain how proposed bed and banks authorization is not detrimental to the public welfare. Consider any public welfare matters that might be relevant to a decision on the application. Examples could include concerns related to the well-being of humans and the environment.

   RESPONSE: Consistent with the beneficial uses described in paragraph b. above, the public welfare will be benefitted by having additional water supplies available for various beneficial uses that will provide potential drinking water supplies, water for irrigated agriculture for growing of food sources, and water available for industrial purposes including the generation of oil, gas and other energy sources necessary for the public welfare. The availability of water in the San Antonio River Basin for recreation and environmental purposes also serves the public welfare. All of the proposed uses associated with SARA's request for authorization to use the bed and banks within the San Antonio River Basin as described in the application are consistent with the water needs and proposed strategies as identified in both the Region L Plan and the State Water Plan.

d. **Groundwater Effects.** Discuss effects of proposed bed and banks authorization on groundwater or groundwater recharge.

RESPONSE: The effects, if any, on groundwater or groundwater recharge should be positive. SARA is not seeking an appropriation of any new water, but the right to beneficially reuse effluent it has acquired from groundwater based sources it will be discharging after treating the same at the Martinez IV plant. Making this treated effluent available for various beneficial uses described above will reduce the demand for water for these purposes. That availability means that less groundwater has to be produced for the same purposes within the region. Assuming SARA's treated effluent is applied to these beneficial purposes as a substitute for water which would otherwise be developed from groundwater resources, SARA's application will have the beneficial effect of allowing the groundwater to remain in situ, or available for other purposes. With respect to recharge, one of the components of the transportation losses that SARA anticipates being required to account for in the delivery of its groundwater, in addition to evaporative losses, are losses due to recharge in the bed of the water courses the effluent will travel through. Any such recharge will enhance the availability of groundwater within the region.

e. **State Water Plan.** Describe how proposed bed and banks authorization addresses a water supply need in a manner that is consistent with the state water plan or the applicable approved regional water plan for any area in which the proposed beneficial reuse of groundwater based effluent is located or, in the alternative, describe conditions that warrant a waiver of this requirement. The state and regional water plans are available for download at: http://www.twdb.texas.gov/waterplanning/swp/index.asp.

RESPONSE: The Region L planning group's water plan, as incorporated into the State Water Plan, includes components for beneficial use of groundwater based effluent, in addition to identifying multiple demands for water to meet the needs of the Region's ever growing population. As described above, making SARA's treated effluent available for beneficial use within the Region by allowing its transport using the bed and banks of the state water courses within the San Antonio River Basin will provide a means to address some of the demand for water within Region L contemplated by the State Water Plan. Finally, as this is not an application for a new or amended appropriation of state water, but rather the right for authorization to use the bed and banks for groundwater based effluent, the criteria requirement for compliance of State Water Plan is not truly applicable. It is satisfied, however, by the proposed use/reuse of the groundwater based effluent proposed by SARA.

f. **Waste Avoidance.** Provide evidence that reasonable diligence will be used to avoid waste and achieve water conservation as defined in TWC § 11.002. Examples of evidence could include, but are not limited to, a water conservation plan or, if required, a drought contingency plan, meeting the requirements of 30 TAC Chapter 288.

RESPONSE: SARA has on file updated Water Conservation Plans and Drought Contingency Plans compliant with both Section 11.002, Texas Water Code, and Chapter 288, Title 40 of the Texas Administrative Code. SARA intends to apply the criteria in these plans in the beneficial reuse of its groundwater based effluent, including the use of the state's bed and banks within the San Antonio River Basin to transport the treated effluent.

g. **Impacts on Water Rights or On-stream Environment.** Explain how proposed bed and banks authorization will not impact other water right holders or the on-stream environment beyond and irrespective of the fact that the water right can be used to its full authorized amount.

RESPONSE: SARA's application for authorization to utilize the bed and banks of state water courses within the San Antonio River Basin will have a positive impact on water rights and on-stream environment. SARA's application contemplates the introduction of a new source of water in the form of treated groundwater based wastewater effluent into the San Antonio River Basin. By adding water to the water course, SARA will increase the percentage of time that the bed and banks of the water courses remain wetted within the reach between the point of discharge and the point of diversion. This has the benefit of not requiring state water to be relied upon 100 percent to maintain the wetted perimeter and the saturated surface of the bed and banks. By providing a continual source of water into the water course between the point of discharge and point of diversion, SARA's use of the bed and banks will help maintain the riverine environment of the affected water courses. In times of low flow, the presence of SARA's groundwater based treated effluent will add a supply of water to maintain for vegetation and wildlife within the reach the effluent will be transported. The availability of the additional source water from SARA's proposed use of the bed and banks of the affected stretch of river will also provide additional flow to enhance recreational opportunities within the reach.

WORKSHEET 2.0
Impoundment/Dam Information

This worksheet **is required** for any impoundment, reservoir and/or dam. Submit an additional Worksheet 2.0 for each impoundment or reservoir requested in this application.

If there is more than one structure, the numbering/naming of structures should be consistent throughout the application and on any supplemental documents (e.g. maps).

1. Storage Information (Instructions, Page. 21)

a. Official USGS name of reservoir, if applicable:______________________________

b. Provide amount of water (in acre-feet) impounded by structure at normal maximum operating level: ________________.

c. The impoundment is on-channel______ or off-channel______ (mark one)

1. Applicant has verified on-channel or off-channel determination by contacting Surface Water Availability Team at (512) 239-4691? **Y / N**
2. If on-channel, will the structure have the ability to pass all State Water inflows that Applicant does not have authorization to impound? **Y / N**

d. Is the impoundment structure already constructed? **Y / N**

i. For already constructed **on-channel** structures:

1. Date of Construction:______________________________
2. Was it constructed to be an exempt structure under TWC § 11.142? **Y / N**
   a. If Yes, is Applicant requesting to proceed under TWC § 11.143? **Y / N**
   b. If No, has the structure been issued a notice of violation by TCEQ? **Y / N**
3. Is it a U.S. Natural Resources Conservation Service (NRCS) (formerly Soil Conservation Service (SCS)) floodwater-retarding structure? **Y / N**
   a. If yes, provide the Site No. ______and watershed project name____________;
   b. Authorization to close "ports" in the service spillway requested? **Y / N**

ii. For **any** proposed new structures or modifications to structures:

1. Applicant **must** contact TCEQ Dam Safety Section at (512) 239-0326, *prior to submitting an Application.* Applicant has contacted the TCEQ Dam Safety Section regarding the submission requirements of 30 TAC, Ch. 299? **Y / N**
   Provide the date and the name of the Staff Person________________________
2. As a result of Applicant's consultation with the TCEQ Dam Safety Section, TCEQ has confirmed that:
   a. No additional dam safety documents required with the Application. **Y / N**
   b. Plans (with engineer's seal) for the structure required. **Y / N**
   c. Engineer's signed and sealed hazard classification required. **Y / N**
   d. Engineer's statement that structure complies with 30 TAC, Ch. 299 Rules required. **Y / N**

3. Applicants **shall** give notice by certified mail to each member of the governing body of each county and municipality in which the reservoir, or any part of the reservoir to be constructed, will be located. (30 TAC § 295.42). Applicant must submit a copy of all the notices and certified mailing cards with this Application. Notices and cards are included? **Y / N**

iii. Additional information required for **on-channel** storage:

1. Surface area (in acres) of on-channel reservoir at normal maximum operating level:______________.

2. Based on the Application information provided, Staff will calculate the drainage area above the on-channel dam or reservoir. If Applicant wishes to also calculate the drainage area they may do so at their option.
   Applicant has calculated the drainage area. **Y/N**
   If yes, the drainage area is____________ sq. miles.
   (If assistance is needed, call the Surface Water Availability Team prior to submitting the application, (512) 239-4691).

2. Structure Location (Instructions, Page. 23)

a. On Watercourse (if on-channel) (USGS name):______________________________

b. Zip Code: ________________

c. In the __________________Original Survey No. ______________, Abstract No.______________, ________________County, Texas.

**** A copy of the deed(s) with the recording information from the county records must be submitted describing the tract(s) that include the structure and all lands to be inundated.***

*****If the Applicant is not currently the sole owner of the land on which the structure is or will be built and sole owner of all lands to be inundated, Applicant must submit documentation evidencing consent or other documentation supporting Applicant's right to use the land described.***

d. A point on the centerline of the dam (on-channel) or anywhere within the impoundment (off-channel) is:

Latitude ______________°N, Longitude ______________°W.

****Provide Latitude and Longitude coordinates in decimal degrees to at least six decimal places***

di. Indicate the method used to calculate the location (examples: Handheld GPS Device, GIS, Mapping Program):______________________________

dii. Map submitted which clearly identifies the Impoundment, dam (where applicable), and the lands to be inundated. See instructions Page. 15. **Y / N**

WORKSHEET 3.0
DIVERSION POINT (OR DIVERSION REACH) INFORMATION

This worksheet **is required** for each diversion point or diversion reach. Submit one Worksheet 3.0 for **each** diversion point and two Worksheets for **each** diversion reach (one for the upstream limit and one for the downstream limit of each diversion reach).

The numbering of any points or reach limits should be consistent throughout the application and on supplemental documents (e.g. maps).

1. Diversion Information (Instructions, Page. 24)

a. This Worksheet is to add new (select 1 of 3 below):

1. Existing Permit 5611 Diversion Point No.
2. __________Upstream Limit of Diversion Reach No.
3. __________Downstream Limit of Diversion Reach No.

b. Maximum Rate of Diversion for **this new point** 1.16 cfs (cubic feet per second) or 521 gpm (gallons per minute)

c. Does this point share a diversion rate with other points? Y / N Y
If yes, submit Maximum ***Combined*** *Rate of Diversion for all points/reaches* 2.76 cfs or 1220.82 gpm

d. For amendments, is Applicant seeking to increase combined diversion rate? Y / N

*** An increase in diversion rate is considered a new appropriation and would require completion of Section 1, New or Additional Appropriation of State Water.*

e. Check (√) the appropriate box to indicate diversion location and indicate whether the diversion location is existing or proposed):

Check one		Write: Existing or Proposed
X	Directly from stream	Existing
	From an on-channel reservoir	
	From a stream to an on-channel reservoir	
	Other method (explain fully, use additional sheets if necessary)	

f. Based on the Application information provided, Staff will calculate the drainage area above the diversion point (or reach limit). If Applicant wishes to also calculate the drainage area, you may do so at their option.

Applicant has calculated the drainage area. Y / N Y

If yes, the drainage area is 756.06 sq. miles.
(If assistance is needed, call the Surface Water Availability Team at (512) 239-4691, prior to submitting application)

2. Diversion Location (Instructions, Page 25)

a. On watercourse (USGS name): Cibolo Creek tributary of San Antonio River

b. Zip Code: 78114

c. Location of point: In the Caballerias Original Survey No. 1, Abstract No.________, Wilson County, Texas.

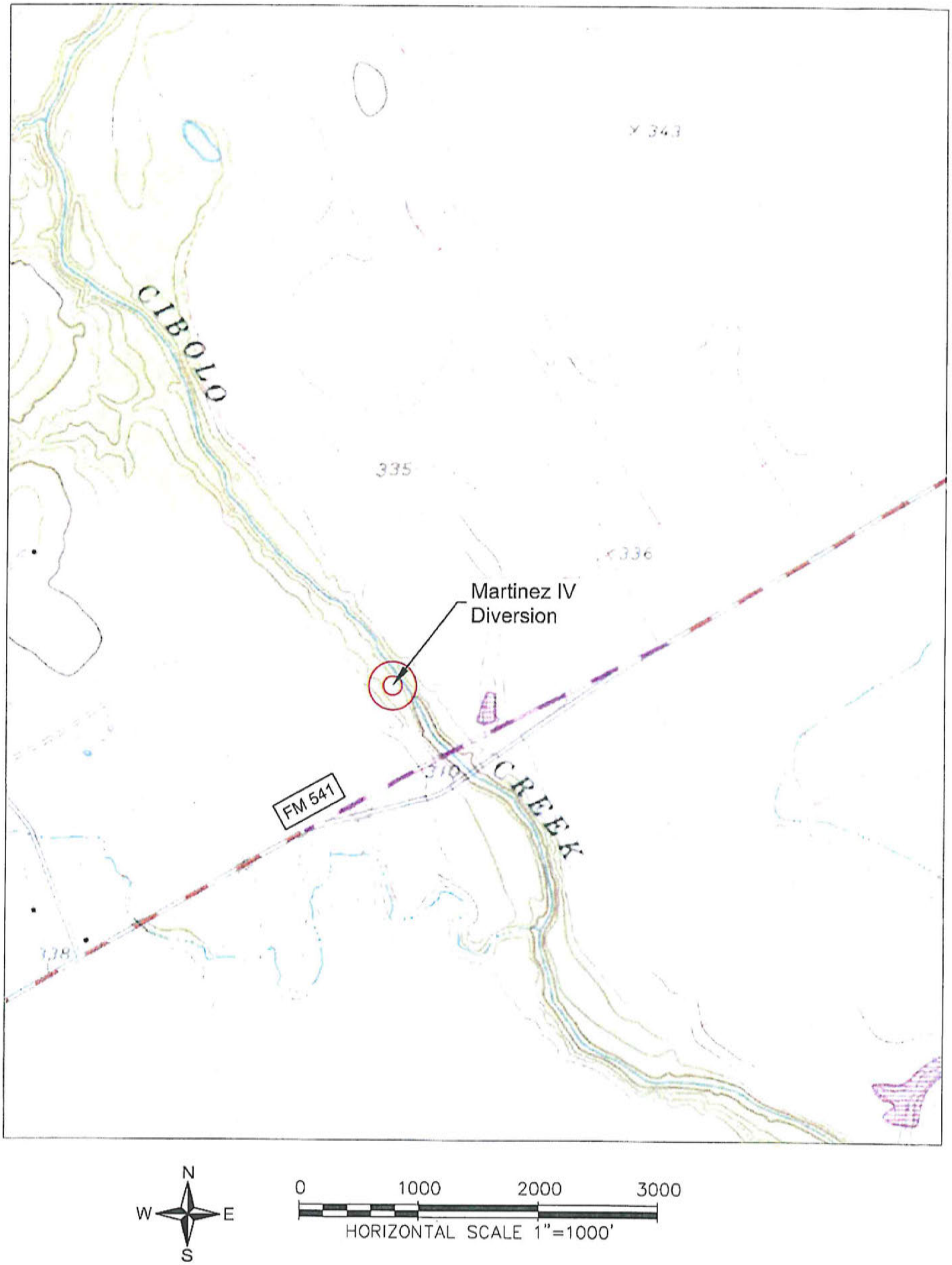
> ***A copy of the deed(s) with the recording information from the county records must be submitted describing tract(s) that include the diversion structure. For diversion reaches, the Commission cannot grant an Applicant access to property that the Applicant does not own or have consent or a legal right to access, the Applicant will be required to provide deeds, or consent, or other documents supporting a legal right to use the specific points when specific diversion points within the reach are utilized. Other documents may include, but are not limited to: a recorded easement, a land lease, a contract, or a citation to the Applicant's right to exercise eminent domain to acquire access.***

d. Point is at:
Latitude 29.0351 °N, Longitude -97.97146 °W.
Provide Latitude and Longitude coordinates in decimal degrees to at least six decimal places

e. Indicate the method used to calculate the location (examples: Handheld GPS Device, GIS, Mapping Program): Previous Water Right Application/Google Maps GPS Coordinates

f. Map submitted must clearly identify each diversion point and/or reach. See instructions Page. 38.

g. If the Plan of Diversion is complicated and not readily discernable from looking at the map, attach additional sheets that fully explain the plan of diversion.



CIBOLO CREEK
343
335
336
310
Martinez IV Diversion
FM 541
N
W
E
S
0
1000
2000
3000
HORIZONTAL SCALE 1"=1000'

WORKSHEET 4.0
DISCHARGE INFORMATION

This worksheet required for any requested authorization to discharge water into a State Watercourse for conveyance and later withdrawal or in-place use. Worksheet 4.1 is also required for each Discharge point location requested. **Instructions Page. 26.** ***Applicant is responsible for obtaining any separate water quality authorizations which may be required and for insuring compliance with TWC, Chapter 26 or any other applicable law.***

a. The purpose of use for the water being discharged will be municipal, agricultural, industrial, recreation, & environmental.

b. Provide the amount of water that will be lost to transportation, evaporation, seepage, channel or other associated carriage losses 78 % and explain the method of calculation: TWDB Methodology

Is the source of the discharged water return flows? Y / N Y If yes, provide the following information:

1. The TPDES Permit Number(s). WO0010749007 (attach a copy of the **current** TPDES permit(s))

2. Applicant is the owner/holder of each TPDES permit listed above? Y / N Y

PLEASE NOTE: If Applicant is not the discharger of the return flows, the application should be submitted under Section 1, New or Additional Appropriation of State Water, as a request for a new appropriation of state water. If Applicant is the discharger, then the application should be submitted under Section 3, Bed and Banks.

3. Monthly WWTP discharge data for the past 5 years in electronic format. (Attach and label as "Supplement to Worksheet 4.0").

4. The percentage of return flows from groundwater 100 , surface water ______?

5. If any percentage is surface water, provide the base water right number(s) ______.

c. Is the source of the water being discharged groundwater? Y / N N If yes, provide the following information:

1. Source aquifer(s) from which water will be pumped: ______

2. Any 24 hour pump test for the well if one has been conducted. If the well has not been constructed, provide production information for wells in the same aquifer in the area of the application. See http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp. Additionally, provide well numbers or identifiers ______.

3. Indicate how the groundwater will be conveyed to the stream or reservoir.

4. A copy of the groundwater well permit if it is located in a Groundwater Conservation District (GCD) or evidence that a groundwater well permit is not required.

ci. Is the source of the water being discharged a surface water supply contract? Y / N N
If yes, provide the signed contract(s).

cii. Identify any other source of the water ______

WORKSHEET 4.1
DISCHARGE POINT INFORMATION

This worksheet is required for **each** discharge point. Submit one Worksheet 4.1 for each discharge point. If there is more than one discharge point, the numbering of the points should be consistent throughout the application and on any supplemental documents (e.g. maps). **Instructions, Page 27.**

For water discharged at this location provide:

a. The amount of water that will be discharged at this point is 560 acre-feet per year. The discharged amount should include the amount needed for use and to compensate for any losses.

b. Water will be discharged at this point at a maximum rate of 1.16 cfs or 521 gpm.

c. Name of Watercourse as shown on Official USGS maps: Martinez Creek, tributary of Cibolo Creek, tributary of San Antonio River

d. Zip Code: 78152

f. Location of point: In the John Isham Original Survey No. 27, Abstract No. 365, Bexar County, Texas.

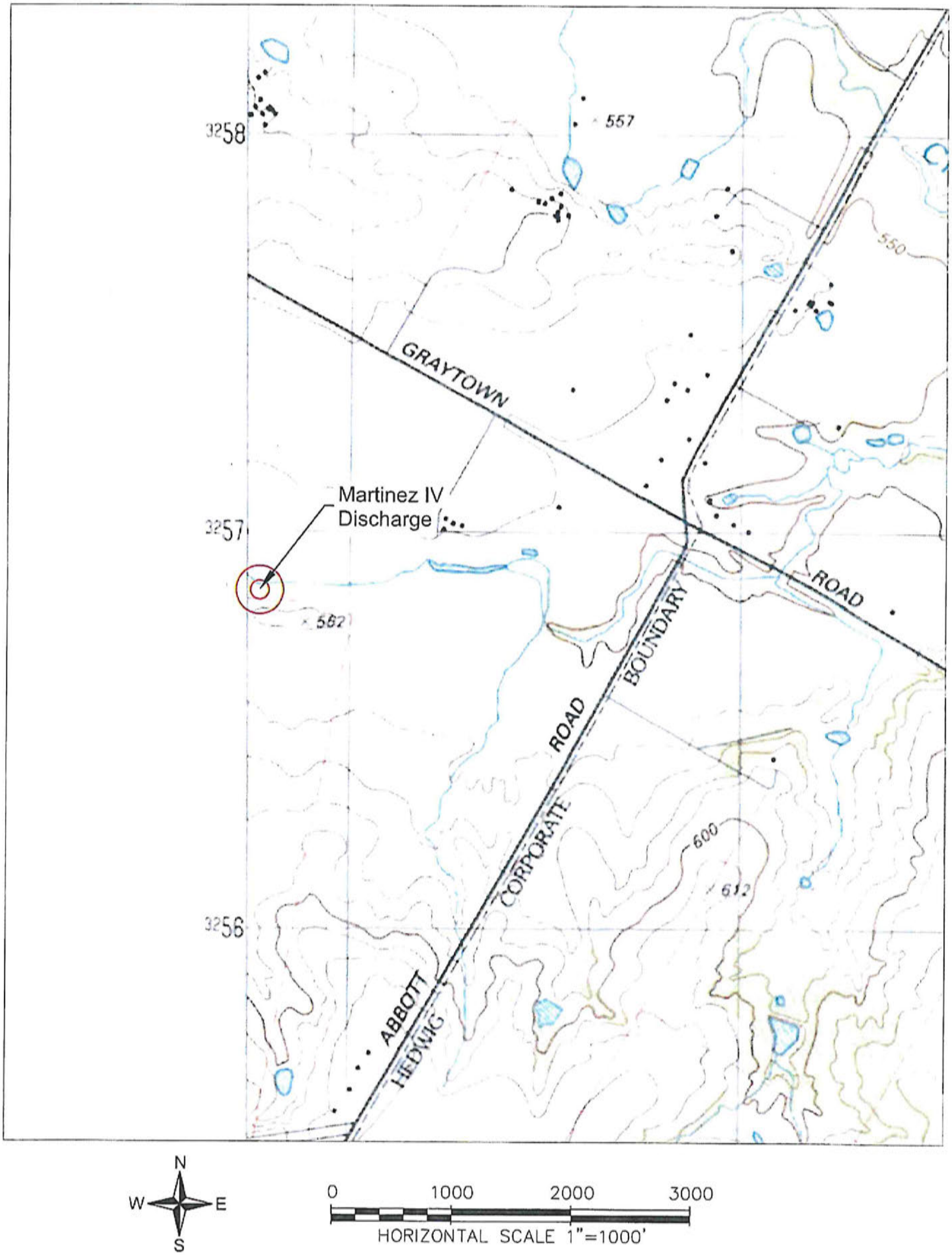
g. Point is at:

Latitude 29.440833 °N, Longitude 99.250000 °W.

Provide Latitude and Longitude coordinates in decimal degrees to at least six decimal places

h. Indicate the method used to calculate the discharge point location (examples: Handheld GPS Device, GIS, Mapping Program): Handheld GPS Device

Map submitted must clearly identify each discharge point. See instructions Page. 15.


3258
557
550
GRAYTOWN
3257
Martinez IV
Discharge
582
ROAD
BOUNDARY
ROAD
CORPORATE
600
612
3256
ABBOTT
HEDWIG
N
W
E
S
0
1000
2000
3000
HORIZONTAL SCALE 1"=1000'

WORKSHEET 5.0
ENVIRONMENTAL INFORMATION

This worksheet is required for new appropriations of water in the Canadian, Red, Sulphur, and Cypress Creek Basins. The worksheet is also required in all basins for: requests to change a diversion point, applications using an alternate source of water, and bed and banks applications. **Instructions, Page 28.**

1. New Appropriations of Water (Canadian, Red, Sulphur, and Cypress Creek Basins only) and Changes in Diversion Point(s)

Description of the Water Body at each Diversion Point or Dam Location. (Provide an Environmental Information Sheet for each location),

a. Identify the appropriate description of the water body.

- [x] Stream
- [ ] Reservoir

Average depth of the entire water body, in feet: ____________________

- [ ] Other, specify: ____________________

b. Flow characteristics

If a stream, was checked above, provide the following. For new diversion locations, check one of the following that best characterize the area downstream of the diversion (check one).

- [ ] Intermittent - dry for at least one week during most years
- [ ] Intermittent with Perennial Pools - enduring pools
- [x] Perennial - normally flowing

Check the method used to characterize the area downstream of the new diversion location.

- [x] USGS flow records
- [ ] Historical observation by adjacent landowners
- [ ] Personal observation
- [ ] Other, specify: ____________________

c. Waterbody aesthetics

Check one of the following that best describes the aesthetics of the stream segments affected by the application and the area surrounding those stream segments.

☐ Wilderness: outstanding natural beauty; usually wooded or unpastured area; water clarity exceptional

☒ Natural Area: trees and/or native vegetation common; some development evident (from fields, pastures, dwellings); water clarity discolored

☐ Common Setting: not offensive; developed but uncluttered; water may be colored or turbid

☐ Offensive: stream does not enhance aesthetics; cluttered; highly developed; dumping areas; water discolored

d. Waterbody Recreational Uses

Are there any known recreational uses of the stream segments affected by the application?

☐ Primary contact recreation (swimming or direct contact with water)

☒ Secondary contact recreation (fishing, canoeing, or limited contact with water)

☐ Non-contact recreation

Submit the following information in a Supplemental Attachment, labeled Addendum to Worksheet 5.0:

1. Photographs of the stream at the diversion point or dam location. Photographs should be in color and show the proposed point or reservoir and upstream and downstream views of the stream, including riparian vegetation along the banks. Include a description of each photograph and reference the photograph to the map submitted with the application indicating the location of the photograph and the direction of the shot.
2. Measures the applicant will take to avoid impingement and entrainment of aquatic organisms (ex. Screens on the new diversion structure).
3. If the application includes a proposed reservoir, also include:
   - i. A brief description of the area that will be inundated by the reservoir.
   - ii. If a United States Army Corps of Engineers (USACE) 404 permit is required, provide the project number and USACE project manager.
   - iii. A description of how any impacts to wetland habitat, if any, will be mitigated if the reservoir is greater than 5,000 acre-feet.

2. Alternate Sources of Water and/or Bed and Banks Applications

For all bed and banks applications:

a. Indicate the measures the applicant will take to avoid impingement and entrainment of aquatic organisms (ex. Screens on the new diversion structure).

b. An assessment of the adequacy of the quantity and quality of flows remaining after the proposed diversion to meet instream uses and bay and estuary freshwater inflow requirements.

If the alternate source is treated return flows, provide the TPDES permit number WQ0010749007

If groundwater is the alternate source, or groundwater or other surface water will be discharged into a watercourse provide:

a. Reasonably current water chemistry information including but not limited to the following parameters in the table below. Additional parameters may be requested if there is a specific water quality concern associated with the aquifer from which water is withdrawn. If data for onsite wells are unavailable; historical data collected from similar sized wells drawing water from the same aquifer may be provided. However, onsite data may still be required when it becomes available. Provide the well number or well identifier. Complete the information below for each well and provide the Well Number or identifier.

Parameter	Average Conc.	Max Conc.	No. of Samples	Sample Type	Sample Date/Time
Sulfate, mg/L					
Chloride, mg/L					
Total Dissolved Solids, mg/L					
pH, standard units					
Temperature*, degrees Celsius					

* Temperature must be measured onsite at the time the groundwater sample is collected.

b. If groundwater will be used, provide the depth of the well ________ and the name of the aquifer from which water is withdrawn ____________________________.

WORKSHEET 6.0
Water Conservation/Drought Contingency Plans

This form is intended to assist applicants in determining whether a Water Conservation Plan and/or Drought Contingency Plans is required and to specify the requirements for plans. **Instructions, Page 31.**

The TCEQ has developed guidance and model plans to help applicants prepare plans. Applicants may use the model plan with pertinent information filled in. For assistance submitting a plan call the Resource Protection Team (Water Conservation staff) at 512-239-4691, or e-mail wras@tceq.texas.gov. The model plans can also be downloaded from the TCEQ webpage. ***Please use the most up-to-date plan documents available on the webpage.***

1. Water Conservation Plans

a. The following applications must include a completed Water Conservation Plan (30 TAC § 295.9) for each use specified in 30 TAC, Chapter 288 (municipal, industrial or mining, agriculture – including irrigation, wholesale):

1. Request for a new appropriation or use of State Water.
2. Request to amend water right to increase appropriation of State Water.
3. Request to amend water right to extend a term.
4. Request to amend water right to change a place of use.
   **does not apply to a request to expand irrigation acreage to adjacent tracts.*
5. Request to amend water right to change the purpose of use.
   **applicant need only address new uses.*
6. Request for bed and banks under TWC § 11.042(c), when the source water is State Water
   **including return flows, contract water, or other State Water.*

b. If Applicant is requesting any authorization in section (1)(a) above, indicate each use for which Applicant is submitting a Water Conservation Plan as an attachment:

1. __X__Municipal Use. See 30 TAC § 288.2. **
2. __X__Industrial or Mining Use. See 30 TAC § 288.3.
3. __X__Agricultural Use, including irrigation. See 30 TAC § 288.4.
4. _____Wholesale Water Suppliers. See 30 TAC § 288.5. **

**If Applicant is a water supplier, Applicant must also submit documentation of adoption of the plan. Documentation may include an ordinance, resolution, or tariff, etc. See 30 TAC §§ 288.2(a)(1)(J)(i) and 288.5(1)(H). Applicant has submitted such documentation with each water conservation plan? Y / N Y

c. Water conservation plans submitted with an application must also include data and information which: supports applicant's proposed use with consideration of the plan's water conservation goals; evaluates conservation as an alternative to the proposed

appropriation; and evaluates any other feasible alternative to new water development. See 30 TAC § 288.7.
Applicant has included this information in each applicable plan? **Y / N**

2. Drought Contingency Plans

a. A drought contingency plan is also required for the following entities if Applicant is requesting any of the authorizations in section (1) (a) above – indicate each that applies:

1. __X__ Municipal Uses by public water suppliers. See 30 TAC § 288.20.

2. __X__ Irrigation Use/ Irrigation water suppliers. See 30 TAC § 288.21.

3. _____ Wholesale Water Suppliers. See 30 TAC § 288.22.

b. If Applicant must submit a plan under section 2(a) above, Applicant has also submitted documentation of adoption of drought contingency plan (*ordinance, resolution, or tariff, etc. See 30 TAC § 288.30*) Y / N Y

RESOLUTION NO. R-1551

RESOLUTION R-1551 APPROVING THE UPDATES TO THE RIVER AUTHORITY CONSERVATION PLAN TO BE SUBMITTED TO THE TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

WHEREAS, the San Antonio River Authority adopted a Water Conservation and Drought Contingency Plan on October 15, 2003 as part of its overall stewardship of the water resources within the San Antonio River Basin; and

WHEREAS, as a water right holder and wholesale reuse water supplier, the River Authority was required to submit a Water Conservation and Drought Contingency Plan to the Texas Commission on Environmental Quality (TCEQ); and

WHEREAS, the conservation plan was updated on June 20, 2007 and May 18, 2011 and needs to be updated every five years in order to apply for Texas Water Development Board funding;

NOW, THEREFORE, BE IT RESOLVED BY THE BOARD OF DIRECTORS OF THE RIVER AUTHORITY THAT:

The San Antonio River Authority Water Conservation and Drought Contingency Plan, attached hereto, is approved and the General Manager is authorized and directed to submit said Plan to the Texas Commission on Environmental Quality.

PASSED AND APPROVED this the 18 day of January, 2017.

MICHAEL W. LACKEY, P.E., Chairman

ATTEST:

HECTOR R. MORALES, Secretary

CERTIFICATE OF SECRETARY

SAN ANTONIO RIVER AUTHORITY	§
	§
SAN ANTONIO, BEXAR COUNTY, TEXAS	§

I hereby certify the above and foregoing to be a duplicate original of Resolution R-1551 of the Board of Directors of the SAN ANTONIO RIVER AUTHORITY as passed and approved by the members of said Board at a regular meeting of the Board of Directors of said AUTHORITY held on January 18, 2017, in San Antonio, Bexar County, Texas, at which a quorum was present, as shown by the Minutes of said meeting.

IN TESTIMONY WHEREOF, witness my hand and the official seal of the SAN ANTONIO RIVER AUTHORITY on this the 18 day of January, A.D., 2017, in San Antonio, Bexar County, Texas.

HECTOR R. MORALES, Secretary