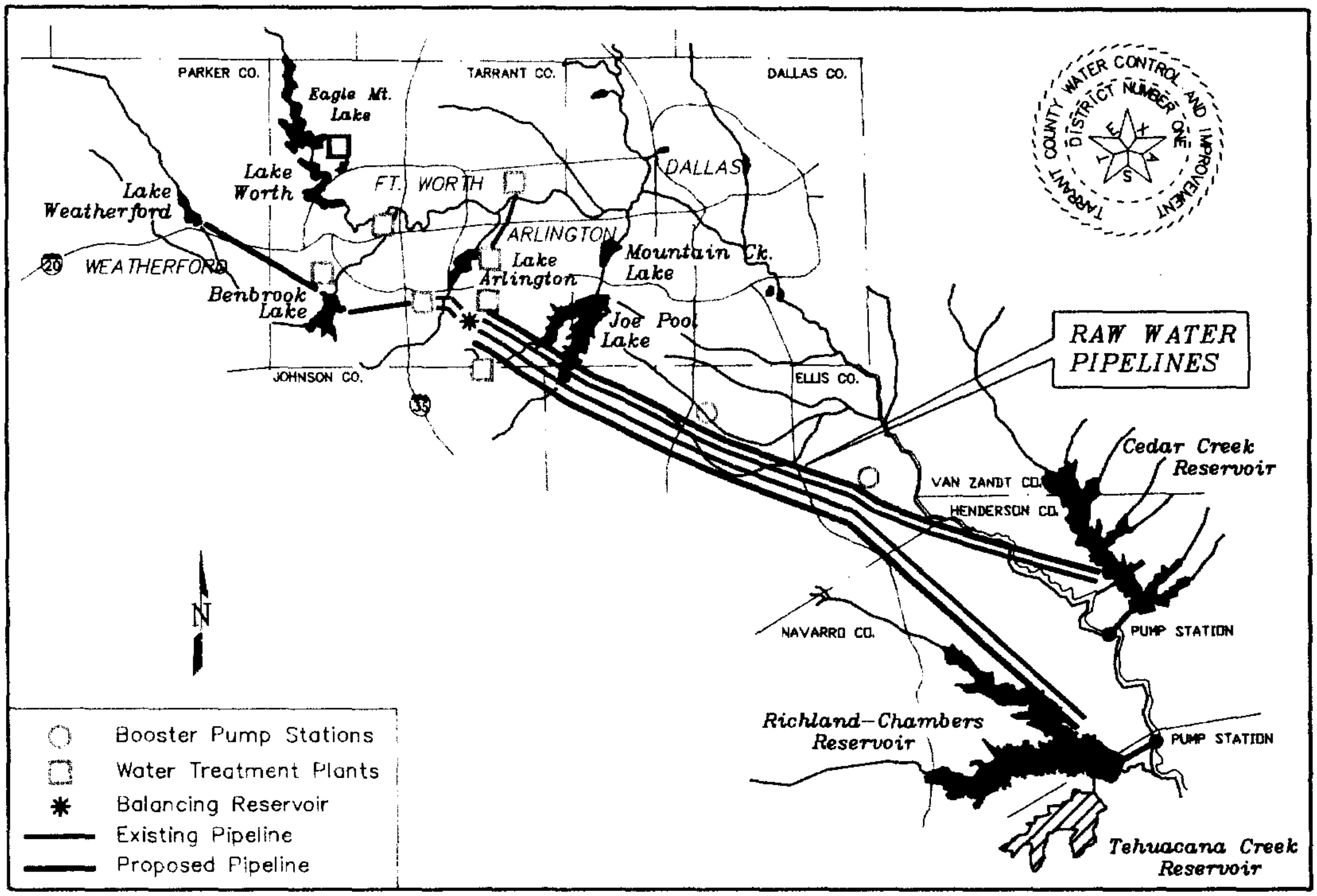
November 1991

Report for

Tarrant County
Water Control and Improvement
District Number One



Water Quality Assessments
and
Recommended Pilot–Scale/Bench–Scale Studies

November 1991

Report for

Tarrant County
Water Control and Improvement
District Number One

Water Quality Assessments
and
Recommended Pilot–Scale/Bench–Scale Studies
Associated with Water Supply Diversion
from
the Trinity River

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EXECUTIVE SUMMARY

The Tarrant County Water Control and Improvement District Number One (District) Regional Water Supply Plan, completed in 1990, recommends the following water supply plan for the future:

Step 1: Construct facilities to divert supplemental water from the Trinity River into Richland-Chambers Reservoir by about the year 2016.

Step 2: Construct facilities to divert supplemental water from the Trinity River into Cedar Creek Reservoir by about the year 2028.

Step 3: Construct facilities to allow the Richland-Chambers and Cedar Creek Reservoirs to operate as a system by about the year 2037.

Step 4: Construct Tehuacana Reservoir and a facility to divert supplemental water from the Trinity River into Tehuacana Reservoir by about the year 2042.

The District's Plan also recommends that more detailed water quality evaluations and laboratory-scale/pilot-scale studies be conducted before making a definite decision regarding the construction of the Trinity River diversion system. This study is the first of several detailed investigations that are needed to make this decision. The primary objectives of this study are:

1. Determine the quality of diversion water for the various Trinity River flow regimes that occur during diversion of flows.

2. Determine the impact of diverted flows on Richland-Chambers and Cedar Creek Reservoirs and the possible need for treatment of the diversions.

3. Determine the impact of the diversions on downstream Trinity River water quality and quantity.

4. Assess alternative methods for treating diverted flows and recommend pilot-scale and/or laboratory-scale studies for obtaining additional information concerning the cost and effectiveness of selected alternatives.

5. Prepare conceptual designs and cost estimates for selected additional studies.

Preliminary lake quality modeling performed by the District using the U.S. Army Corps of Engineers (COE) "BATHTUB" model indicates that nutrients in the Trinity diversion water will impact water quality in Cedar Creek Reservoir when the diversion is into the main body of the lake. The effect of treatment of the diverted flow to reduce nutrient concentrations to those levels experienced in runoff in the Cedar Creek watershed was examined. This examination showed little improvement in water quality associated with reducing nutrient concentrations in the diversion flows to those levels experienced in lake inflows. This suggests that further reductions in nutrients would be required to improve water quality. For Richland-Chambers Reservoir the model indicates a water quality impact associated with nutrients from the diverted flow. A substantial improvement in water quality is associated with reducing nutrients to concentrations experienced in lake inflows.

The "BATHTUB" model employs a series of empirical relations to represent key processes. The empirical relations are based on data from existing COE reservoirs and are not represented, in the model, by fundamental mechanisms. The processes characterized by these empirical formulations substantially influence chlorophyll "a" which is the variable used to determine the effects of diversions. Therefore, the results from the "BATHTUB" modeling provides an initial indication of the water quality effects from diversions. Further substantiation, is required, employing models such as WASP which can employ representations of the fundamental mechanisms governing chlorophyll "a" responses to changes in nutrient inputs. The District is currently developing a database for use in calibrating and verifying the WASP model for Richland-Chambers Reservoir. As the WASP model is more deterministic than BATHTUB, we recommend its use in verifying the above mentioned quality impacts of nutrients in Trinity

Diversion water on Richland-Chambers Reservoir. Similar use should be made of the WASP model for Cedar Creek Reservoir as soon as the District is able to obtain a database suitable for calibration/verification of the model.

Water quality modeling of the impact of the diversion on Trinity River water quality was performed by Alan Plummer and Associates, Inc. (APAI) using the Texas Water Commission's (TWC) QUAL-TX model. This modeling revealed that, if anything, the diversion will have a slight positive impact on dissolved oxygen in downstream reaches of the river.

Based on the results of this study which included a detailed literature review involving the District, APAI and Texas Christian University (TCU), the following additional investigations should be considered:

1. Pilot-scale constructed wetland in the vicinity of Richland-Chambers dam.

2. Laboratory-scale investigation of removal of phosphorus from Trinity River water using chemical precipitation.

3. Bench-scale studies of nutrient removal using periphyton/fish culture.

The objectives of a pilot-scale constructed wetland are:

- To provide data on removal efficiencies of the wetland cells for nutrients (P and N), heavy metals, TSS, fecal coliforms and toxic organics.

- To test the suitability of various aquatic macrophyte plants and communities based on removal efficiencies for the contaminants listed above, seasonality of removal efficiencies, and adaptation of the aquatic macrophytes to the constructed wetland environment.

- To determine if harvesting will be necessary for long-term removal of contaminants.

- To determine the long-term effectiveness of constructed wetlands in the removal of contaminants.

- To determine operational requirements for effective contaminant removal from the diverted river water.

Using contractor labor and material, a 0.1 MGD pilot-scale wetland constructed on District property below the Richland-Chambers dam would cost approximately $233,000 depending on proximity to the Trinity River and other factors such as hydraulic considerations, and access requirements. Once the specifications for the final design are completed, the information will be submitted to the District for their review to determine what portions of the construction the District will undertake.

The laboratory-scale investigation of phosphorus removal using chemical precipitation will cost approximately $25,000 for the District to perform. In view of this relatively modest cost and the potential benefit to Richland-Chambers lake associated with phosphorus reduction in the diversion water, APAI recommends that the District proceed with this investigation.

Though information on the effectiveness of periphyton/fish culture systems in removing nutrients is relatively sparse, literature reviewed by TCU during this study suggest that periphyton (attached algae) may have potential in removing nutrients from Trinity River water and that certain species of fish can then be used in removing the algae. Initial bench-scale studies to obtain information on the effectiveness of this process have been proposed. Again, the relative low cost of these additional studies and the potential benefit associated with nutrient reduction in the diversion water justify the District's proceeding with the periphyton/fish culture bench-scale studies. It should be noted that if the initial studies prove successful, additional study will be warranted.

The above recommendations will require a substantial amount of water quality sampling and testing by the District. The following recommendations are made regarding additional water quality monitoring:

1. Conduct weekly sampling and testing of the pilot-scale constructed wetland. Weekly sampling will be performed for influent to the constructed wetland, effluent from the constructed wetland, and various cells within the wetland. Routine analyses will be performed for total suspended solids, nutrients (N and P), heavy metals, and fecal coliform. Some testing of toxic organic compounds may also be required depending on the results of Trinity River sampling and testing proposed herein.

2. Conduct sampling and testing for pH, total suspended solids, alkalinity, total phosphorus, dissolved phosphorus, and total orthophosphorus relative to the laboratory-scale study of phosphorus removal by chemical precipitation.

3. Conduct a sampling program on the Trinity River in the vicinity of Trinidad to gather additional data for metals and toxic organics under low and high streamflow conditions.

4. Continue existing water quality sampling and testing program for Richland-Chambers and Cedar Creek Reservoirs and watersheds.

5. As the proposed Water Supply Plan calls for the construction of Tehuacana Reservoir by the year 2042, the District should consider developing an ongoing water quality monitoring program for Tehuacana Creek within the next two to three years.

The above sampling and testing recommendations are discussed in detail in Chapter VIII.

CHAPTER I
BACKGROUND

In 1990 Tarrant County Water Control and Improvement District Number One (District), with assistance from the Texas Water Development Board (TWDB), completed a Regional Water Supply Plan that projects water supply requirements through the year 2050 and evaluates various options for meeting these requirements. This Plan indicates that by the year 2016 a new water supply source should be added and that by the year 2050 a total of 213,000 AF/Y (190 MGD) of new supply will be needed.

In evaluating various options for supplying the water, 46 alternative potential sources were identified. These alternatives were divided into the following categories:

a. Gains in yield due to coordinated system operation of the District's reservoirs.

b. Reuse of reclaimed water.

c. Diversions from the Trinity River to increase the yields of Richland-Chambers Reservoir and/or Cedar Creek Reservoir.

d. Existing reservoirs that are not yet fully used and may not be totally committed.

e. Proposed new reservoirs.

Preliminary evaluations conducted in the Regional Water Supply Plan resulted in four scenarios to be considered by the District. <u>Scenario 1</u>, which is slightly more economical than the lowest cost competing scenario, involves the following four general steps:

Step 1: Construct facilities to divert supplemental water from the Trinity River into Richland-Chambers Reservoir by about 2016.

Step 2: Construct facilities to divert supplemental water from the Trinity River into Cedar Creek Reservoir by about 2028.

Step 3: Construct facilities to allow the Richland-Chambers and Cedar Creek Reservoirs to operate as a system by about the year 2037.

Step 4: Construct Tehuacana Reservoir and a facility to divert supplemental water from the Trinity River into Tehuacana Reservoir by about 2042.

The above four-step program provides an estimated new supply of 237,000 AF/Y, or slightly more than the projected need of 213,000 AF/Y as of 2050.

The three other potentially viable scenarios which were considered would involve the construction of reservoir(s) in the Sulphur River Basin and the transmission of water from the Sulphur River Basin to Tarrant County. However, these scenarios are estimated to be from $37 million and $293 million more expensive than the "Trinity Diversion" scenario previously outlined[1]. Also, construction of reservoirs in the Sulphur River Basin may involve a greater number of environmental considerations and potentially more public opposition.

Taking these factors into consideration, the Water Supply Plan recommended that between 1990 and 1995 further water quality testing, evaluations, and pilot-scale operations be conducted. This allows a determination to be made regarding the need for and effectiveness of pretreatment of Trinity River water prior to discharge into Richland-Chambers or Cedar Creek Reservoirs. These additional investigations include the following:

a. Perform additional detailed water quality monitoring of the Trinity River in the area of the proposed diversions, to develop more data on specific constituents at varying flow conditions.

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[1] Present value analyses using 1989 dollars.

b. Continue to monitor the water quality of Richland-Chambers and Cedar Creek Reservoirs. Expand the existing quality monitoring program in the lake areas that will receive the diversions.

c. Set up a program of water quality sampling on Tehuacana Creek at or close to the proposed Tehuacana Dam site.

d. Calibrate and verify the eutrophication computer model for Richland-Chambers and Cedar Creek Reservoirs.

e. Using the total body of available data, including the additional data obtained under "a" above, run additional computer model simulations to show the effect of the Trinity diversions on the quality of water in Richland-Chambers and Cedar Creek Reservoirs.

f. Perform a preliminary investigation of possible treatment methods applicable to the Trinity River water, based on available water quality data.

g. Carry out a pilot-scale demonstration project at Richland-Chambers Reservoir to determine whether there will be a need to pretreat the river water as it is diverted and, if pretreatment is needed, to determine the effectiveness of alternative methods such as natural systems, detention basins, chemical clarifiers, etc.

h. Develop a conceptual design of the required diversion facilities and pretreatment facilities (if needed).

i. Prepare an updated opinion of probable diversion system costs.

This report provides the following of the above listed items:

1. Water quality monitoring programs required in items a, b and c;

2. Preliminary water quality modeling of Richland-Chambers and Cedar Creek Reservoirs called for in items d and e; (Note: Additional work is needed on these items.)

3. Preliminary investigation of possible treatment methods applicable to Trinity River water (item f); and

4. Conceptual design of pilot-scale/bench-scale demonstration project(s) called for in item g.

The Water Supply Plan also recommends that the District make a final decision by the year 2000 on the feasibility of supplemental diversions from the Trinity River into Richland-Chambers and Cedar Creek Reservoirs. If it is determined that the diversion concept is not desirable or that the required degree of pretreatment makes it uneconomical, the District will proceed with development of other alternatives to provide the needed additional supply (213,000 AF/Y). Studies to date indicate that the preferred other alternative probably would be a surface water reservoir in the Sulphur River Basin. If the Trinity diversion approach continues to be the preferred alternative, the District will proceed with permitting, designing, and constructing facilities based on the Water Supply Plan and the results of the testing programs.

CHAPTER II
STUDY OBJECTIVES AND PROCEDURES

As mentioned in Chapter I, the District's Regional Water Supply Plan recommends that more detailed water quality evaluations and pilot-scale/bench-scale studies be conducted before making a definite decision before the year 2000, concerning the construction of the Trinity River diversion alternative. This study is the first of several detailed investigations that are needed to facilitate this decision. The primary objective of this study is to determine the need for, and effectiveness of, pretreatment of Trinity River water prior to discharge into Richland-Chambers or Cedar Creek Reservoirs. The following procedures were followed, to the extent possible, in performing this study:

a. Task 1 - Gathered and Reviewed Information and Data: Involved identifying, gathering, and reviewing the following information and data:

   1) Information about pretreatment alternatives such as: water hyacinth ponds, natural wetlands, constructed wetlands, fish culture, rock/plant filters, physical-chemical processes, and overland flow processes. The District performed a literature search for this material and provided the Engineer a list of references and available abstracts for selected references. The District provided a copy of selected relevant documents for review by the Engineer.

   2) Water quality data for the Trinity River, Cedar Creek Reservoir, and Richland-Chambers Reservoir.

b. Task 2 - Performed a Hydrologic Analysis of the Proposed Diversions: Involved performing an analysis of the hydrologic considerations related to diverting water from the Trinity River into Cedar Creek and Richland-Chambers Reservoirs. The hydrologic analysis included:

1) Extending available hydrologic data for Cedar Creek and Richland-Chambers Reservoirs to cover 1987 and 1988, so that data are available from 1941 through 1988.
2) Developing estimates of historical daily Trinity River flows at a Cedar Creek diversion pump station site and at Richland-Chambers diversion pump station site from 1941 through 1988.

3) Estimating the historic return flow of treated effluent on a monthly basis, and the historic natural runoff at each diversion site on a daily basis based on available records from the TWC and other agencies.

4) Projecting return flows of treated effluent and the resulting flows in the Trinity River at the two diversion points under the following conditions:

   a) Projected 2020 return flows with minimal upstream reuse of treated effluent.

   b) Projected 2050 return flows with reuse of treated effluent by Dallas, as proposed in their recent water plan.

5) Developing pump station capacities and operation policies for diversions from the Trinity River. Considered the need for makeup water to achieve a desired 30 percent increase in yield resulting from the diversions, the projected daily flows in the river, and the possible impact of diversions on river flows, including the 7-day 2-year low flow.

6) Conducting monthly operation studies of Cedar Creek and Richland-Chambers Reservoirs to determine diversions from the Trinity River into Cedar Creek and Richland-Chambers Reservoirs using 1941-1988 hydrologic data and operating policies. Developing a record of the monthly flow to the reservoirs from runoff from the reservoir watersheds, diversions of natural runoff from the

Trinity River, and diversions of treated effluent return flow from the Trinity River.

7) Determining the impact of the diversions on the flow of the Trinity River downstream from the diversion sites in detail for one set of operation policies.

c. Task 3 - Established Probable Trinity River Diversion Water Quality Conditions: Based on Information developed in Tasks 1 and 2, previously mentioned. The probable Trinity River water quality conditions were determined during the time periods that diversions are projected.

d. Task 4 - Established Quality Criteria for the Trinity River Water to be Diverted to the Reservoirs: Involved a cooperative effort between the District and Engineer to establish water quality criteria for Trinity River water diverted to the reservoirs. The establishment of the criteria will include an examination, using available data, of the concentrations of nitrogen and phosphorus associated with the tributaries discharging into the reservoirs and the assessment of the water quality impact of the proposed diversions on water quality in the two study reservoirs (Task 7). As explained in more detail later in this report, this task will require ongoing work beyond the time frame for the current study.

e. Task 5 - Preliminary Selection of Alternate Treatment Methods (ATM): Involved the selection of alternative treatment methods. An initial assessment was made of the applicability of the selected ATMs for treating the Trinity River diversions. A screening of the ATMs was performed jointly by the District and Engineer, which identified candidates to be examined in more detail.

f. Task 6 - Performed Assessment of the Trinity River Diversion Impact on the Downstream Trinity River Water Quality Conditions: Focused on the dissolved oxygen conditions in the river with respect to potential treatment requirements that could be imposed on the upstream wastewater treatment plants as a result of diverting flows from the Trinity River.

g. Task 7 - Performed Assessment of the Impact of the Trinity River Diversion on the Water Quality Conditions of the Two Study Reservoirs: A preliminary assessment of the impacts of Trinity River water was performed using a nutrients lake quality model ("BATHTUB") obtained from the U.S. Army COE. This assessment will be refined and checked in the future using calibrated/verified water quality models being developed by the District for Richland-Chambers and Cedar Creek Reservoirs.

h. Task 8 - Performed Detailed Assessment of Primary Alternative Treatment Method Candidates: A more detailed assessment was performed of the candidates identified in Task 5 to identify two to six candidates for recommended pilot-scale/bench-scale studies. This assessment included a preliminary examination of treatment performance, operation requirements, maintenance requirements, construction and operation costs, accumulation potential of metals in solids/sediments in the treatment units, and response to both high-flow and low-flow conditions. Consideration was also given to permitting and environmental protection requirements.

i. Task 9 - Developed Conceptual Design of Pilot-Scale Demonstration Facilities for Selected ATMs: Involved development of the conceptual designs of pilot-scale/bench-scale demonstration facilities for the three candidates identified on the basis of Task 8. The demonstration facilities were described to the District's legal counsel for an examination of legal considerations. Field visits were made to the Richland-Chambers Reservoir area to inspect possible locations(s) for constructing the demonstration facilities. The probable costs for constructing, operating, and maintaining pilot-scale demonstration facilities was also developed.

j. Task 10 - Developed Pilot-Scale Demonstration Project Plan of Operation: Involved developing a detailed Plan of Operation for the pilot-scale demonstration project. The Plan identifies the time period and length of operation for each of the candidates to be implemented. It defines, in general terms, operation and maintenance activities for the pilot-scale facilities. Sampling and testing programs are also described.

k. Task 11 - Prepared Report: Ten draft copies of this report are being presented for review and comments. Twenty-five copies of the final report will be submitted to the District.

l. Task 12 - Meetings: This study involved working very closely with the District and a significant amount of coordination with various parties. The following meetings and coordination efforts were conducted.

1) Four meetings and workshops with District staff
2) Two meetings with District Advisory Committee
3) One meeting with District Board
4) Two meetings with the TWC
5) Two meetings with TWDB
6) Two meetings with the Texas Department of Parks and Wildlife

CHAPTER III
HYDROLOGIC ANALYSIS OF THE PROPOSED DIVERSIONS

INTRODUCTION

The District is the major water supplier within the area for which it provides water service. The District obtains its water supply from five reservoirs - Lake Bridgeport and Lake Eagle Mountain on the West Fork of the Trinity River, Lake Benbrook on the Clear Fork, and Cedar Creek and Richland-Chambers Reservoirs in East Texas. As of 1990, the District's total dependable water supply from these facilities was estimated to be approximately 470,800 AF/Y. The combined yields from Cedar Creek and Richland-Chambers Reservoirs account for approximately 82 percent of the total.

Projections for the future water requirements within the study area through 2050 were presented in the Regional Water Supply Plan. These projections were based on the TWDB's projections using the high series population trends, high per capita use, and water conservation measures. Figure III-1 shows the projected net requirements that might logically be provided by the District through 2050. Also shown in Figure III-1 is the District's present total water supply capability of approximately 470,800 AF/Y. This total yield is shown to decrease slightly with time, due to siltation in the lakes.

Based on the projected water requirements, it is indicated in Figure III-1 that a new source of supply should be added by about the year 2016 and that a total of 213,000 AF/Y of new supply will be needed by the year 2050. The preferred development plan recommended in the Regional Water Supply Study will ultimately provide 237,000 AF/Y and would be implemented as follows:

Step 1: By about the year 2016, add facilities to divert supplemental water from the Trinity River into Richland-Chambers Reservoir, for a gain in yield of 63,000 AF/Y.

COMPARISON OF EXISTING SUPPLY AND PROJECTED REQUIREMENTS

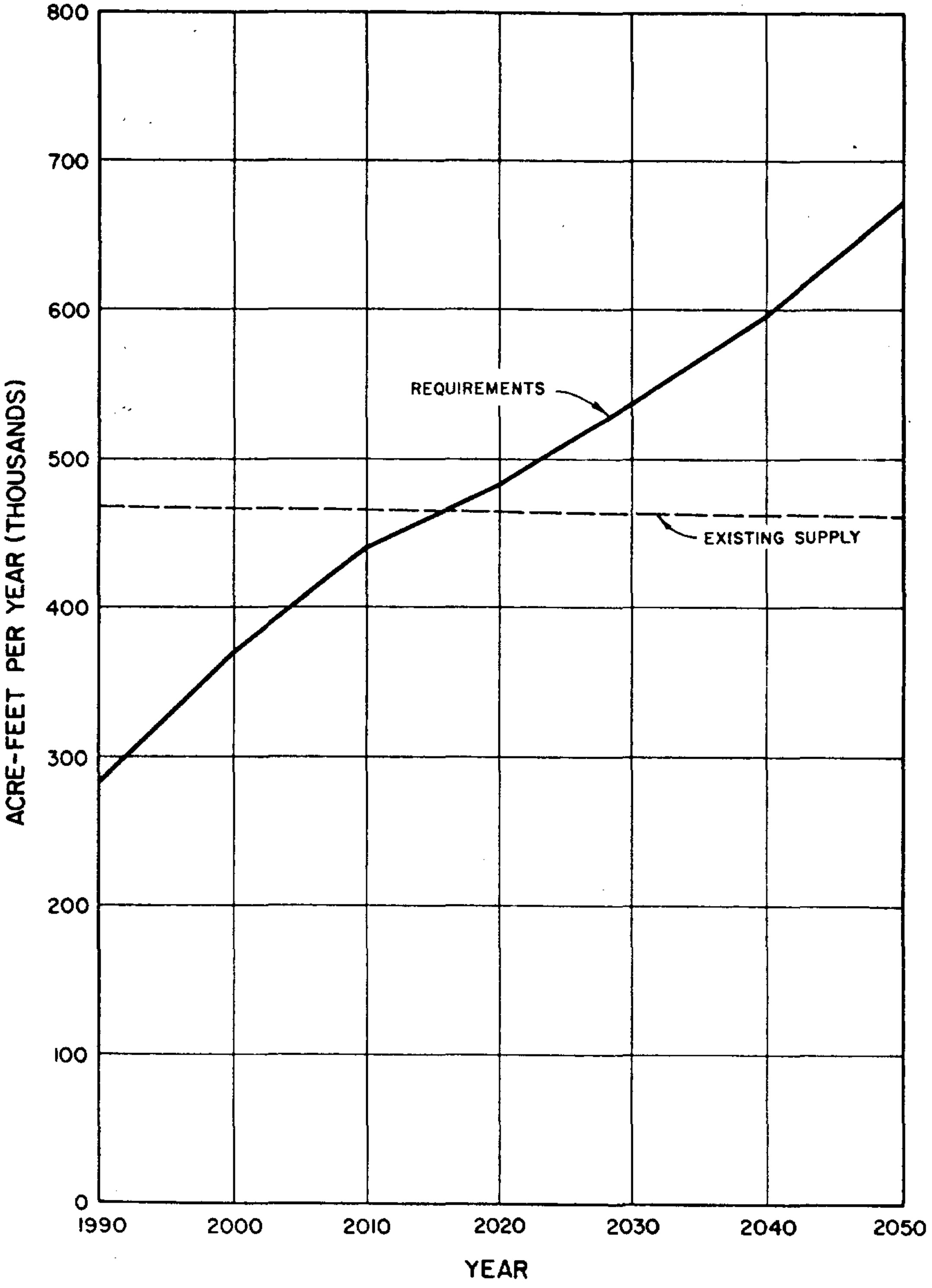


FIGURE III-1

Step 2: By about the year 2028, add similar facilities to divert supplemental water from the Trinity River into Cedar Creek Reservoir, for a gain in yield of 52,500 AF/Y.

Step 3: By about the year 2037, begin operation of Richland-Chambers Reservoir and Cedar Creek Reservoir as a coordinated system, for a gain in yield of 32,800 AF/Y.

Step 4: By about the year 2042, construct Tehuacana Reservoir and excavate a connecting channel between Tehuacana and Richland-Chambers. Also increase the diversion capacity from the Trinity River into Richland-Chambers in proportion to the added dependable yield made available by Tehuacana Reservoir. The total gain in yield from Tehuacana and the additional Trinity diversion capability will be 88,700 AF/Y.

The anticipated gains in yield due to Trinity diversions represent 30 percent increases in the reservoirs' yields. An implementation schedule for this development plan is shown graphically in Figure III-2.

ANALYSIS OF TRINITY RIVER FLOW AT DIVERSION POINTS

Further analysis has been made to determine the feasibility of diverting flow from the Trinity River to Cedar Creek and Richland-Chamber Reservoirs. Feasibility was investigated in terms of both quantity and quality of the diversion flow. Wastewater return flows from the Dallas-Fort Worth metroplex area comprise a large proportion of the streamflow during low-flow conditions in the Trinity River. As later sections of this report will show, it is during the low streamflow conditions that flow diversions to the reservoirs are most required. For that reason, it is necessary to analyze the historical streamflow in conjunction with the historical return flows. This conjunctive analysis allowed a projection of future flow conditions in the Trinity River that will

WATER SUPPLY IMPLEMENTATION SCHEDULE

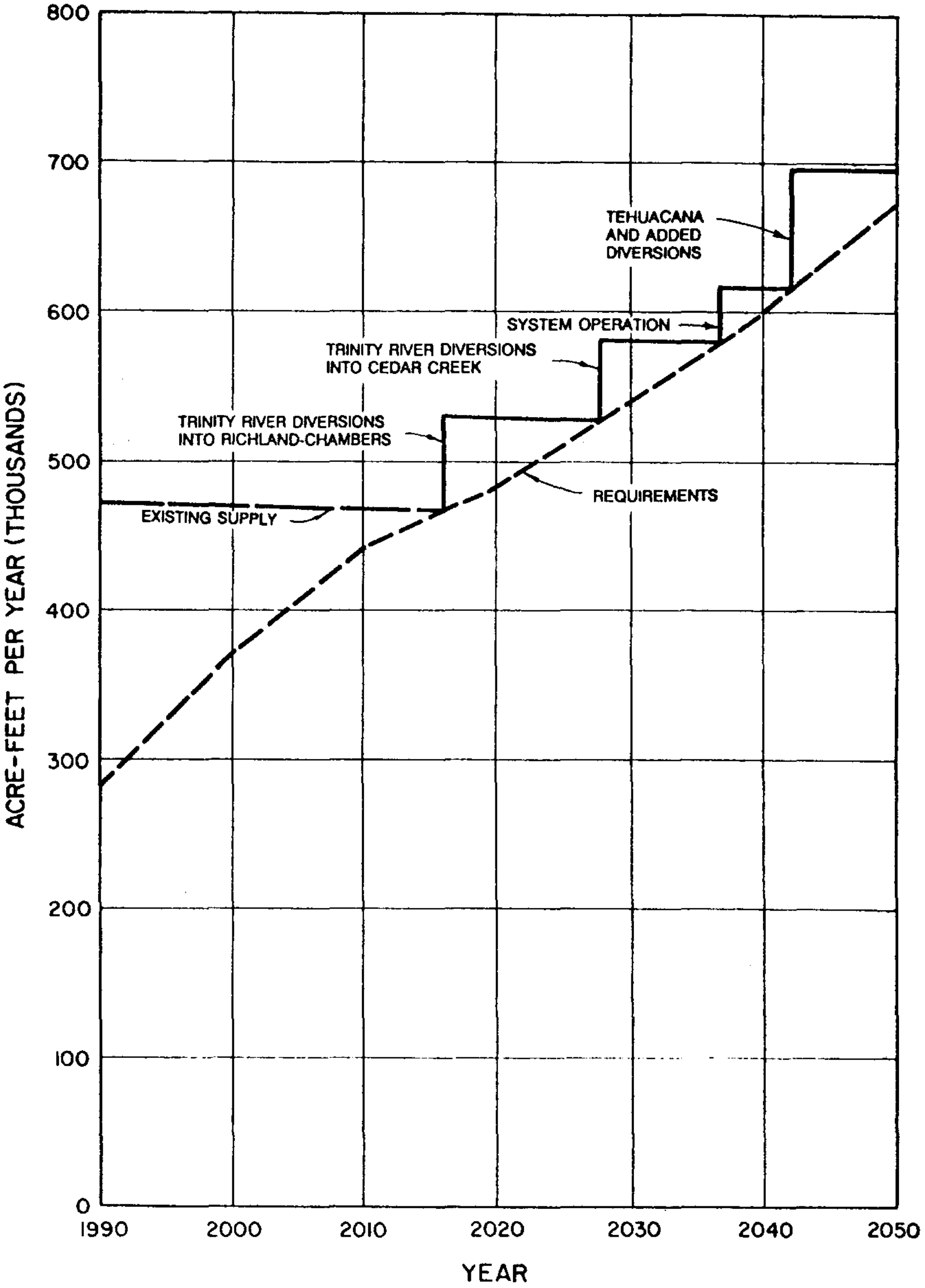


FIGURE III-2

take into consideration the effect of increased return flows to the stream. The following paragraphs briefly describe the procedure for this analysis. A more detailed account may be found in Appendix B.

Historical Trinity River Flow

The proposed diversion points are located near United States Geological Survey (USGS) Station 08062700, otherwise known as Trinity River at Trinidad, Texas. Daily streamflow data are available for this gaging station beginning in 1965. The critical drought of record for this area occurred from the late 1940s through the mid-1950s. USGS Station 08062500, also known as Trinity River Near Rosser, Texas, is located approximately 60 river miles upstream of the Trinidad gage and was in service through the critical drought period. Streamflow data from the Rosser gage were used to estimate the daily streamflows at the Trinidad gage from the period 1941 through 1965. A double mass curve for these two gages was determined from record of flow observations during their common period of record (1965-1988). The double mass curve plots the accumulation of streamflow at the Trinidad gage versus the accumulation of streamflow at the Rosser gage over this time period. A plot of the double mass curve is shown in Figure B-3 in Appendix B. The curve maintains a relatively constant slope of 1.097. The estimated daily flows at the Trinidad gage from 1941 to 1965 were determined by multiplying the daily flows at the Rosser gage by 1.097.

Historical Wastewater Return Flows

Historical monthly wastewater return flow data were available for the period from 1970 through 1988. The majority of the data were obtained from the North Central Texas Council of Governments and then supplemented with data from the TWC. The return flow database was edited to reflect only those return flows contributing directly to the Trinity River by removing all flows intercepted by reservoirs. The many sources of return flows were grouped into four major categories: Dallas, Fort Worth, Trinity River Authority (TRA), and "other." The groups are listed here in decreasing order of magnitude of flow contribution. Figure B-4 in Appendix B is a plot of these return flows from 1970 to 1990.

Historical return flows prior to 1970 were determined from data from Fort Worth, Dallas, and TRA. The "other" contributions were estimated as a percentage of the total of these return flows. For years where only average annual flow values were available, monthly values were estimated on the basis of the historical distribution of monthly flows during the years with monthly records.

Natural Trinity River Flow

The natural flow is the historical flow in the Trinity River with no return flow contributions. These flows may be determined by subtracting the daily return flows from the daily streamflows for each day in the historical database (1941-1988). The daily streamflow record at Trinidad was compiled with the assistance of the Trinidad-Rosser double mass curve, as previously explained. The daily wastewater return flow record was created by using the monthly return flow record described in the preceding paragraph, assuming the historical daily return flows to be constant throughout each given month.

Future Wastewater Return Flows

The Regional Water Supply Study defined the 60-year period from 1990 to 2050 as the planning period. Separate analyses were conducted in this study, to focus on two different times during the planning period, to monitor the effects of the increasing return flows on the proposed water supply development scenario. One analysis was selected to reflect the conditions during the middle of the planning period at 2020, and the other was selected to reflect conditions at the end of the period in 2050. It is fair to anticipate that the 2020 condition will prove to be the more critical water **quantity** condition, since less return flow will be contributed in 2020 than in 2050, making less total flow available for diversions. The 2050 condition might be considered the more critical water **quality** condition for the same reason; however, more return flow in the Trinity River in the future may or may not mean a worse quality of water than exists today, depending on future treatment technologies and stream standards, etc.

Estimates of 2020 and 2050 return flows were made using historical ratios of return flow to total water use. (Note: The return flow indicated in this discussion is the return flow contributing directly to the Trinity River, excluding flows intercepted by upstream reservoirs.) From 1974 to 1990, these historical ratios varied from 0.57 to 0.70 and averaged 0.64. In order to be conservative with respect to water quantity and to allow for some additional wastewater recycling in the future, a ratio of 0.55 was selected for the purpose of projecting future return flows. The 0.55 ratio was applied to the total projected water use for the study area for the years 2020 and 2050. In addition, the 2050 return flow projection was reduced by 60 MGD to reflect City of Dallas reuse activities proposed to begin in 2035. The resulting average daily return flow projections are approximately 800 cfs (517 MGD) in 2020 and 930 cfs (601 MGD) in 2050.

Future Trinity River Flow

Two "synthesized" Trinity River daily streamflow databases were generated to reflect 2020 and 2050 return flow conditions in the stream. These databases were created by adding the projected flows of 800 cfs and 930 cfs to the daily natural flows, producing the total Trinity River streamflows for 2020 and 2050, respectively.

ANALYSIS OF DIVERSIONS FOR YIELD AUGMENTATION

Monthly Reservoir Operation Simulation

A computer model was utilized to simulate monthly reservoir operations for Cedar Creek and Richland-Chambers Reservoirs. Conventional reservoir operation models perform a monthly water balance between inflows to the reservoir (i.e. runoff and precipitation) and outflows from the facility (i.e. evaporation, demand, releases, and spills). A typical reservoir operation simulation will first involve defining the monthly demand and release conditions for the analysis. The computer program will then subject the reservoir model to the historical runoff, precipitation, and evaporation conditions to monitor its behavior under the defined demand/release conditions. Output from the simulation will indicate the monthly fluctuation in the water surface elevation of the reservoir over the period of record used for the simulation.

The reservoir operation model employed for this study worked as previously described, with the added capability of incorporating some makeup flow when a "trigger" condition is met. The "trigger" condition for this study was chosen to be when the water surface level drops to 5 feet below the top of the conservation pool. In other words, if the end-of-month pool elevation is 5 feet or more below the conservation pool elevation, makeup flow will be diverted from the Trinity River into the reservoir throughout the following month. The pumping rates from the river to the reservoirs were set at 110 cfs (5,360 AF/mo) for Cedar Creek Reservoir and 125 cfs (6,050 AF/mo) for Richland-Chambers Reservoir. These rates provide an allowance for 20 percent average downtime.

The demand condition set to achieve in the reservoir operation simulation reflects a 30 percent increase in the dependable yield of each reservoir. This condition results in an increase in yield from 175,000 AF/Y to 227,500 AF/Y for Cedar Creek Reservoir and from 210,000 AF/Y to 273,000 AF/Y for Richland-Chambers Reservoir. Reservoir yields and diversions rates are summarized in Table III-1.

The period of record utilized for the reservoir operation simulation was 1941 to 1988. Reservoir operation was simulated under both 2020 and 2050 return flow conditions in the Trinity River to monitor the quantity of return flow in the diverted makeup flow in each case.

A conservative simplifying assumption was made in regard to the implementation schedule presented earlier in Figure III-2. As shown in Figure III-2, diversions to Richland-Chambers Reservoir and Cedar Creek Reservoir are proposed in 2016 and 2028, respectively. Available 2020 data were used to analyze operation of both diversions even though the Cedar Creek diversion is not scheduled until 2028.

Monthly Diversion Schedule

Reservoir operations were simulated over the 1941-1988 period of record. Makeup flows to the reservoirs were diverted from the Trinity River when the reservoirs fell below the five-foot trigger point. Results from the operation simulation have been separated into two output sets to reflect the different diversion requirements for a "drought" period, as opposed to a "non-drought" period. The

TABLE III-1

RESERVOIR OPERATION SUMMARY

Parameter	Cedar Creek Reservoir	Richland/Chambers Reservoir
Original yield	175,000 AF/Y	210,000 AF/Y
New yield	227,500 AF/Y	273,000 AF/Y
Increase in yield	52,500 AF/Y	63,000 AF/Y
Percent increase in yield	30%	30%
Maximum diversion rate	110 cfs	125 cfs
Downtime allowance	20%	20%
Maximum monthly diversion	5,360 AF/mo	6,050 AF/mo
Maximum yearly diversion	63,320 AF/Y	72,600 AF/Y
Diversion trigger*	5 ft.	5 ft.

*Distance below conservation pool elevation.

1948-1957 period is defined to represent the drought condition for this area while the years from 1941-1947 together with the years from 1958-1988 represent the "non-drought" condition.

Tables III-2 and III-3 summarize the total monthly diversion requirements to both reservoirs for the drought and non-drought periods, respectively. Recalling the monthly pumping rates previously presented, a "5,360" value in the tables denotes a diversion to Cedar Creek Reservoir for the month indicated while a "6,050" value denotes a diversion to Richland-Chambers Reservoir. An "11,410" value denotes a diversion to both reservoirs for the month indicated. These tables portray well the frequency of makeup water requirements on a monthly basis under both drought and non-drought conditions. This information will prove useful in the design of necessary treatment facilities for this diverted flow. The tables illustrate that a treatment facility may be required to be in full operation for four years continuously during a drought period. A non-drought period, however, may produce a variety of operating conditions for the facility. A very wet period like the early to mid-1940s may result in several years of zero makeup flow requirements, while a dry period like the early 1980s may require as much continuous makeup flow as the critical drought condition. Between these extremes, it may be seen that diversions may be required for only one month or a few months in a row with no need for makeup flow for several months following. In summary, any facility required to treat flows diverted from the Trinity River to the reservoirs must be able to accommodate a wide range of flow input from the river.

The last columns of Tables III-2 and III-3 have been plotted in Figure III-3. The values in these two columns are the average monthly makeup volumes over several years that are required under drought and non-drought conditions. While examining Figure III-3, recall that the rate of diversion for each reservoir is the same for drought as non-drought conditions. The average monthly makeup volumes plotted in Figure III-3 simply indicate that diversions are just required more frequently during drought conditions. The diversion requirements under drought conditions are a little more than double the non-drought requirements. The average monthly diversion volumes also indicate that the winter months produce the highest diversion requirements under both drought and non-drought

TABLE III-2

TOTAL MONTHLY MAKEUP
WATER REQUIREMENT
DROUGHT PERIOD: 1948 - 1957
(All flows in acre-feet)

MONTH	YEAR										AVERAGE
	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	
JAN	0	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	11,410	10,269
FEB	0	11,410	11,410	11,410	11,410	11,410	6,050	11,410	11,410	11,410	9,733
MAR	0	6,050	0	6,050	11,410	11,410	6,050	11,410	11,410	11,410	7,520
APR	0	0	6,050	11,410	11,410	11,410	11,410	11,410	11,410	11,410	8,592
MAY	0	0	0	11,410	11,410	6,050	11,410	11,410	11,410	6,050	6,915
JUN	0	0	0	11,410	6,050	0	6,050	11,410	11,410	0	4,633
JUL	0	0	0	6,050	6,050	6,050	11,410	11,410	11,410	0	5,238
AUG	0	6,050	0	11,410	6,050	6,050	11,410	11,410	11,410	0	6,379
SEP	0	6,050	0	11,410	11,410	6,050	11,410	11,410	11,410	0	6,915
OCT	0	11,410	6,050	11,410	11,410	6,050	11,410	11,410	11,410	0	8,056
NOV	5,360	11,410	6,050	11,410	11,410	6,050	11,410	11,410	11,410	0	8,592
DEC	11,410	11,410	6,050	11,410	11,410	11,410	11,410	11,410	11,410	0	9,733
TOTAL	16,770	75,200	47,020	126,200	120,840	93,350	120,840	136,920	136,920	51,690	92,575
AVERAGE	1,398	6,267	3,918	10,517	10,070	7,779	10,070	11,410	11,410	4,308	7,715

TABLE III-3

TOTAL MONTHLY MAKEUP
WATER REQUIREMENT
NON-DROUGHT PERIOD: 1941 - 1947; 1958 - 1988
(All flows in acre-feet)

MONTH	YEAR												
	1941	1942	1943	1944	1945	1946	1947	1958	1959	1960	1961	1962	1963
JAN	0	0	0	0	0	0	0	0	0	0	0	0	0
FEB	0	0	0	0	0	0	0	0	5,360	0	0	0	0
MAR	0	0	0	0	0	0	0	0	0	0	0	0	0
APR	0	0	0	0	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	0	0	0	0	0	0	0
JUN	0	0	0	0	0	0	0	0	0	0	0	0	0
JUL	0	0	0	0	0	0	0	0	0	0	0	0	6,050
AUG	0	0	0	0	0	0	0	0	0	0	0	0	6,050
SEP	0	0	0	0	0	0	0	0	0	0	0	0	11,410
OCT	0	0	0	0	0	0	0	0	0	0	0	0	11,410
NOV	0	0	0	0	0	0	0	0	0	5,360	0	0	11,410
DEC	0	0	0	0	0	0	0	0	0	5,360	0	0	11,410
TOTAL	0	0	0	0	0	0	0	0	5,360	10,720	0	0	57,740
AVERAGE	0	0	0	0	0	0	0	0	447	893	0	0	4,812

TABLE III-3 (cont'd)

TOTAL MONTHLY MAKEUP
WATER REQUIREMENT
NON-DROUGHT PERIOD: 1941 - 1947; 1958 - 1988
(All flows in acre-feet)

MONTH	YEAR												
	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
JAN	11,410	11,410	11,410	11,410	0	0	0	0	0	11,410	0	0	5,360
FEB	11,410	11,410	11,410	11,410	0	5,360	6,050	0	0	11,410	0	0	11,410
MAR	11,410	11,410	11,410	11,410	0	0	0	6,050	0	0	0	0	11,410
APR	11,410	11,410	11,410	11,410	0	0	0	6,050	0	0	0	0	11,410
MAY	11,410	11,410	0	11,410	0	0	0	11,410	0	0	0	0	0
JUN	11,410	11,410	0	11,410	0	0	0	11,410	0	0	0	0	0
JUL	11,410	11,410	0	11,410	0	0	0	11,410	0	0	0	0	0
AUG	11,410	11,410	0	11,410	0	0	0	11,410	0	0	0	0	0
SEP	11,410	11,410	0	11,410	0	0	0	11,410	11,410	0	0	0	0
OCT	11,410	11,410	0	11,410	0	0	0	11,410	11,410	0	0	0	0
NOV	11,410	11,410	0	0	0	0	0	6,050	11,410	0	0	0	0
DEC	11,410	11,410	0	0	0	11,410	0	6,050	11,410	0	0	5,360	0
TOTAL	136,920	136,920	45,640	11,4100	0	16,770	6,050	92,660	45,640	22,820	0	5,360	39,590
AVERAGE	11,410	11,410	3,803	9,508	0	1,398	504	7,722	3,803	1,902	0	447	3,299

TABLE III-3 (cont'd)

TOTAL MONTHLY MAKEUP
WATER REQUIREMENT
NON-DROUGHT PERIOD: 1941 - 1947; 1958 - 1988
(All flows in acre-feet)

MONTH	YEAR												AVERAGE
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	
JAN	0	11,410	11,410	6,050	11,410	6,050	6,050	11,410	6,050	6,050	0	0	3,639
FEB	0	11,410	11,410	6,050	11,410	6,050	6,050	11,410	6,050	6,050	0	0	4,240
MAR	0	6,050	11,410	6,050	11,410	6,050	6,050	11,410	6,050	6,050	0	0	3,517
APR	0	6,050	6,050	6,050	11,410	6,050	6,050	6,050	6,050	6,050	0	0	3,234
MAY	0	6,050	6,050	0	11,410	6,050	6,050	6,050	6,050	6,050	0	6,050	2,775
JUN	0	6,050	0	0	11,410	6,050	6,050	11,410	6,050	6,050	0	6,050	2,757
JUL	0	11,410	0	0	0	6,050	6,050	11,410	6,050	0	0	6,050	2,598
AUG	0	11,410	0	0	0	6,050	6,050	11,410	6,050	0	0	6,050	2,598
SEP	0	11,410	0	0	6,050	6,050	6,050	11,410	6,050	0	0	6,050	3,198
OCT	0	11,410	6,050	6,050	6,050	11,410	6,050	11,410	6,050	0	0	11,410	3,799
NOV	11,410	11,410	6,050	11,410	6,050	11,410	6,050	11,410	6,050	0	0	11,410	3,940
DEC	11,410	11,410	11,410	11,410	6,050	11,410	6,050	11,410	6,050	0	0	11,410	4,522
TOTAL	22,820	115,480	69,840	53,070	92,660	88,680	72,600	126,200	72,600	36,300	0	64,480	40,816
AVERAGE	1,902	9,623	5,820	4,423	7,722	7,390	6,050	10,517	6,050	3,025	0	5,373	3,401

COMBINED AVERAGE MONTHLY MAKEUP WATER REQUIREMENTS FOR CEDAR CREEK AND RICHLAND-CHAMBERS RESERVOIRS

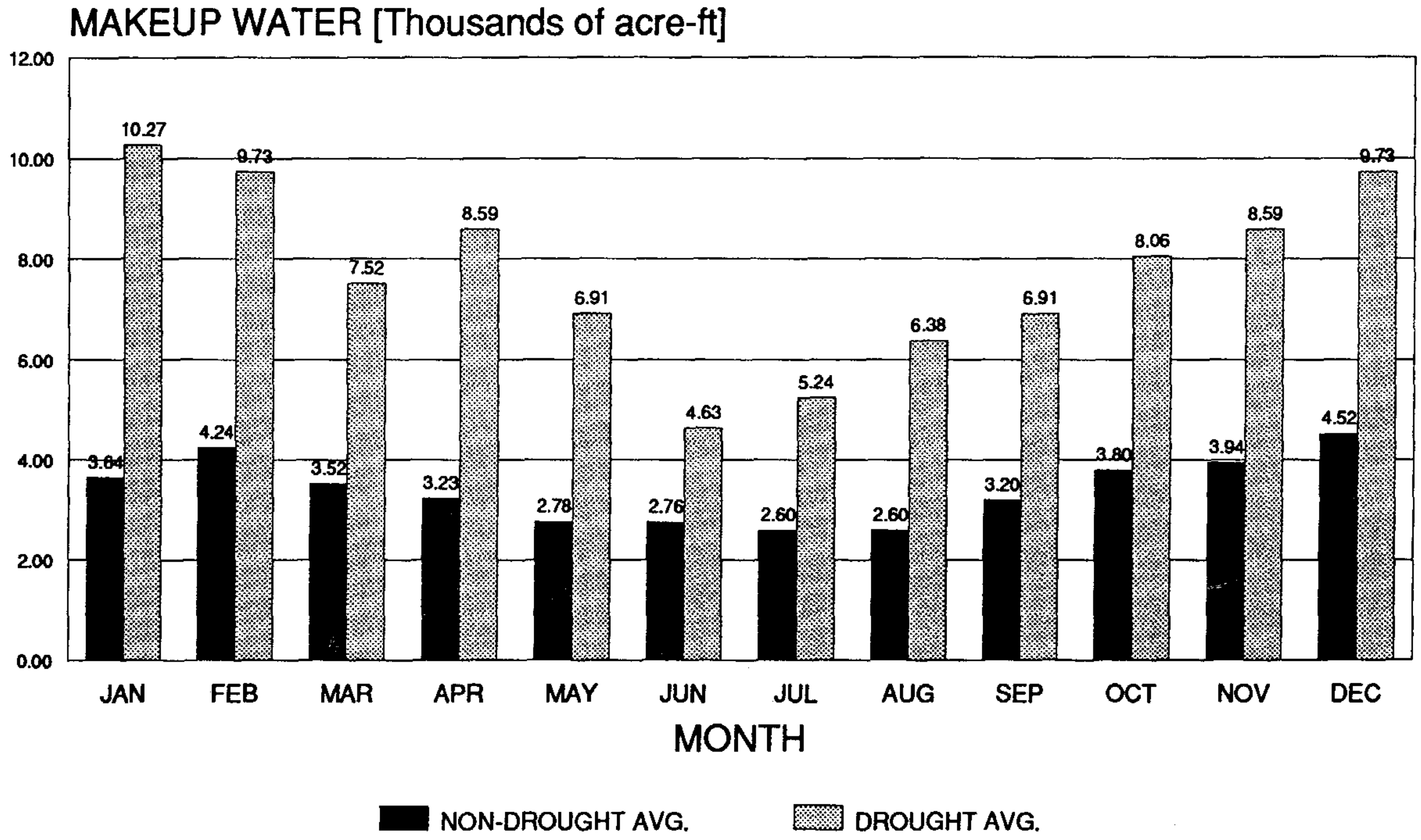


FIGURE III-3

conditions. This type of seasonal behavior is due to the heavy spring rains. These heavy rains are often sufficient to fill the reservoirs early in the spring and even sustain the reservoir through the summer. But as fall comes, the water supply begins to decrease under a relatively constant demand, and very little precipitation is available for replenishing the reservoirs. As a consequence, the makeup requirement grows through the winter until spring precipitation begins to refill the reservoirs.

Makeup Water In Reservoirs

Tables III-2 and III-3 provide estimations of the quantity and frequency of makeup water diverted from the Trinity River into the reservoirs, but offer no real indication of the accumulation of these diverted makeup flows in the reservoirs nor of the amount of return flow present in these diversions and in the reservoirs. During the reservoir operation simulations, when a makeup flow requirement was realized at a particular month in the historical record, the character of that makeup flow was determined by reading the percent of return flow in the synthesized Trinity River flow files for that same month in the record. These synthesized flow files are the flow records described earlier, created to reflect either 2020 or 2050 return flow conditions in the stream.

Using the synthesized 2020 and 2050 Trinity River flow files in conjunction with the reservoir operation simulation, it was possible to keep an account of the percent return flow in the makeup flow and the amount accumulated in the reservoirs over the entire period of simulation (1941-1988). A summary of monthly statistics regarding the makeup and return flows in the diversions and in the reservoirs is shown in Table III-4. Table III-4 had been created so that comparisons may be made between the two reservoirs and between drought and non-drought conditions. The first column denotes the reservoir and weather condition for which the average, maximum, and minimum monthly values for makeup flow and return flow have been recorded. The second column indicates the percentage of months during simulation that diversions were required. This column illustrates that Richland-Chambers Reservoir required makeup water significantly more often than did Cedar Creek Reservoir - 75.8 percent versus 58.3 percent during drought conditions and 36.4 percent versus 22.4 percent during non-drought conditions.

TABLE III-4

SUMMARY OF MONTHLY MAKEUP WATER AND RETURN FLOWS FOR CEDAR CREEK AND RICHLAND CHAMBERS RESERVOIRS DURING DROUGHT AND NON-DROUGHT WEATHER CONDITIONS

Reservoir and weather condition designation*	Percent of months makeup flow required	Monthly statistic	2020 Return Flow Conditions					2050 Return Flow Conditions				
			Make-up (ac-ft)	Return flow in make-up (ac-ft)	Pct. Rtn. flow in makeup	EOM** reservoir fraction of Make-up	EOM** reservoir fraction of Return flow	Make-up (ac-ft)	Return flow in make-up (ac-ft)	Pct. Rtn. flow in make-up	EOM** reservoir fraction of Make-up	EOM** reservoir fraction of Return flow
CC-D	58.3%	AVERAGE	3127	2437	77.9%	0.10554	0.08248	3127	2486	79.5%	0.10554	0.08415
		MAXIMUM	5360	5360	100.0%	0.34274	0.31328	5360	5360	100.0%	0.34274	0.31581
		MINIMUM	0	0	8.4%	0.00001	0.00001	0	0	9.6%	0.00001	0.00001
CC-ND	22.4%	AVERAGE	1199	801	66.8%	0.03674	0.02502	1199	824	68.7%	0.03674	0.02568
		MAXIMUM	5360	5360	100.0%	0.23288	0.13412	5360	5360	100.0%	0.23288	0.13954
		MINIMUM	0	0	10.0%	0.00002	0.00001	0	0	11.4%	0.00002	0.00001
RC-D	75.8%	AVERAGE	4588	3452	75.2%	0.14096	0.10652	4588	3528	76.9%	0.14096	0.10894
		MAXIMUM	6050	6050	100.0%	0.38338	0.34783	6050	6050	100.0%	0.38338	0.35082
		MINIMUM	0	0	3.2%	0.00005	0.00004	0	0	3.7%	0.00005	0.00004
RC-ND	36.4%	AVERAGE	2202	1327	60.2%	0.05748	0.03504	2202	1370	62.2%	0.05748	0.03610
		MAXIMUM	6050	6050	100.0%	0.25864	0.15421	6050	6050	100.0%	0.25864	0.15942
		MINIMUM	0	0	4.6%	0.00008	0.00006	0	0	5.3%	0.00008	0.00006

*CC-D	Cedar Creek Reservoir - Drought Conditions
CC-ND	Cedar Creek Reservoir - Non-Drought Conditions
RC-D	Richland-Chambers Reservoir - Drought Conditions
RC-ND	Richland-Chambers Reservoir - Non-Drought Conditions

**End of Month

The fourth column of Table III-4 shows the average, maximum, and minimum monthly makeup flows for each scenario. The fifth and sixth columns show how much return flow was in the makeup flow based upon the synthesized 2020 and 2050 return flow files. The seventh column lists the end-of-month fraction of makeup flow in the total reservoir volume and column eight lists the fraction of return flow of the total volume. Columns 4 through 8 have been calculated based upon 2020 return flow conditions in the stream. Columns 9 through 13 present the same type of information except for 2050 return flow conditions in the stream. Closer inspection of Table III-4 reveals only slight differences between the return flow values under 2020 and 2050 conditions.

Two important values to notice in Table III-4 are the maximum end-of-month fraction of return flow in the reservoir for each reservoir under 2050 return flow conditions during the drought period. These maximum values are 31.6 percent for Cedar Creek Reservoir and 35.1 percent for Richland-Chambers Reservoir. Figures III-4 and III-5 are plots of the end-of-month fractions of makeup flow and return flow for each reservoir under 2050 return flow conditions. From these plots it may be seen that the fraction of return flow in the reservoir volume remains greater than 30 percent for a period of 6 months in Richland-Chambers Reservoir before the reservoir is "flushed" in two months time to a return flow fraction less than 5 percent. This same behavior is illustrated in Cedar Creek Reservoir where the return flow fraction persisted above 30 percent for 4 months before being flushed out.

Trinity River Flows at Times of Diversions

The amount of flow in the Trinity River at the time water is diverted to the reservoirs is important for two reasons. First, there must be sufficient flow in the stream to allow the diversions. The maximum pumping rate from the river to the reservoirs has been set at 235 cfs (110 cfs to Cedar Creek Reservoir plus 125 cfs to Richland-Chambers Reservoir). There must be more than 235 cfs in the river to provide the required makeup flow and still leave adequate remaining flow to travel downstream. Secondly, the magnitude of streamflow is an important parameter in characterizing the quality of the makeup water. Later sections of

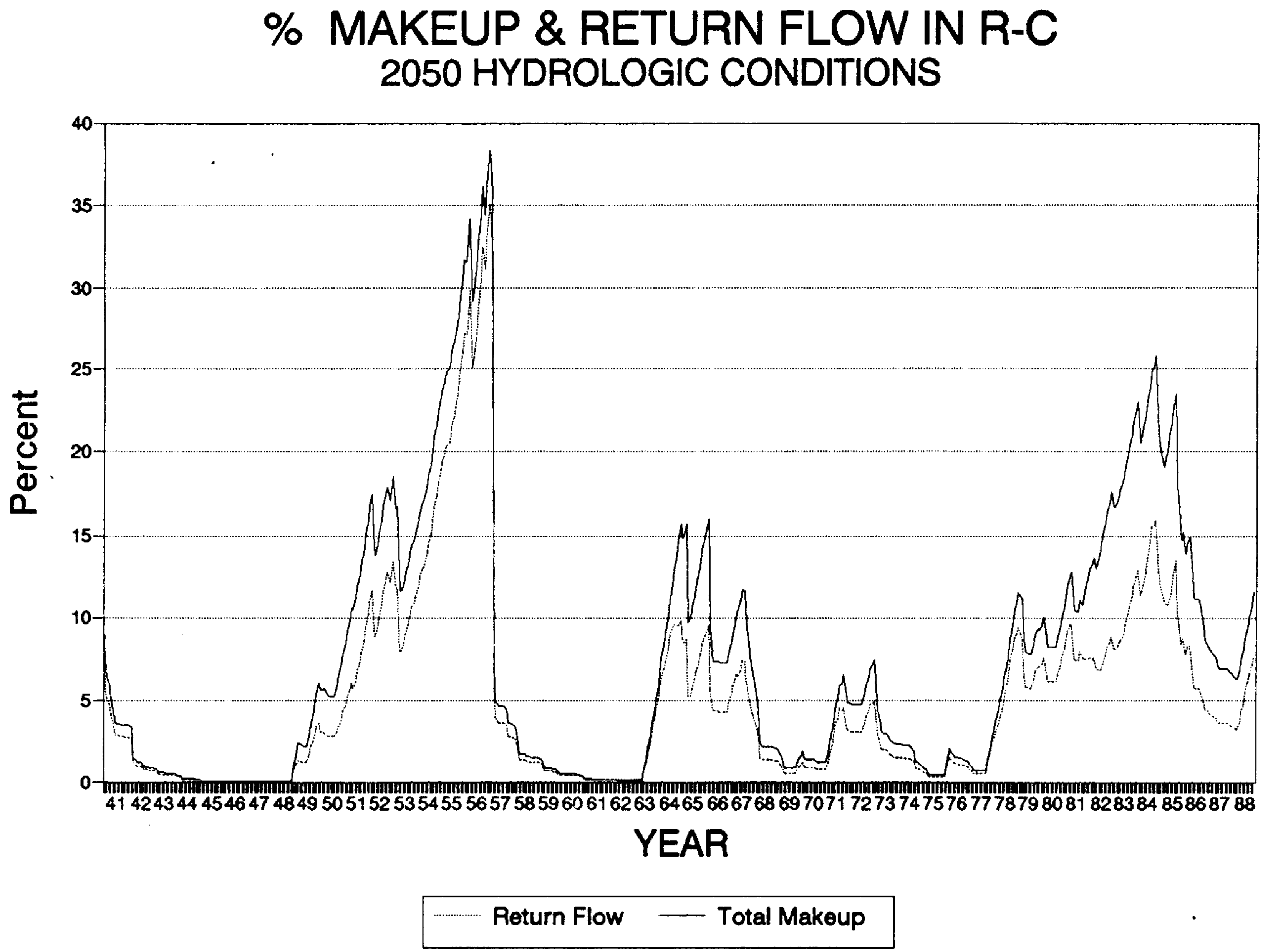

% MAKEUP & RETURN FLOW IN R-C
2050 HYDROLOGIC CONDITIONS
Percent
40
35
30
25
20
15
10
5
0
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88
YEAR
Return Flow
Total Makeup

FIGURE III-4

% MAKEUP & RETURN FLOW IN CEDAR
2050 HYDROLOGIC CONDITIONS

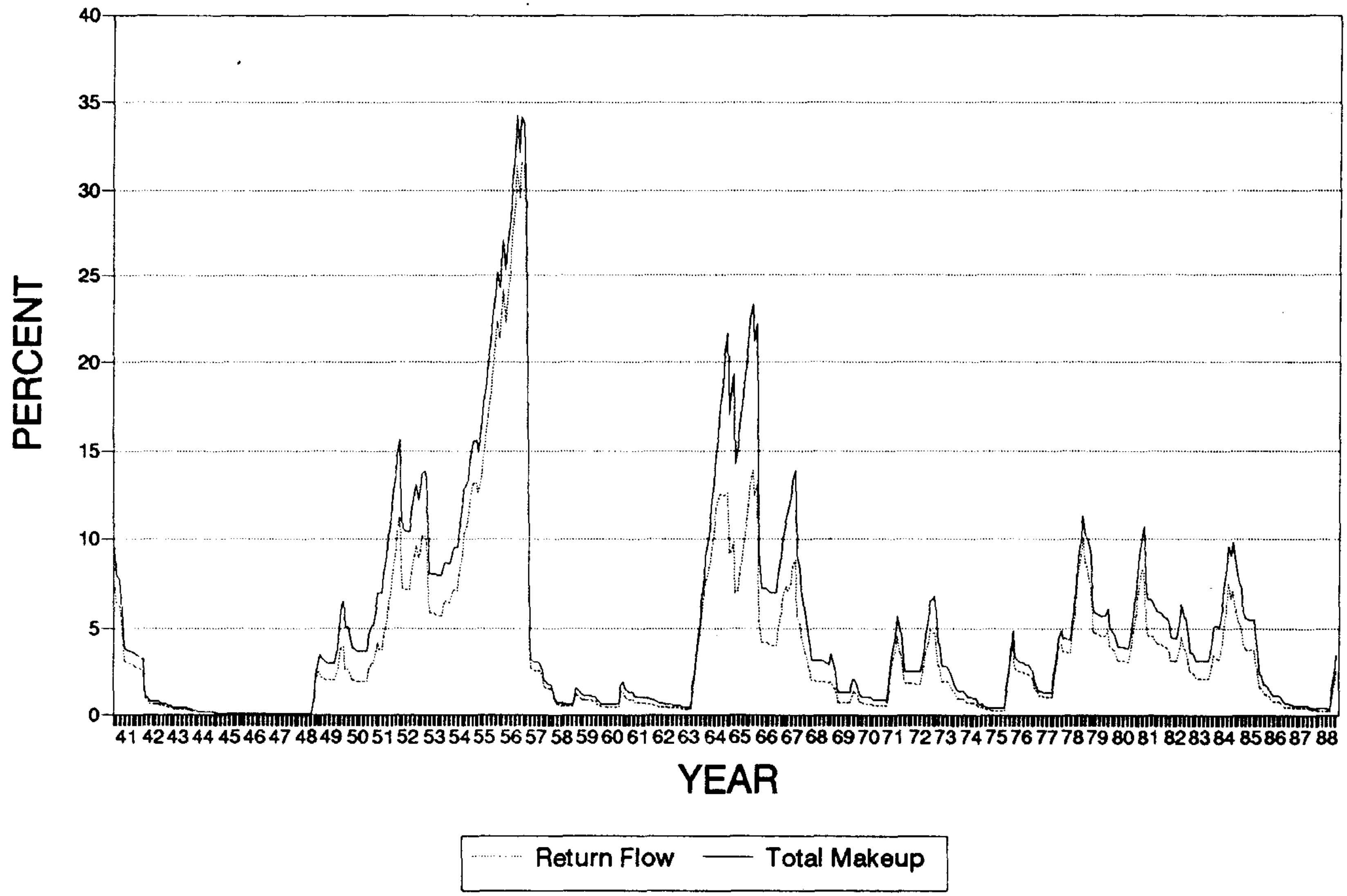


FIGURE III-5

this report will show the quality of river water varies as a function of streamflow.

The critical condition for investigating flow availability in the Trinity River is the drought period under 2020 return flow conditions, as this condition will produce lower streamflows than the 2050 condition. The total amount of water proposed for diversion can be visually compared to the estimated 2020 total streamflow in Figure III-6 for the entire 48 year period of analysis. Figure III-7 is a probability plot of the estimated mean daily streamflows on the days which diversions to one or both reservoirs are required during the 10 year drought period. Figure III-7 illustrates that, on days when diversions are required, the flow in the Trinity River will be less than 3,000 cfs approximately 91 percent of the time and less than 1,000 cfs approximately 58 percent of the time. A determination of the concentrations of nutrients and various other water quality parameters in these flow regimes in the Trinity River will allow the makeup flows to the reservoirs to be properly characterized in the reservoir water quality models. The impact of these diversions on the water quality of the reservoirs can then be addressed.

Trinity River Flows Downstream of the Diversion Point

Return flows for 2020 and 2050 are 800 cfs and 930 cfs, respectively. These flows are essentially the minimum streamflows for 2020 and 2050, since the return flow will be contributed even if the natural flow in the river is zero. If the maximum pumping rate for diversions is 235 cfs, then the estimated minimum flow remaining in the river after maximum diversion will be 565 cfs in 2020 and 695 cfs in 2050. This compares to a historical minimum flow at the Trinity River gage near Rosser during the drought of the 1950s of 96 cfs on October 3, 1953. The return flow estimates for that time period indicate that all of the 96 cfs was wastewater return flow. The estimated historical return flow during the critical period varied from around 100 cfs to 180 cfs. Examination of the historical "natural flow" in the river (i.e., the record created by subtracting the estimated historical return flows from the historical gaged streamflows) reveals that the Trinity River during the 1950s would have had many days of

Flow At Diversion Point
Acre-Feet Per Year

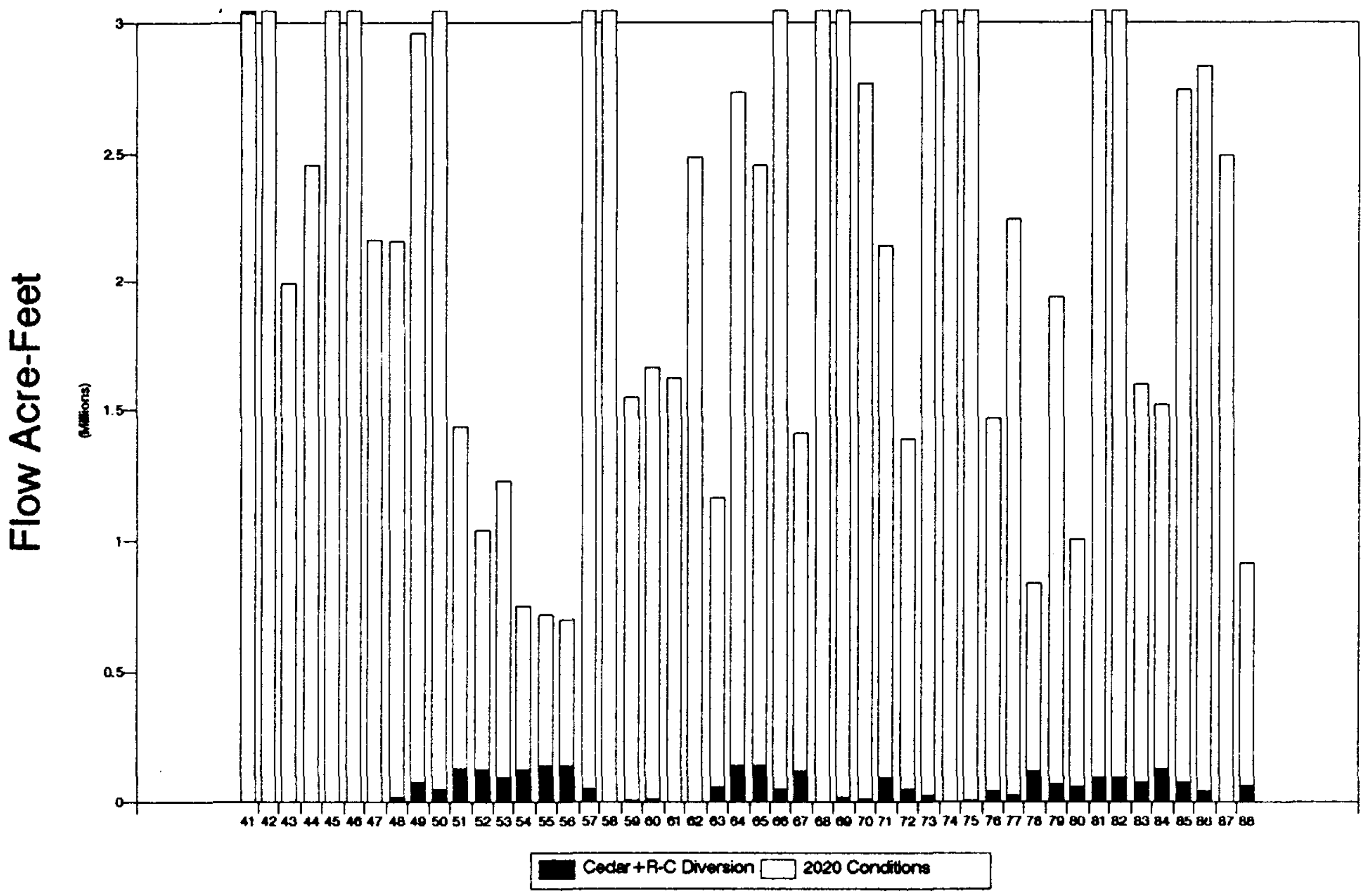


FIGURE III-6

PROJECTED TRINITY RIVER FLOWS AT TIMES OF RESERVOIR MAKEUP DIVERSIONS DURING THE 1948-1957 DROUGHT PERIOD

(2020 Return Flow Condition)

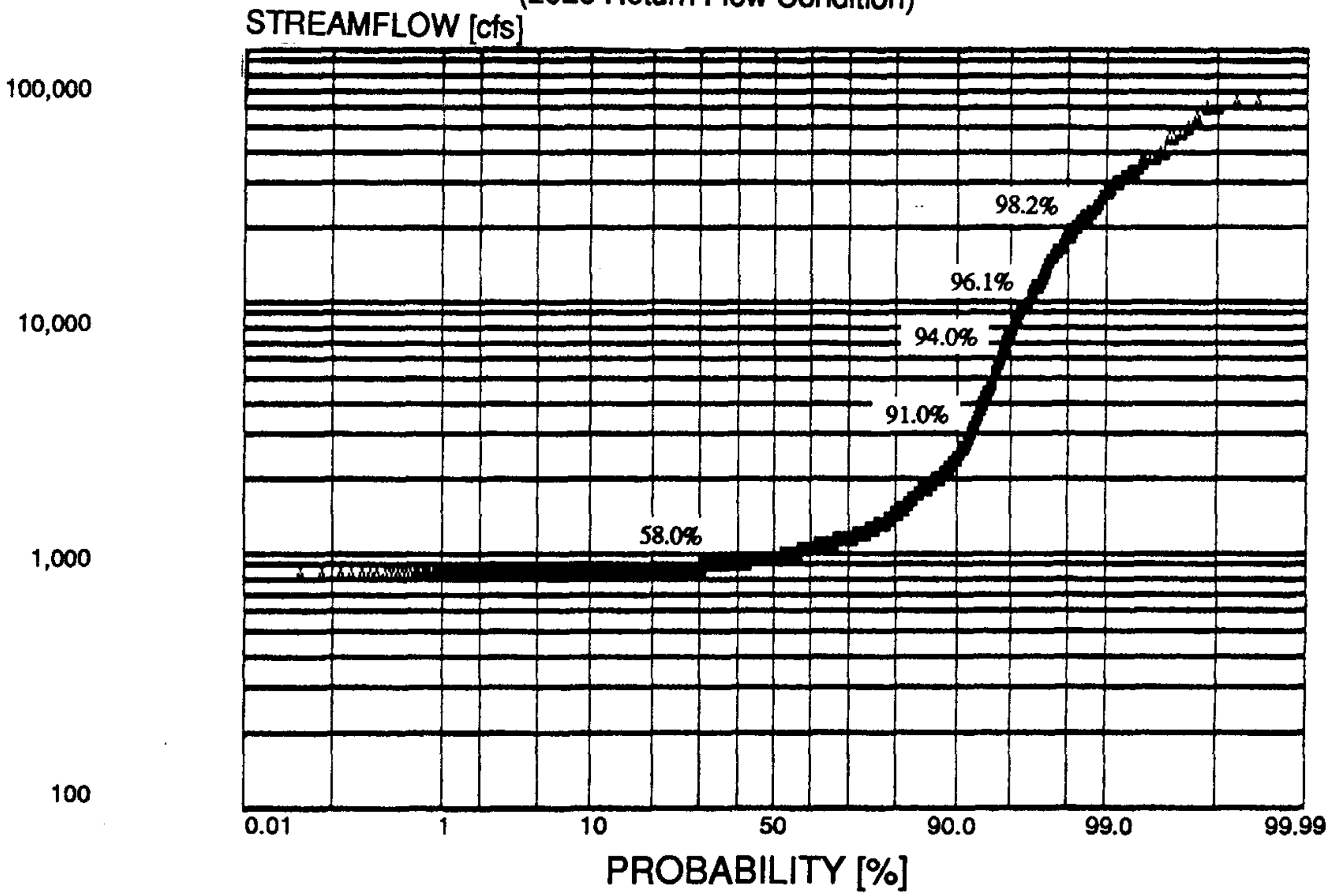


FIGURE III-7

essentially zero flow. The term "essentially zero flow" is used here to appreciate the following imprecisions in the development of the natural record:

- the Rosser gage was used to estimate streamflows at Trinidad;
- imprecise data were used to estimate return flows in the 1950s; and
- channel losses of return flows were ignored.

Recognizing these imprecisions, it has been estimated that, without return flows of treated wastewater, the proposed diversion point would have had 55 zero-flow days in 1954, 103 zero-flow days in 1955, 201 zero-flow days in 1956 and 32 zero-flow days in 1957. With the proposed diversions, the remaining 2020 flow of 565 cfs in the Trinity River greatly exceeds the historical minimum of around 100 cfs and the natural flow minimum of zero.

CHAPTER IV
WATER QUALITY IMPACTS OF DIVERSION ON RICHLAND-CHAMBERS AND CEDAR CREEK RESERVOIRS

TRINITY RIVER DIVERSION WATER QUALITY

Water Quality Data

The initial project task was the review of available water quality data for the Trinity River, Richland-Chambers and Cedar Creek Reservoirs, and the tributaries to the reservoirs. The following categories of water quality parameters were identified for review and subsequent analysis in this phase of the project: nutrients, metals, solids, and bacteriological parameters. A comprehensive review of the available water quality data for the Trinity River at Trinidad near the proposed diversion point revealed that the most complete sources of data in these water quality categories were the annual USGS Water-Data Texas Reports and the TWC's Statewide Monitoring Network. In addition, a significant amount of dissolved metals data were secured from the following intensive surveys:

1. "Evaluation of Certain Toxic Substances in Segment 0804 of the Trinity River," TRA Interim Report, July 1986;

2. "Analysis of Fish Kills and Associated Water Quality Conditions in the Trinity River, Texas," Davis, J.R., Bastian, M.V., TWC, February 1990;

3. "A Water Quality and Ecological Survey of the Trinity River," Dickson, K.L., Institute of Applied Sciences - University of North Texas, November 1989, et. al.

More information regarding water quality data sources for this project may be found in the technical memorandum, "Trinity River Diversion Study, Task 1: Data Acquisition and Review," February 1991.

To make meaningful analyses of these data, an adequate number of samples is required during the period of interest, 1980 to 1989. This time period was selected for the reason that improved wastewater treatment technologies and more stringent discharge requirements in the recent past render data prior to about the last ten years to be unrepresentative of today's water quality conditions. Tables IV-1, IV-2, and IV-3 list the number of data points for various parameters in each water quality category collected/analyzed over the last decade in the Trinity River at Trinidad. In addition, Table IV-2 presents the percent of samples below detectable limits for the dissolved metals listed. The method employed for handling these "nondetectables" is important in the proper analysis of the data, as will be illustrated in subsequent paragraphs. The following material also demonstrates that sufficient data were available to satisfy the requirements and purposes of this project.

Data Analysis

In Section III of this report, the statement was made that 58 percent of the diversions to the reservoirs are expected to be made when flow in the Trinity River is less than 1,000 cfs and 91 percent are expected to occur when the streamflow is less than 3,000 cfs. It is therefore desirable to determine the relationship of water quality with streamflow so that these diversion flows may be assessed a particular quality which in turn may be reflected as an input into the water quality models for Richland-Chambers and Cedar Creek Reservoirs. It is only then that the water quality impacts of these diverted flows on the reservoirs may be properly evaluated.

With the exception of the dissolved metals, all other water quality parameters investigated exhibited a strong correlation with streamflow. As an example, Figure IV-1 demonstrates the influence of streamflow on total phosphorous concentrations. This plot is typical of most all the nutrient data. It may be seen in Figure IV-1 that the data seem to behave differently for different streamflow regimes. For instance, there appears to be a marked difference between the concentrations of total phosphorous for flows less than 1,000 cfs and concentrations for flows greater than 1,000 cfs. Closer inspection reveals that

TABLE IV-1

NUTRIENT DATA FOR TRINITY RIVER AT TRINIDAD
1980 - 1989

Parameter name	Total number of samples
Total Phosphorus	69
Dissolved Phosphorous	69
Dissolved Ortho-Phosphorous	42
Dissolved Ortho-Phosphate	24
Dissolved Nitrate	24
Dissolved Nitrite	24
Total Nitrate + Nitrite	21
Dissolved Nitrate + Nitrite	69
Total Ammonia	44
Dissolved Ammonia	69
Total Organic	43
Dissolved Organic	20
Total Organic + Ammonia	68
Dissolve Organic + Ammonia	20

TABLE IV-2

DISSOLVED METALS DATA FOR TRINITY RIVER AT TRINIDAD
1980-1989

Metal	Total number of samples	Pct. Samples below detection limits
Arsenic, As	87	37.9%
Cadmium, Cd	85	78.8%
Copper, Cu	89	50.6%
Lead, Pb	89	67.4%
Mercury, Hg	89	80.9%
Selenium, Sc	89	86.5%
Zinc, Zn	96	11.5%

TABLE IV-3

SOLIDS AND BACTERIOLOGICAL DATA FOR TRINITY RIVER AT TRINIDAD
1980-1989

Parameter	Total number of samples
TSS	58
Fecal coliform	65

TOTAL PHOSPHORUS VS. STREAMFLOW
TRINITY RIVER AT TRINIDAD: 1980 - 1989

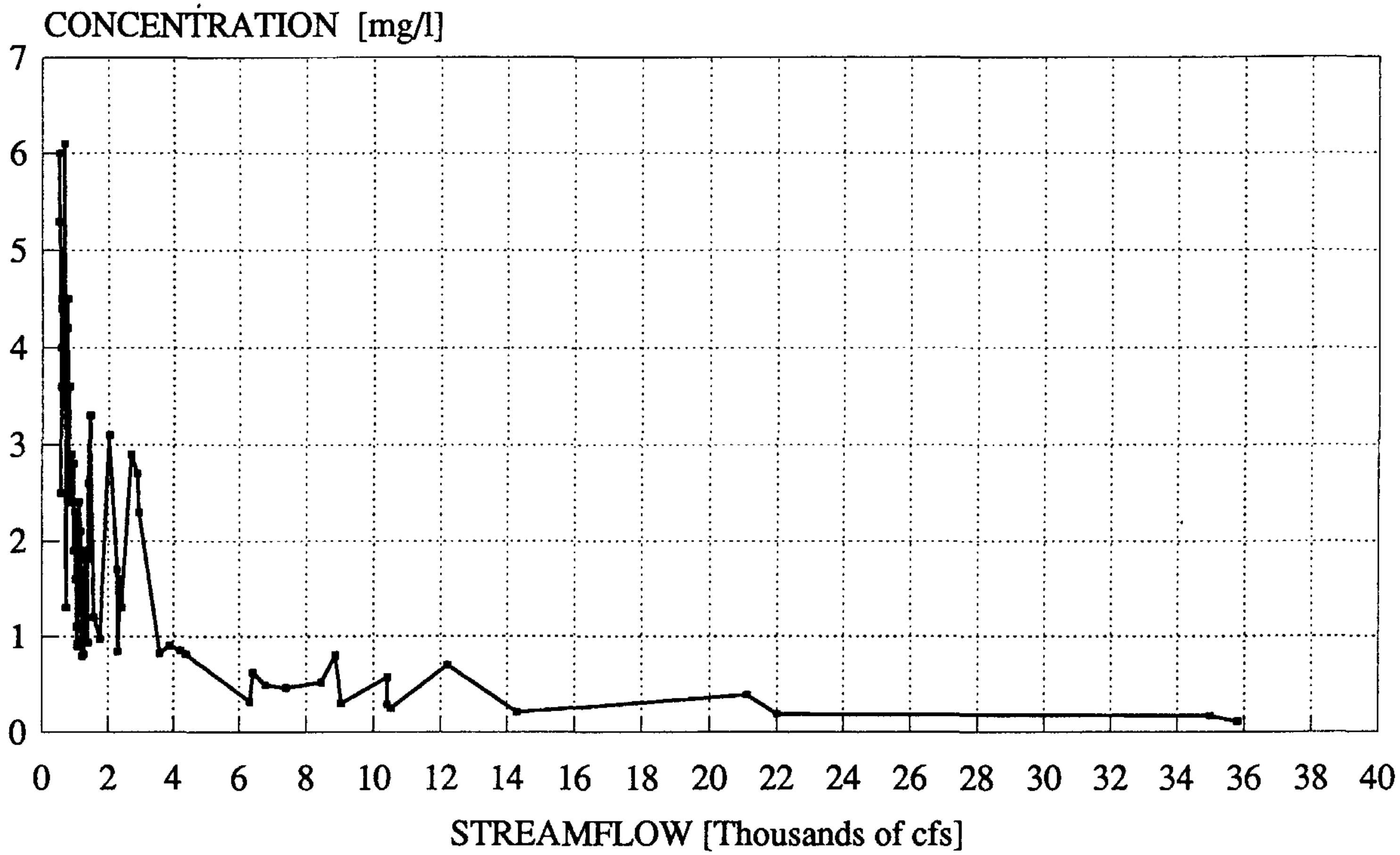


FIGURE IV-1

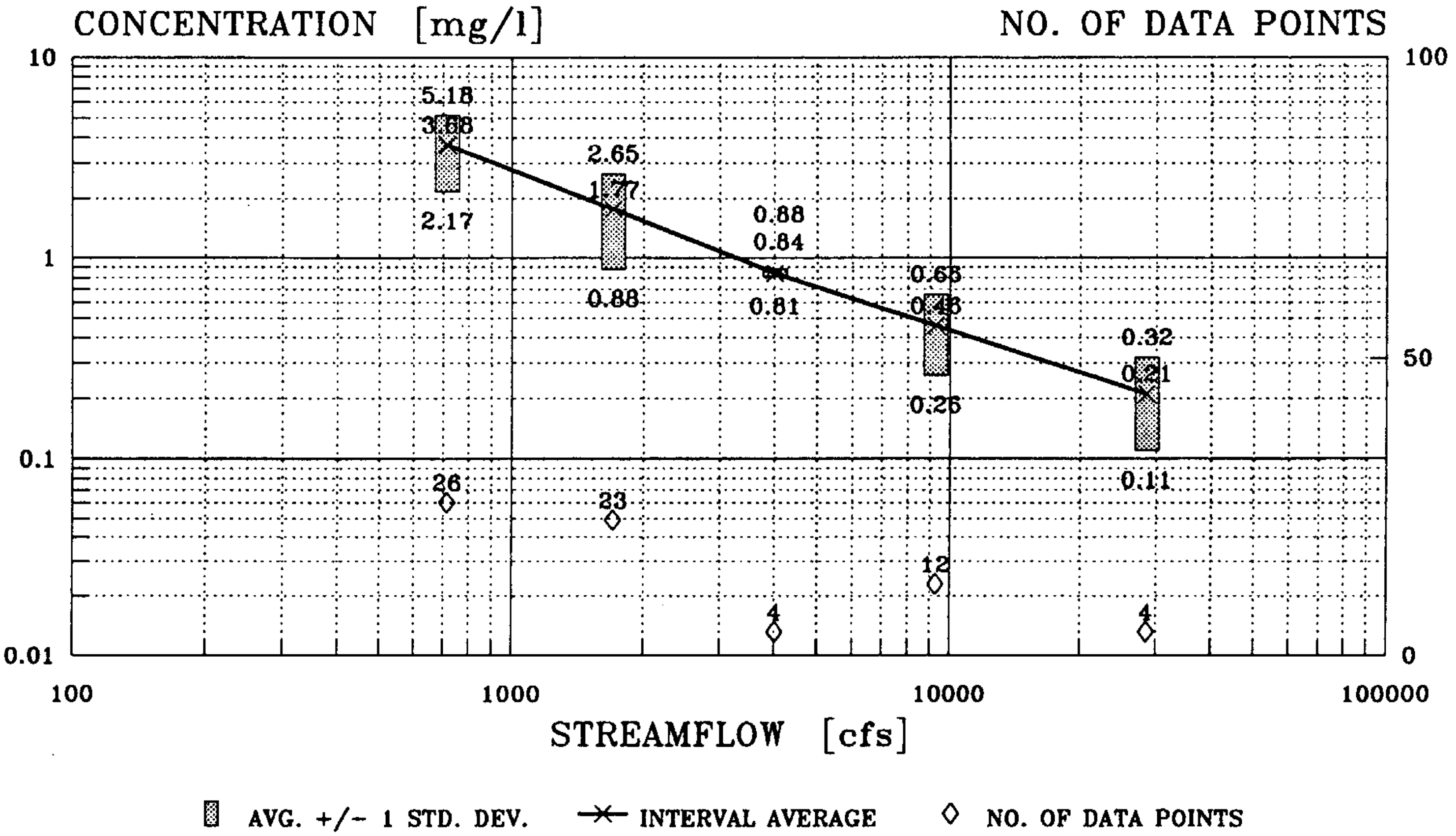
the concentrations seem to recognize the following streamflow regimes or categories: 0-1,000 cfs, 1,000-3,000 cfs, 3,000-6,000 cfs, 6,000-20,000 cfs, and >20,000 cfs. To use these data for characterizing the quality of proposed diversion flows, the expected values of the concentrations in each flow category were calculated. Figure IV-2 is a log-log plot of these expected values versus streamflow. The shaded bars represent a band of one standard deviation above and below the expected values. There is a reaffirmation that the streamflow categories have been properly defined since the curve connecting the expected values is very linear. The plot of the individual sample data shown in Figure IV-3 indicates that this relationship should be linear on a log-log scale.

With a few exceptions, the streamflow categories presented above were used for the expected value calculations for all of the nutrient, solids, and bacteriological data. The results of these calculations are presented in Tables IV-4 and IV-5. The sample data, the plots versus streamflow, and the supporting calculations for all parameters are included in Appendix C. Based on the material presented in Section III of this report, water quality modeling for the reservoirs should consider that the diversion water will have characteristics of Trinity River streamflow in the 0-1,000 cfs categories shown in these tables.

While the nutrients, solids, and bacteriological parameters exhibited a strong correlation with streamflow, the dissolved metals concentrations did not. Figure IV-4, a plot of dissolved zinc concentrations versus streamflow, typifies the behavior of the dissolved metals investigated with regard to streamflow. To characterize these data, a statistical analysis was used to determine a range of concentrations that can be expected based on the limited historical record. The nondetectables were incorporated into the analysis. The following paragraph briefly describes the statistical analysis and how the nondetectables were incorporated.

Figure IV-5 is a probability plot of zinc concentrations in the Trinity River during the 10-year period of interest. These concentrations were detected over the wide range of streamflows illustrated in Figure IV-4. All the metals analyzed exhibited the same log-normal behavior portrayed by the zinc data. Note that while there are 85 data points plotted in Figure IV-5, plotting positions

TOTAL PHOSPHOROUS CONCENTRATION BY STREAMFLOW INTERVAL CLASS TRINITY RIVER AT TRINIDAD: 1980 – 1989



USGS GAGE NO. 08062700
TWC STATION NO. 0804.0600

FIGURE IV–2

TOTAL PHOSPHORUS VS. STREAMFLOW
TRINITY RIVER AT TRINIDAD: 1980 - 1989

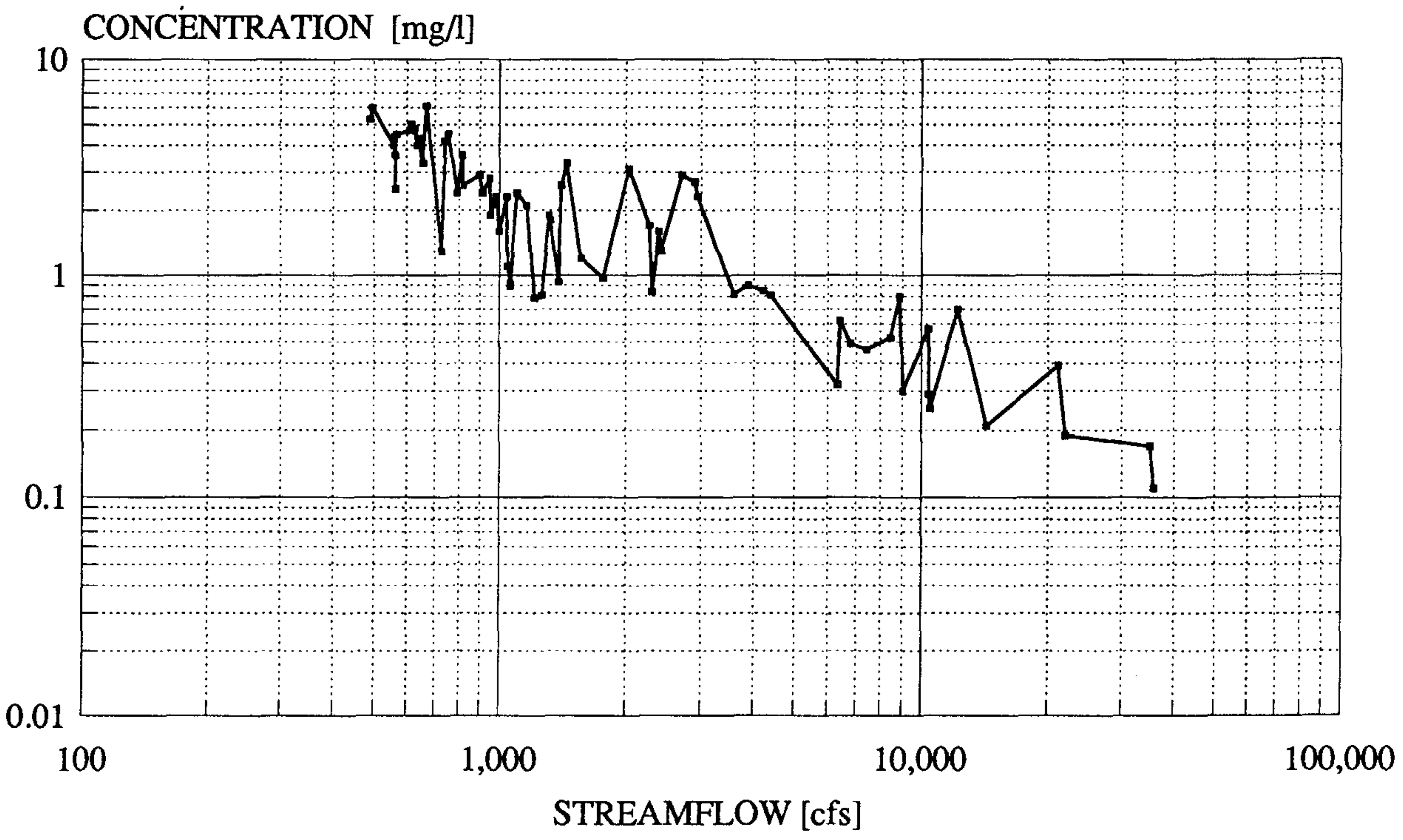


FIGURE IV-3

TABLE IV-4

EXPECTED VALUES* OF NUTRIENT CONCENTRATIONS BY STREAM FLOW INTERVALS TRINITY RIVER AT TRINIDAD: 1980-1989

(all concentrations in mg/L)

Nutrient form	Stream Flow Interval (cfs)				
	0-1,000	1,000-3,000	3,000-6,000	6,000 20,000	>20,000
Total phosphorus	3.68	1.77	0.84	0.46	0.21
Dissolved phosphorus	3.43	1.41	0.55	0.25	0.16
Dissolved ortho-phosphorus	2.99	1.26	0.52	0.23	0.07
Dissolved ortho-phosphate	9.83	4.16	1.90	0.71	0.21
Total NO_2+NO_3 nitrogen	5.36	3.45	0.77		0.41
Dissolved NO_2+NO_3 nitrogen	5.71	3.50	1.71	0.97	0.43
Total ammonia nitrogen	2.41	0.77		0.18	0.09
Dissolved ammonia nitrogen	2.33	1.23	0.51	0.23	0.08
Total organic nitrogen	2.34	1.34	1.10		0.84
Dissolved organic nitrogen	2.57	1.40	0.80	0.62	0.74

*Expected values calculated assuming the data to be lognormally distributed.

TABLE IV-5

EXPECTED VALUES FOR TSS AND FECAL COLIFORM BY STREAMFLOW INTERVALS TRINITY RIVER AT TRINIDAD: 1980-1989

Parameter designation	Parameter name	Stream Flow Interval (cfs)			
		0-1,000	1,000-3,000	3,000-10,000	>10,000
TSS[1]	Total suspended solids, (mg/L)	57.5	275.5	341.6	241.0
FC[2]	Fecal coliform, (col/100 ml)	89	305	291	406

[1] Expected values calculated assuming the data to be lognormally distributed.

[2] Values shown are the geometric mean for the given flow interval.

DISSOLVED ZINC CONCENTRATIONS
TRINITY RIVER AT TRINIDAD
1980 - 1989

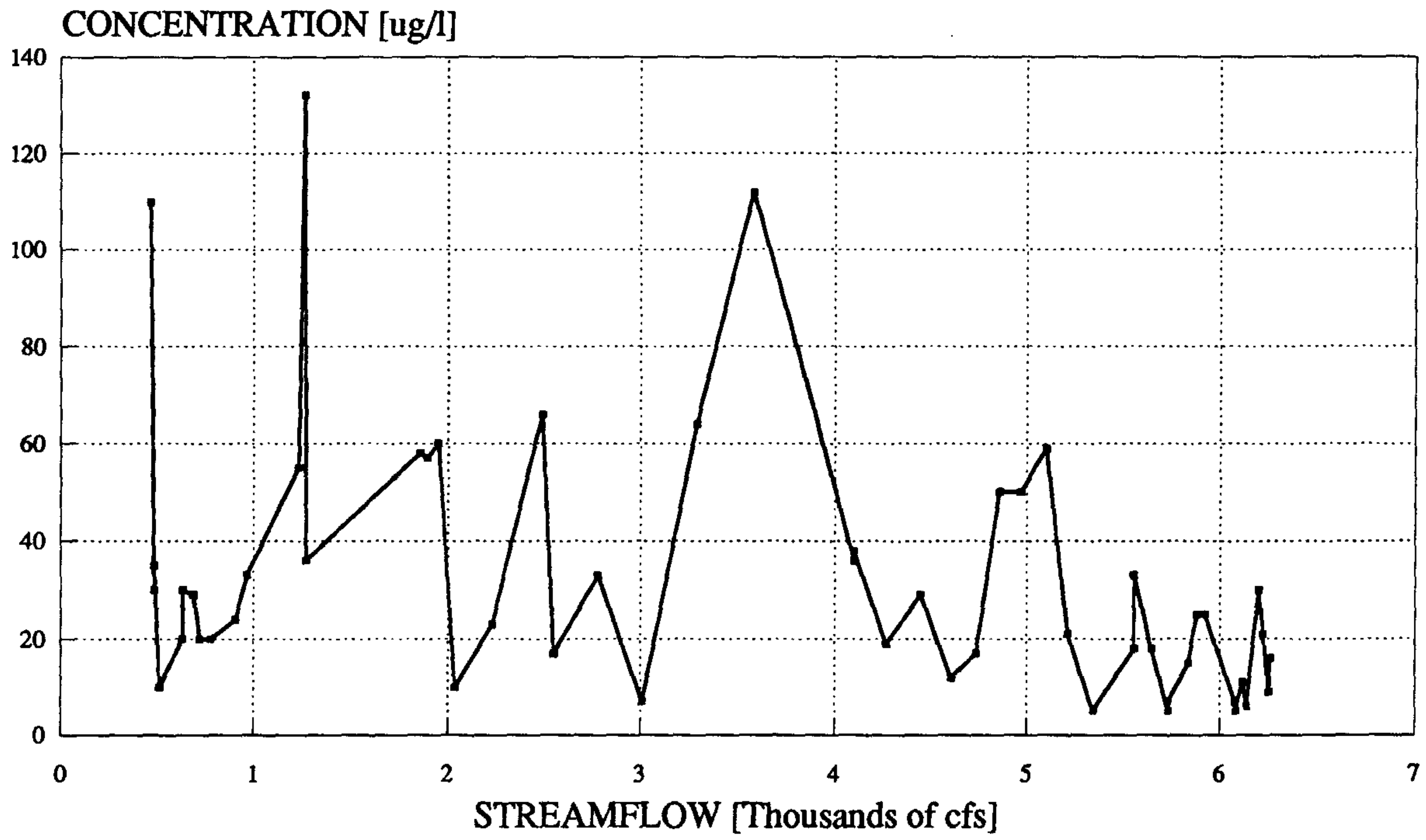


FIGURE IV-4

PROBABILITY PLOT FOR DISSOLVED ZINC
TRINITY RIVER AT TRINIDAD
1980 - 1989

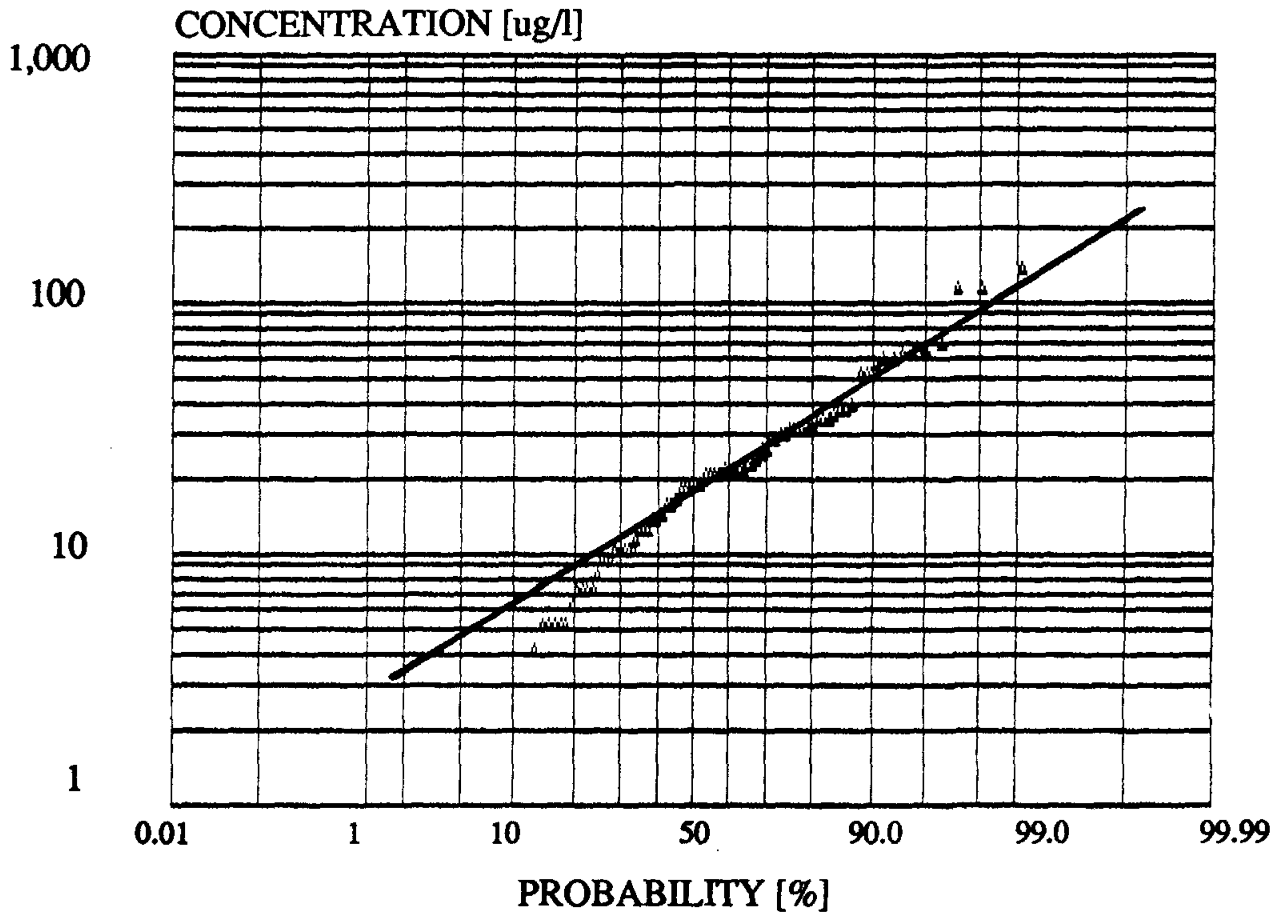


FIGURE IV-5

were actually calculated for all of the 96 samples, including the 11 nondetectables. There is a real probability of collecting a sample with a concentration less than detectable limits and the methodology for incorporating nondetectables into the analysis in this manner is supported by Travis and Land in "Estimating The Mean of Data Sets With Nondetectable Values." A copy of this reference is included in Appendix C. Probability plots like Figure IV-5 were generated for all the dissolved metals under investigation and are included in Appendix C.

Table IV-6 presents summary information for the dissolved metals. Expected values and standard deviations were calculated using only the data above detectable limits; however, the more proper way to summarize these data utilizes the probability plots which take into consideration the nondetectables. The 50th, 90th, and 99th percentile values from the probability plots have been recorded in Table IV-6. The fresh water stream standards have also been included in the table for reference. Data and supporting calculations for Table IV-6 are included in Appendix C.

WATER QUALITY IMPACT ON RICHLAND-CHAMBERS AND CEDAR CREEK RESERVOIRS

Cedar Creek Reservoir Data Analysis

Cedar Creek Reservoir water quality varies from its headwaters in Kaufman County to the dam in Henderson County (see Figure IV-6). The headwaters are turbid and shallow and heavily influenced by the two major tributaries, Kings Creek and Cedar Creek. The reservoir becomes more "lake-like" and less riverine south of Highway 85. The best reservoir water quality is found near the dam. During 1989, the Chlorophyll "a" and secchi depths at the dam averaged 16 ug/l and 43 inches, respectively, while at the headwaters chlorophyll "a" averaged 25 ug/l and secchi depth was 14 inches. These data show chlorophyll "a" levels already exceeding 20 ug/l and indicate that Cedar Creek Reservoir has existing enrichment in some areas of the reservoir.

TABLE IV-6

SUMMARY OF DISSOLVED METALS CONCENTRATIONS
TRINITY RIVER AT TRINIDAD
1980-1989

Dissolved metal	Cumulative probability Values[1] (ug/L)			Stream standards (fresh water) (ug/L)	
	50%	90%	99%	Acute	Chronic
Arsenic	2.1	6.5	16	360	190
Cadmium	0.015	1.5	55	37.5[2]	1.22[2]
Copper	2.7	7.8	19	21.0[2]	13.9[2]
Lead	0.14	7.0	110	92.2[2]	1.28[2]
Mercury	0.016	0.19	1.4	2.4	1.3
Selenium	0.16	1.1	5	20	5
Zinc	19	30	125	126.9[2]	114.9[2]

[1] The percent values in the column headings indicate the probability that a sample value will be less than or equal to the value listed in the table column. Cumulative probability values were determined considering all the data, including concentrations that were below detection limits. The data were assumed to be lognormally distributed.

[2] Standard calculated based on a hardness of 110 mg/L.

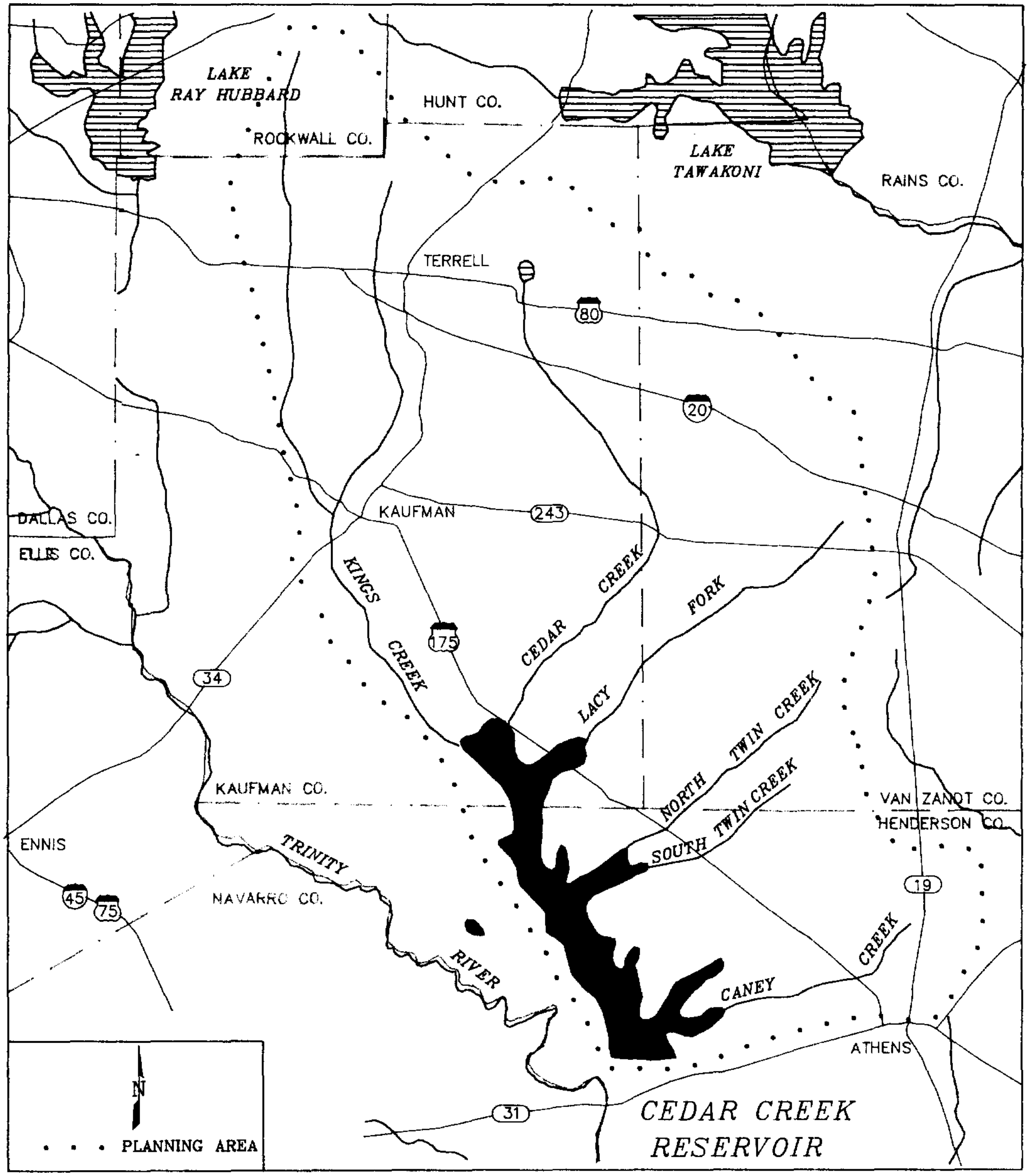


FIGURE IV–6
WATERSHED FOR CEDAR CREEK RESERVOIR

TABLE IV-6

SUMMARY OF DISSOLVED METALS CONCENTRATIONS
TRINITY RIVER AT TRINIDAD
1980-1989

Dissolved metal	Cumulative probability Values[1] (ug/L)			Stream standards (fresh water) (ug/L)	
	50%	90%	99%	Acute	Chronic
Arsenic	2.1	6.5	16	360	190
Cadmium	0.015	1.5	55	37.5[2]	1.22[2]
Copper	2.7	7.8	19	21.0[2]	13.9[2]
Lead	0.14	7.0	110	92.2[2]	1.28[2]
Mercury	0.016	0.19	1.4	2.4	1.3
Selenium	0.16	1.1	5	20	5
Zinc	19	30	125	126.9[2]	114.9[2]

[1] The percent values in the column headings indicate the probability that a sample value will be less than or equal to the value listed in the table column. Cumulative probability values were determined considering all the data, including concentrations that were below detection limits. The data were assumed to be lognormally distributed.

[2] Standard calculated based on a hardness of 110 mg/L.

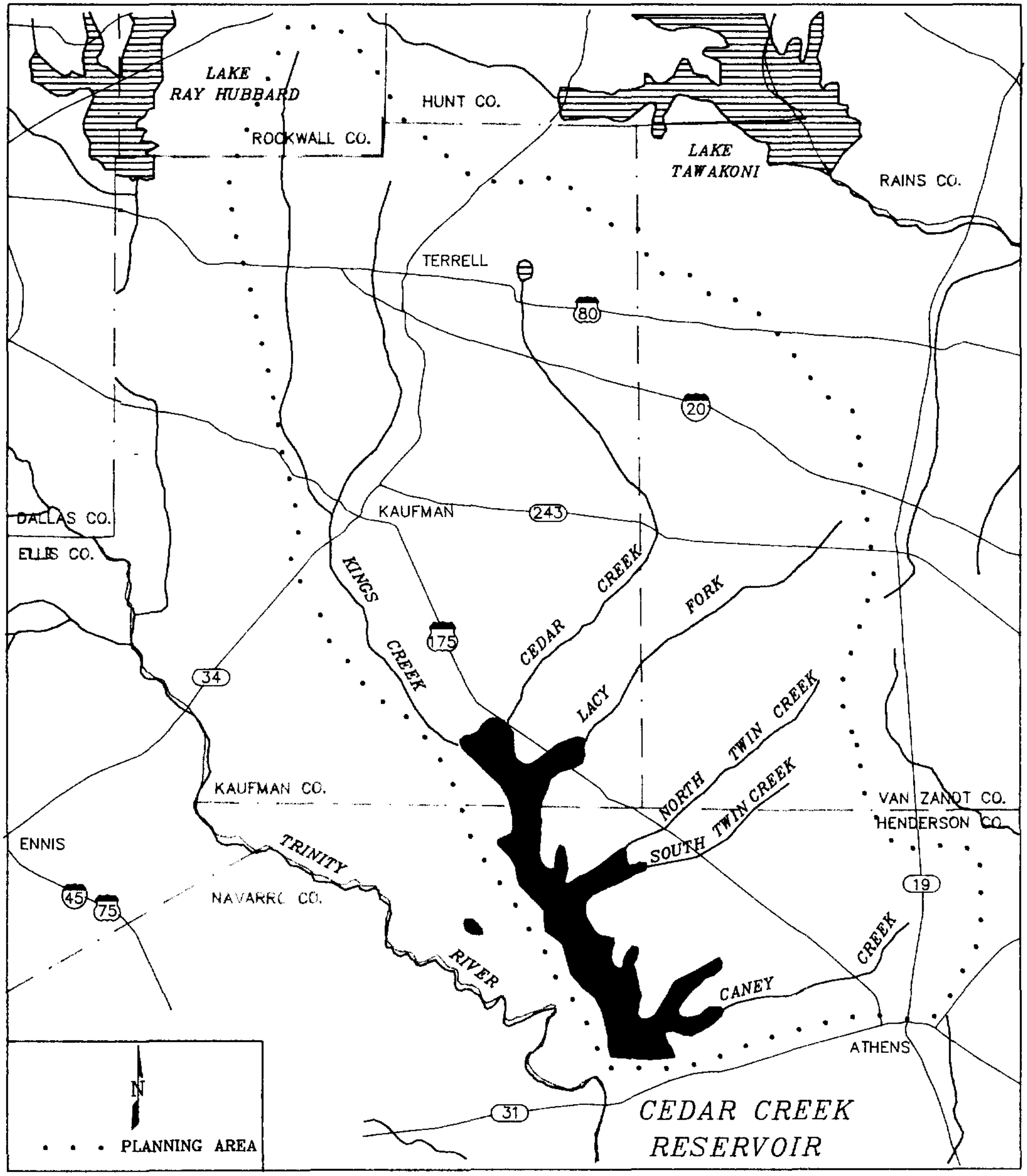


FIGURE IV–6
WATERSHED FOR CEDAR CREEK RESERVOIR

Richland-Chambers Reservoir Data Analysis

Richland-Chambers Reservoir (see Figure IV-7) is a new reservoir, having filled to its conservation level in 1989. As a new reservoir, Richland-Chambers Reservoir can be expected to experience dynamic water quality changes. The 1990 database shows turbid, nutrient-rich headwaters and high quality mainpool water quality conditions. The major tributaries for Richland-Chambers Reservoir are Chambers Creek and Richland Creek, with Chambers Creek having the lower water quality of the two. During 1990, chlorophyll "a" and secchi depth averaged 13 ug/l and 53 inches, respectively at the dam and 16 ug/l and 11 inches at the headwaters.

Water Quality Modeling

The District calibrated and verified a mathematical model for Cedar Creek Reservoir and calibrated a mathematical model for Richland-Chambers Reservoir (see Appendix E). The U.S. Army COE "BATHTUB" model was used for each lake. This model is an empirical eutrophication model which uses mass balance calculations for water and total nutrient balances. Empirical formulations for nutrient limitations, light limitations, within lake nutrient sources, and phytoplankton growth and death are used. The empirical relations are based on data from existing COE reservoirs and are not represented, in the model, by fundamental mechanisms. The processes characterized by these empirical formulations substantially influence chlorophyll "a" which is the variable used to determine the effects of diversions. Therefore, the results from the "BATHTUB" modeling provides an initial indication of the water quality effects from diversions. Further substantiation is required employing models such as WASP which can employ representations of the fundamental mechanisms governing chlorophyll "a" responses to changes in nutrient inputs. Table IV-7 describes the source of data used in the "BATHTUB" water quality modeling. Copies of all "BATHTUB" output and data files are filed at the District's Eagle Mountain office.

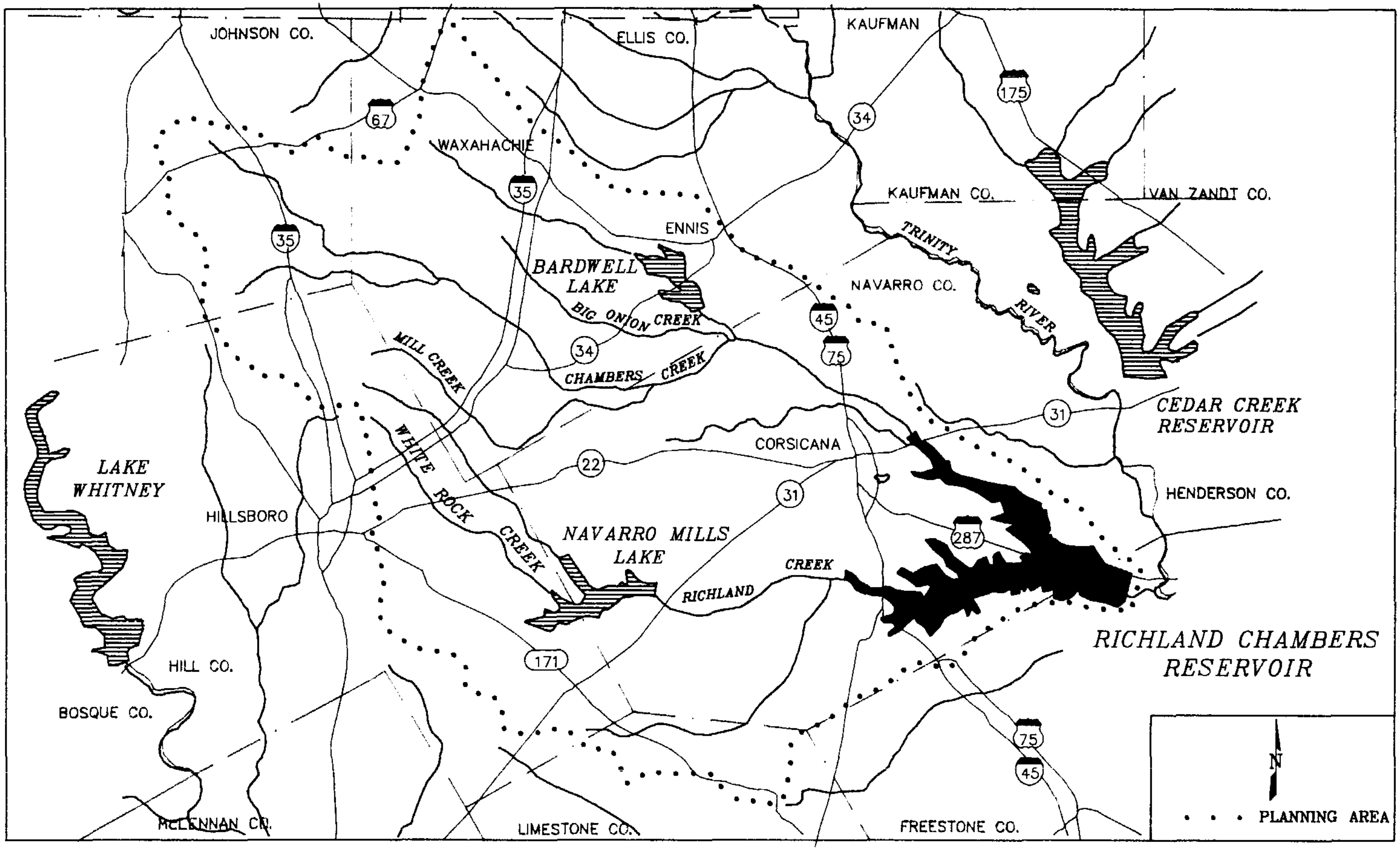


FIGURE IV-7
WATERSHED FOR THE RICHLAND-CHAMBERS RESERVOIR

TABLE IV-7

DATA SOURCES FOR LAKE WATER QUALITY MODELING

Data type	Data Source	
	Cedar Creek Reservoir	Richland-Chambers Reservoir
Water Balance	TCWCID operations, except evaporation from COE	TCWCID Operations, except evaporation from COE
Rainfall Quality	TCWCID monitoring program 1989 to present at Richland-Chambers	TCWCID monitoring program 1989 to present at Richland-Chambers
Tributary Flows	USGS where available, back-calculated from water balance	USGS where available, back-calculated from water balance
Tributary Quality	TCWCID monitoring program 1989 to present	TCWCID monitoring program 1989 to present
WWTP Quantity	1989 TWC self-reporting	1990 TWC self-reporting
WWTP Quality	TCWCID monitoring program 1989 to present	TCWCID monitoring program 1989 to present
Reservoir Quality Calibration Data	TCWCID intensive survey 1989	TCWCID quarterly monitoring 1990
Reservoir Quality Verification Data	TCWCID Quarterly Monitoring 1990	None available
Makeup Quantity	This report	This report

Model Calibration-Verification

Cedar Creek and Richland-Chambers Reservoir's water quality models were calibrated to fit observed data using second order phosphorus sedimentation curves. This formulation is reported to work when much of the phosphorus load to a reservoir is associated with particulates. Nitrogen removal formulations differed between the reservoirs. For Richland-Chambers Reservoir second order nitrogen removal formulations were used. For Cedar Creek Reservoir nitrogen profiles were calculated considering first order removals. Chlorophyll "a" was modeled using an empirical formulation which considers phosphorus, light and hydraulic residence time. Changes in nitrogen did not improve the fit of observed and predicted chlorophyll "a" data. Secchi depth was calculated using chlorophyll "a" and turbidity information.

The 1989 Cedar Creek Reservoir water quality model was verified using 1990 quarterly reservoir water quality data. A 1990 water balance was substituted into the 1989 model but all calibration coefficients were left unchanged. The resulting fit was good for most parameters with the exception of nitrogen for which the model predicted values that were low by an average factor of 1.7. The impact of this on model predictions is insignificant because chlorophyll "a" and secchi depth, the parameters of concern in evaluating makeup water quality requirements, are not derived from nitrogen calculations. Data for Richland-Chambers Reservoir model verification are not available at this time.

Table IV-8 compares observed water quality data to values predicted by the model. The closer the ratio shown is to one (1), the better the fit of observed and predicted values.

Water Quality Modeling Results

Using a calibrated water quality model for each reservoir, water quality projection scenarios were run with makeup flows diverted from the Trinity River to each reservoir during 1956 (drought) and 1957 (flood) hydraulic conditions. The water balances for each condition were based on the hydrologic information presented in Chapter III. The quality of diverted makeup water considered was either "treated" or "untreated." Table IV-9 summarizes the nutrient levels

TABLE IV-8

RATIOS OF ACTUAL VERSUS PREDICTED VALUES

Bathtub run	Phosphorous		Nitrogen		Chlorophyll 'a'		Secchi Depth	
	Dam	PS[1]	Dam	PS[1]	Dam	PS[1]	Dam	PS[1]
Cedar Creek Calibration	0.86	0.69	0.97	0.92	0.96	1.07	1.02	0.98
Cedar Creek Verification	0.95	0.92	1.24	1.69	1.19	1.16	0.93	1.00
Richland-Chambers Calibration	1.04	1.10	0.91	1.05	1.04	1.04	1.40	0.99

[1] District's Pump Station

TABLE IV-9

NUTRIENT CONCENTRATIONS USED IN BATHTUB MODELING

	Total Phosphorous (mg/l)	Ortho Phosphorous (mg/l)	Total Nitrogen (mg/l)	Inorganic Nitrogen (mg/l)
Makeup - Treated[1]	1	0.5	3	1.5
Makeup - Untreated[2]	3.68	2.99	10.3	7.72
Post Oak Creek[3]	0.61	0.3	2.75	1.51
Chambers Creek[3]	0.82	0.18	1.78	1.02
Richland-Chambers Reservoir[4]	0.05	0.02	0.52	0.15
Kings Creek[5]	0.65	0.2	1.63	1.16
Cedar Creek[5]	0.5	0.12	1.22	0.48
Cedar Creek Reservoir[6]	0.09	0.03	0.27	0.09

[1] Trinity River water treated to theoretical goal levels, "best case."

[2] Untreated Trinity River water representing year 2020 conditions with 0-1000 cfs flows, "worst case."

[3] TCWCID Richland-Chambers Reservoir tributary data for period 1989 through 1990.

[4] 1990 average reservoir data from TCWCID quarterly sampling.

[5] TCWCID Cedar Creek tributary data from 1989 intensive survey.

[6] 1989 average reservoir data from TCWCID intensive survey.

associated with each category and compares them to measured concentrations. Treated diverted makeup flow represents Trinity River water with total phosphorous concentrations reduced to 1 mg/L and total nitrogen at 3 mg/L. These treatment levels are considered practical. Treated water quality approximates the quality of existing tributary inflows. Untreated makeup flow reflects measured quality in the Trinity River under low flow conditions (0-1,000 cfs) which is estimated at 4 mg/L phosphorous and 10 mg/L nitrogen.

Cedar Creek Results

Table IV-10 summarizes chlorophyll "a" and secchi depths from eight "BATHTUB" scenarios and the calibration. Two scenarios were run under each hydraulic condition. The first scenario modeled input of makeup water at the dam site. The second scenario modeled input of makeup water above the Highway 85 bridge. During 1957 conditions, the model results indicate that no significant water quality impact will occur. Makeup flows during 1957 conditions account for only 2 percent of the total inflow volume.

Under drought conditions there is a calculated impact of the makeup water and associated nutrients. With diversions of untreated Trinity River water to the vicinity of the dam, chlorophyll "a" levels in that area are calculated to increase by 88 percent and exceed a Texas Department of Water Resources alert level of 20 ug/l by 10 ug/l. It should be recognized that the 20 ug/l alert level is not a legally adopted water quality standard and is used herein only for comparison purposes. The impact at the site of the District's pump station is not as significant. The chlorophyll "a" levels are projected to increase by about 33 percent. Diversion of water to above Highway 85 shows similar results.

Examination of projected chlorophyll "a" values at the dam during drought conditions shows that there is not a large difference in the calculated concentrations associated with treated and untreated Trinity River water. The model's calculations are indicating that, during drought periods, when makeup flow comprises 44 percent of the total tributary inflow, even with nutrient concentrations reduced to 1 mg/L total phosphorous, sufficient phosphorous is available to grow algae to the point that light and hydraulic residence time are

TABLE IV-10

CEDAR CREEK BATHTUB WATER QUALITY MODEL OUTPUT SUMMARY

			Makeup diversion to dam site				Makeup diversion to Highway 85		
			1956[2]		1957[3]		1956[2]		1957[3]
Reservoir segment	Description	Calibration[1]	Treated[4]	Untreated[5]	Treated	Untreated	Treated	Untreated	Untreated
Chlorophyll 'a', ug/l									
1	Upper Lake	30	35	39	30	31	38	45	32
2	Highway 85	22	24	26	21	22	25	27	22
3	Midlake	16	18	19	16	16	18	20	16
4	Dam Site	16	27	30	19	22	23	27	19
5	Pump Station	15	18	20	15	15	18	20	15
	Reserv Average	20	24	26	20	21	24	27	21
Secchi Depth, inches									
1	Upper Lake	12	12	12	12	12	12	12	12
2	Highway 85	20	20	20	20	20	20	20	20
3	Midlake	24	27	24	27	27	24	24	27
4	Dam Site	43	31	31	39	35	35	31	39
5	Pump Station	35	35	31	35	35	35	31	35
	Reserv Average	27	24	24	27	27	28	24	27

Footnotes:	Annual Tributary inflow	Annual Dam outflow	Annual Makeup water	Reservoir hydraulic resident time
	acre-feet x 1000			years
[1]Calibration	413	243	na	1.9
[2]Drought Scenario	149	0	64	8.2
[3]Flood Scenario	1178	429	21	0.6
Average Scenario (Not tabulated)	720	410	0	1.1

[4] Treated Trinity River water, "best case."

[5] Untreated Trinity diversion water, "worst case."

TABLE IV-11

RICHLAND-CHAMBERS BATHTUB WATER QUALITY MODEL OUTPUT SUMMARY

			Makeup diversion to dam site			
			1956[2]		1957[3]	
Reservoir segment	Description	Calibration[1]	Treated[4]	Untreated[5]	Treated	Untreated
Chlorophyll 'a', ug/l						
1	Chambers Creek	15	13	15	15	16
2	Pump Station	11	8	13	11	12
3	Richland Creek	16	10	13	15	16
4	Richland Mid	13	8	11	12	13
5	Confluence	9	8	12	9	10
6	Dam Site	12	14	20	12	14
	Reserv Average	13	10	14	13	14
Secchi Depth, inches						
1	Chambers Creek	12	12	12	12	12
2	Pump Station	35	39	35	35	35
3	Richland Creek	24	27	24	24	24
4	Richland Mid	47	55	47	47	47
5	Confluence	51	51	47	43	47
6	Dam Site	39	35	31	39	35
	Reserv Average	35	35	31	35	31

Footnotes:

	Tributary inflow	Dam outflow	Makeup water	Reservoir hydraulic resident time
	acre-feet x 1000			years
[1]Calibration	1387	1231	na[7]	0.9
[2]Drought Scenario	183	4	73	10.3
[3]Flood Scenario	1535	273	30	0.8
Average Scenario (Not tabulated)	817	76	36	1.6

[4] Treated Trinity River water, "best case."

[5] Untreated Trinity diversion water, "worst case."

on data from existing COE reservoirs and are therefore not represented in the model by fundamental mechanisms. Since the processes represented by these empirical formulations substantially influence chlorophyll "a" concentrations in both lakes, and since chlorophyll "a" concentrations are used as the basic measure of eutrophication, it is necessary to determine if projected water quality is consistent with current knowledge of these fundamental mechanisms. In making this determination, 1989 water quality data for Cedar Creek Reservoir and 1990 data for Richland-Chambers Reservoir were used to examine the limitations on phytoplankton growth from light, phosphorous and nitrogen. These procedures are used to examine current conditions, but are limited in the insights provided for future conditions that are substantially different.

Growth Limitations

The growth rate of phytoplankton in a water body is determined by the optimum organism growth rate and the modifications to that rate caused by environmental conditions. The two environmental conditions that are important in Cedar Creek and Richland-Chambers projections are nutrient and light limitations. Equation 1 illustrates the effects of these factors on phytoplankton growth rates.

$$Ge=Gm*Rl*Rn \qquad (1)$$

where: Ge = phytoplankton growth rate in the lake

GM = maximum phytoplankton growth rate at lake temperatures

Rl = light limitation factor

Rn = nutrient limitation factor

Using Equation 1, the phytoplankton growth rate can be examined by considering the relative limitations on growth, associated with nutrient limitation (which will change) and with light limitations (which will not directly change).

Nutrient Limitations

Nutrient limitations are examined considering a Michaelis-Menton formulation as illustrated in Equation 2.

$$Rn = \min \{P/(Kp+P);N/Kn+N)\} \quad (2)$$

where: Rn = nutrient limitation factor
P = inorganic phosphorous concentration
N = inorganic nitrogen concentration
Kp & Kn = Michaelis constants for P&N
min = the minimum of the calculated nutrient factors

The Michaelis constant for phosphorous used is 0.001 mg/L and for nitrogen is 0.02 mg/L. These are within the range reported in the literature and are consistent with experience in Texas.

Examination of data for both lakes indicates that phosphorous is the limiting nutrient for phytoplankton growth during some periods of time and nitrogen is the limiting nutrient at other times. The "BATHTUB" calculations do not consider the effect of nitrogen limitations. Since the limitation from nutrient concentrations is not very substantial under most circumstances, reductions in phytoplankton growth rates of 10 percent are usually computed. For Cedar Creek, the largest reductions in growth rates were calculated at 17 percent for phosphorous and 22 percent for nitrogen. For Richland-Chambers Reservoir, the largest reduction in growth rates were calculated at 17 percent for phosphorous and 37 percent for nitrogen.

Light Limitations

The light limitation on phytoplankton growth rate is calculated using equations 3, 4, 5 and 6.

$$I_a = \frac{I_T}{f} \quad (3)$$

$$\alpha_o = \frac{I_a}{I_s} \quad (4)$$

$$\alpha_1 = \alpha_o \exp(-K_eH) \quad (5)$$

$$R_I = \frac{2.718f}{K_eH} [\exp(-\alpha_1 - \exp(-\alpha_o] \quad (6)$$

where: I_T = total solar radiation
f = photo period
I_a = average solar radiation
I_s = saturated growth solar radiation
Ke = light extinction coefficient
H = mix water layer at the lake surface
R_I = light limitation factor

The limitation on phytoplankton growth due to light limitations ranges from 85 to 90 percent reduction of total growth potential under average conditions. Under extremes, the limitations can be as large as 99 percent and as low as 60 percent.

Discussion

The results of the "BATHTUB" modeling are more or less consistent with the information obtained from the examination of fundamental processes controlling phytoplankton growth rate. This examination of the limitations on phytoplankton growth rates indicates that both lakes have essentially similar responses to light and nutrients. Light is the major controlling factor. Nutrients appear to exercise a small control on phytoplankton growth rates during some periods. This suggests that, from a technical viewpoint, it may be possible to consider limiting nutrient removal actions for the reused water. A larger data base and a more detailed state-of-the-art technical analysis (using WASP eutrophication modeling) is needed before no nutrient removal of diverted makeup water can be a realistic consideration.

Conclusions

Lake quality modeling performed by the District using the U.S. Army COE "BATHTUB" model indicates that nutrients in the Trinity River diversion water will impact water quality in Cedar Creek Reservoir. However, there is little improvement in water quality associated with reducing nutrient concentrations in the diversion flows to the levels of nutrients experienced in lake inflows. For Richland-Chambers Reservoir, the model indicates a water quality impact associated with nutrients from the diverted flow. A substantial improvement in water quality is associated with reducing nutrients to levels experienced in lake inflows.

Unfortunately, the "BATHTUB" model results require substantiation employing models such as WASP which can consider representation of fundamental mechanisms. The current analysis which considered the fundamental mechanisms controlling phytoplankton growth can not be used to develop projections of future water quality resulting from changes in nutrient and flow inputs. It is recommended that additional lake quality modeling be performed for Cedar Creek and Richland-Chambers Reservoirs using the deterministic WASP model.

CHAPTER V

IMPACT OF TRINITY DIVERSION ON DOWNSTREAM WATER QUALITY

GENERAL

The QUAL-TX water quality simulation mathematical model has been used to evaluate downstream water quality impacts of the potential diversion. The current QUAL-TX models for Segments 806, 805, and 804 of the Trinity River Basin were obtained from the TWC. The models were developed previously by the TWC for determination of wasteload allocations for discharges to the Trinity River. Detailed information concerning the TWC QUAL-TX models is presented in Wasteload Evaluation for the Upper Trinity River System in the Trinity River Basin, TWC, February 1986.

SEGMENT DESCRIPTIONS AND WATER QUALITY STANDARDS

The TWC recently revised the Texas Surface Water Quality Standards. The revisions for the Upper Trinity River Basin include revisions to the segmentation of Segments 806, 805, and 804; as well as revisions to the water quality standards for these segments. The new segment descriptions and water quality standards for the Upper Trinity River Basin are described below. Segment locations are shown schematically on Figure V-1.

The segmentation of the Upper Trinity River System includes Segments 806, 841, 805, and 804. Segment 806 extends from the Lake Worth Dam to a point immediately upstream of the confluence of Village Creek. Segment 841 extends from a point immediately upstream of the confluence of Village Creek to a point immediately upstream of the confluence of the Elm Fork Trinity River. Segment 805 extends from a point immediately upstream of the confluence of the Elm Fork Trinity River to a point immediately upstream of the confluence of the Cedar Creek Reservoir discharge canal. Segment 804 extends from a point immediately upstream of the confluence of the Cedar Creek Reservoir discharge canal to a point 1.1 miles upstream of Boggy Creek.

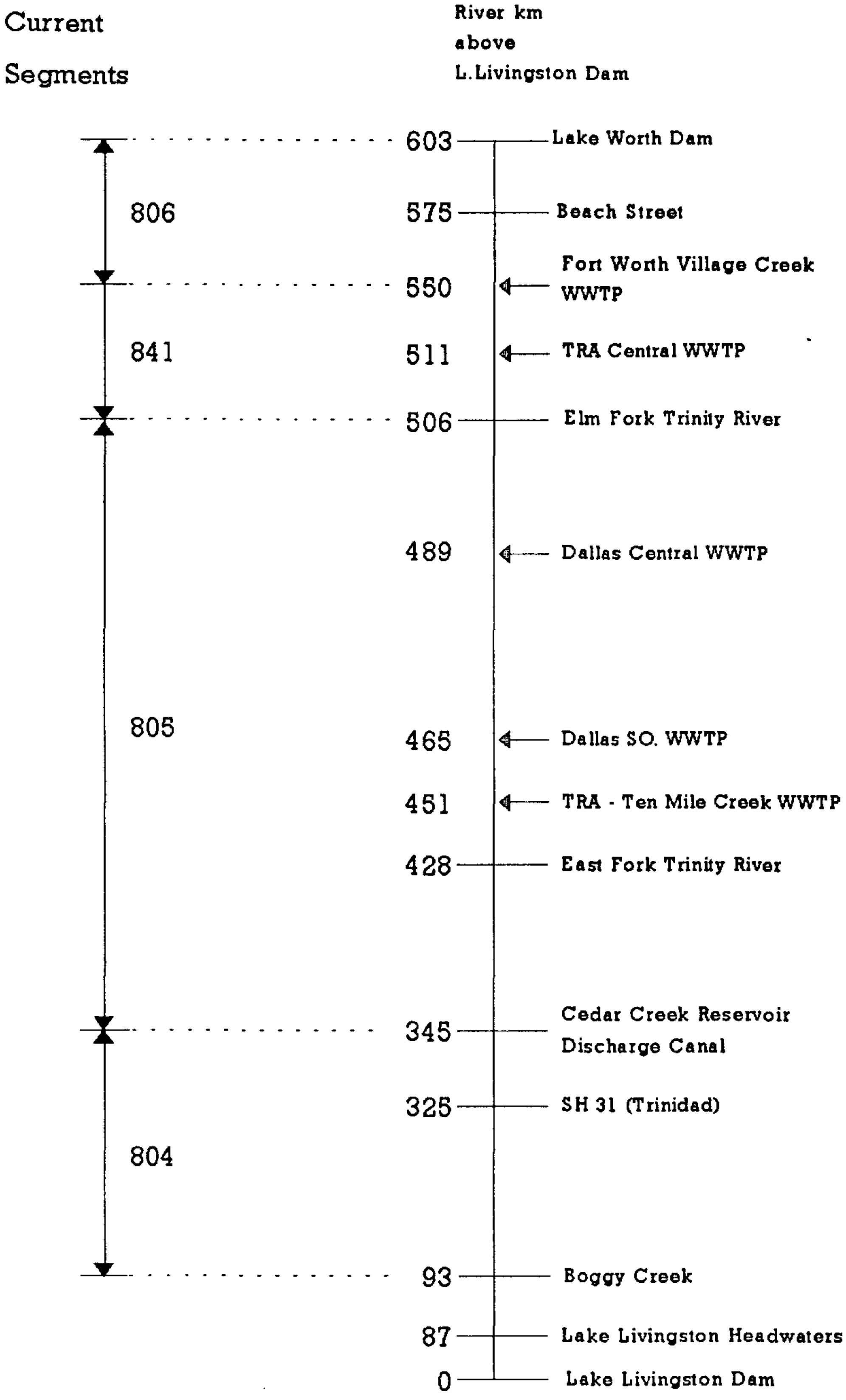


Figure V-1

Schematic Presentation of the Trinity River System
Showing Current Segementation and Major Dischargers

(not to scale)

Texas Stream Quality Standards require an average DO concentration of 5.0 mg/L for Segments 806 and 804. The DO requirements for Segments 805 and 841 are dependent on the flow at USGS Gaging Station 08048000, West Fork Trinity River at Fort Worth. When the flow at Fort Worth is less than 80 cfs, the DO requirement for Segment 841 is 2.5 mg/L and the DO requirement for Segment 805 is 3.5 mg/L. At flows greater than or equal to 80 cfs at Fort Worth, the DO requirement for Segment 841 is 4.0 mg/L and the DO requirement for Segment 805 is 5.0 mg/L.

MAJOR DISCHARGERS

Five major dischargers to the Upper Trinity River System comprise approximately 95 percent of the total permitted wastewater flow. The major dischargers and current permitted flow and quality are listed below.

Dischargers	Flow[1] (MGD)	DO (mg/L)	BOD_5 or CBOD (mg/L)	NH_3-N (mg/L)
Ft. Worth Village Creek	144	6.0	10.0	2.0
TRA Central	135	4.0	7.0	3.0
Dallas Central	150	4.0	7.0	3.0
Dallas South	90	4.0	7.0	3.0
TRA Ten Mile Creek	20	4.0	10.0	3.0

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[1] Permitted flows are daily average values from TWC discharge permits.

The locations of the major dischargers are shown schematically on Figure V-1.

HYDROLOGIC PROJECTIONS

A hydrologic analysis described in Chapter III and Appendix B projects total wastewater return flows, natural flows, and diversions for the years 2020 and 2050. These projected flows were incorporated into the TWC QUAL-TX models to evaluate future conditions.

Natural flows were considered (Appendix B) to determine a seven-day, two-year low flow (7Q2) for natural conditions (e.g., runoff only) of 189 cfs for the Trinity River at Trinidad. Texas Stream Quality Standards indicate a 7Q2 flow value of 4.2 cfs for Segment 806 of the Trinity River. This value is used as the headwater flow for the QUAL-TX model of Segment 806. The difference in 7Q2 flow from Trinidad to the headwater of Segment 806 (189 cfs - 4.2 cfs = 184.8 cfs) was distributed in the QUAL-TX models based on contributing watershed areas.

Currently, the total wastewater return flow that is permitted for the Upper Trinity River System is 882 cfs. The hydrologic analysis presented herein in Chapter III projected total wastewater return flows of 801 cfs (517 MGD) in the year 2020 and 930 cfs (600 MGD) in the year 2050. The wastewater return flow of 930 cfs (600 MGD) that was projected for the year 2050 has already been reduced by 60 MGD to account for the projected pump-back from the Dallas Southside WWTP.

The following procedure was used to determine the projected permitted wastewater return flows for each discharger. The current permitted flow for each discharger was multiplied by the total projected wastewater return flow and divided by the total permitted wastewater return flow. A proportionally direct distribution of the change in projected versus permitted total wastewater return flow was thereby achieved.

A maximum Trinity River diversion rate of 235 cfs was projected on the basis of the hydrologic analysis presented herein in Chapter III. This diversion was modeled as a withdrawal at the beginning of Segment 804.

MODEL RESULTS

The QUAL-TX models for Segments 806, 805, and 804 of the Trinity River that have been obtained from TWC have been revised to reflect projected hydrologic conditions determined in Chapter III herein. Initially, the currently permitted effluent flows and the projected effluent flows for the year 2050 were modeled with no diversion at Trinidad. The quality of effluent flows in both cases was assumed to be the currently permitted quality. In addition, the currently permitted flows and the projected 2020 and 2050 wastewater return flows were modeled with a diversion at Trinidad. The quality of effluent flows in these cases was also assumed to be the currently permitted quality.

In all cases, the minimum DO occurred approximately 25 km downstream of the Village Creek confluence. The DO gradually increased after the DO sag that occurred 25 km below the Village Creek confluence. In general, the predicted DO concentration in the Trinity River near Trinidad is approximately 5 mg/L.

The proposed diversion at Trinidad will not have an effect on the water quality of Segments 806, 841, or 805 since these segments are located upstream of the diversion. Model results also indicated that a possible slight improvement in the water quality of Segment 804 can be expected with the 235 cfs diversion. The minimum DO in Segment 804 was at the headwater of the segment and was not impacted by the diversion. Proceeding downstream, the Segment 804 DO concentration gradually increased from the initial concentration at the headwater of the segment. Treatment levels that are required of the five major discharges in order to maintain water quality standards will not be affected by the proposed diversion.

CHAPTER VI
EVALUATION OF ALTERNATIVE TREATMENT METHODS

INTRODUCTION

Based on a literature search conducted by District as well as current documentation found in the APAI library, approximately twenty alternative treatment methods were identified for treatment of Trinity River water prior to discharge into Richland-Chambers and/or Cedar Creek Reservoirs. The alternative treatment methods identified were evaluated to determine their potential suitability. Since a large percentage of the Trinity River flow is treated effluent discharged from publicly-owned treatment works in the metroplex, the primary water quality parameters for which treatment would be necessary are expected to be phosphorus, nitrogen, heavy metals, pathogens, and possibly toxic organics. Therefore, each of the alternative methods was evaluated for effectiveness in removing nutrients (particularly phosphorus) as well as the other parameters of concern, land requirements/land availability, costs, operating constraints, and regulatory constraints. The gathering of information and evaluation of each alternative has been an ongoing process which resulted in the elimination of many of the alternatives from further consideration. Three alternative treatment methods are recommended for further laboratory/pilot-scale studies and research: constructed wetlands, chemical precipitation, and periphyton/fish culture.

SCREENING OF ALTERNATE TREATMENT METHODS

The preliminary screening by APAI identified approximately twenty alternative methods for consideration. These alternatives and discussion of issues pertaining to the suitability and requirements of each are included in Table VI-1. Preliminary screening primarily considered technical feasibility, nutrient removal capability, permitting requirements, and an estimate of costs. An additional alternative treatment method involving a periphyton/fish culture system was studied by Dr. Ray Drenner of TCU in association with APAI (see Chapter VII and Appendix D). Based on this preliminary screening, five of the alternatives were selected for further literature research and evaluation. These

TABLE VI-1

ISSUES PERTAINING TO TREATMENT ALTERNATIVES OF DIVERTED RIVER WATER

Treatment Alternative	Land Requirements	Technical Feasibility	Operating Requirements	Remarks
Natural Wetland	Approximately 1500 acres of natural wetland located in the vicinity of the diversion.	If 1500 acre natural wetland available, same as for a constructed wetland.		
Constructed Wetland	Approx. 1500 acres based on 80.8 MGD (the estimated diversion flow to Richland/Chambers Reservoir), an 18-inch average depth, and a 7-day detention time in a free-surface flow system. (Based on 71.1 MGD, the expected diversion flow to Cedar Creek Reservoir, approximately 1320 acres will be needed.) Land requirement for subsurface flow would be about one-fourth of that for free-surface flow. Soil analyses for permeability of the soil in the proposed area would be necessary to accurately determine land requirements.	Some plants have demonstrated P concentrations in effluent of <1 mg/L. P removal may be dependent on soil type in area. If soil not adequate to effectively remove P, Ca addition may increase P removal. Operational year-round, but removal efficiency may be reduced in winter months. Need more data either from existing facilities or from pilot study. Has been demonstrated to be very effective advanced treatment of secondary treated effluent of varying input loads.	Maintenance flows to sustain vegetation and microbial populations necessary during periods when not diverting river water. Will need part-time maintenance of structure and observation of operations. Will possibly need periodic harvesting of vegetation to prevent large input of nutrients from senescence of vegetation. Personnel requirements for harvesting will be significant. Composting of harvested vegetation should be possible.	Current reports from two larger plants in Florida show excellent results. Reports indicate effective treatment is occurring in the first tenth to third of the wetlands with some slight degradation through the remainder of the wetland. Reports indicate importance of soil sorption of phosphorus when appropriate soil is used. Review of soil data in the vicinity of the reservoirs indicates suitable soil for good P sorption. Biological precipitation by microorganisms and attached algae in the litter zone of marsh cells has also been indicated as an important site of P removal. Creation of wetland habitat for wildlife and waterfowl.

TABLE VI-1

ISSUES PERTAINING TO TREATMENT ALTERNATIVES OF DIVERTED RIVER WATER

Treatment Alternative	Land Requirements	Technical Feasibility	Operating Requirements	Remarks
Rock/Plant Filters	At recommended 5 acres/mgd for subsurface flow, approximately 400 acres (based on 80.8 MGD diversion flow to Richland/Chambers Reservoir.)	Removal efficiency for P may not be sufficient alone. May be possible to use in conjunction with a soil filter for additional P removal.	Texas Water Commission recommends harvesting of plants before first freeze.	
	Approximately 360 acres at Cedar Creek Reservoir based on a 71.1 MGD diversion flow.	Would need settling basin before rock/plant filter to prevent suspended sediment from clogging filter.	If harvesting required, recommended schedule would be twice a year, with thinning periodically to prevent clogging of pore spaces in filter.	
			Maintenance flows would be necessary to sustain vegetation and microbial population. Storage reservoir and effluent recirculation could be used to satisfy maintenance flows.	
Water Hyacinth Ponds	200-500 acres/mgd	Would require a greenhouse structure to protect from freezing temperatures as well as a special permit from Texas Parks & Wildlife. Very expensive and difficult.		

TABLE VI-1

ISSUES PERTAINING TO TREATMENT ALTERNATIVES OF DIVERTED RIVER WATER

Treatment Alternative	Land Requirements	Technical Feasibility	Operating Requirements	Remarks
Fish Ponds		The culture of fish in high densities is very labor intensive and P removal with this treatment alone may not be sufficient. Would be good as settling basin for suspended sediment in river water if used in conjunction with constructed wetland.	If stocked with native fish at reasonable density would only need part-time maintenance. Would need periodic dredging to remove trapped sediments.	A 60-70 acre storage reservoir would provide >24 hr detention time for a 80.8 MGD flow. This should allow effective removal of suspended sediment as well as some removal of nutrients and metals. Would also allow dispersion of energy before release of water to constructed wetland cells.
Overland Flow	2,152 acres for overland flow for 80.8 MGD. An additional 62 acres would be necessary for a rapid infiltration effluent polishing unit for P.	Removal efficiency for P not sufficient using only overland flow. Would require a rapid infiltration soil filter for the effective removal of P, if suitable soils could be found close by. Initial review of data on soils in the area indicate soils with high clay content and slow permeability which would be very suitable for overland flow, but not suitable for rapid infiltration. Effective removal of ammonia, but possibly not other forms of N.	During the growing season, the grass cover would need to be mowed at least bi-weekly to prevent the grass from laying over and channelizing the flow. During periods of flow, full-time maintenance would be required to oversee distribution system. Beds must be rotated out and allowed to dry fully before harvesting.	Clay soils in area would be very suitable for overland flow. Might be possible to use in conjunction with Rapid Infiltration or constructed wetland to improve P removal.

TABLE VI-1

ISSUES PERTAINING TO TREATMENT ALTERNATIVES OF DIVERTED RIVER WATER

Treatment Alternative	Land Requirements	Technical Feasibility	Operating Requirements	Remarks
Sedimentation Basin	Approximately 60 acres to provide a minimum of 24 hours detention time for 80.8 MGD (projected flow to Richland/ Chambers Reservoir) and include 10% volume storage capacity for sediment.	Effective removal of Total P not possible.	Periodic dredging of sediments.	Effective treatment for the removal of TSS. Could be a viable option for use in conjunction with other treatment alternatives
Sedimentation/ Filtration Basin		Sustained periods of water in the sedimentation portion of the basin would kill the sod cover. Soils in the area have very high clay content and slow permeability and would not be suitable for rapid filtration.		Effective for stormwater treatment, but not suitable for treatment of long term flows. Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Wet Detention Basin	Similar to requirements for constructed wetland.	Application of wet detention basin principles on a large scale would be similar to a constructed wetland with a settling reservoir.		Refer to constructed wetland alternative.
Biological Treatment		Not viable because organic content too low and flow is to intermittent to sustain growth.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.

TABLE VI-1

ISSUES PERTAINING TO TREATMENT ALTERNATIVES OF DIVERTED RIVER WATER

Treatment Alternative	Land Requirements	Technical Feasibility	Operating Requirements	Remarks
Chemical Precipitation	Approximately 50 acres for the plant site. Approximately 3500 acres would be needed for land application of the sludge. Would need to either purchase or lease, or possibly contract for disposal use.	Can reduce P concentrations to <0.5 mg/L. Not affected significantly by seasonal start up and shut down.	Would need approximately 10 full-time operators. Chemical storage and feed systems. Sludge thickening and disposal equipment. Need chemical addition and mixing unit followed by flocculation chamber followed by clarifier. Dewatering and disposal of generated sludge.	Will need to evaluate chemical quality of sludge generated by chemical precipitation as it relates to applicable sludge disposal regulations.
Breakpoint Chlorination		Not effective for removal of P or N other than ammonia.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Air Stripping		Not effective for removal of P or N other than ammonia.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Reverse Osmosis		Significant pretreatment required. Very labor intensive and very expensive.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.

TABLE VI-1

ISSUES PERTAINING TO TREATMENT ALTERNATIVES OF DIVERTED RIVER WATER

Treatment Alternative	Land Requirements	Technical Feasibility	Operating Requirements	Remarks
Ultrafiltration		Does not remove soluble P.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Selective Ion Exchange (Cation)		Not effective for removal of P or N other than ammonia.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Selective Ion Exchange (Anion)		P not effectively removed.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Ion Exchange (Strong Base Anion)		Effective removal of nitrates, but P not effectively removed.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Rapid Sand Filtration		Not effective at removing soluble nutrients.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.

TABLE VI-1

ISSUES PERTAINING TO TREATMENT ALTERNATIVES OF DIVERTED RIVER WATER

Treatment Alternative	Land Requirements	Technical Feasibility	Operating Requirements	Remarks
Slow Sand Filters		Suspended clays in water blind filter. Not effective at removing soluble nutrients.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.
Granular Activated Carbon Filtration		Very expensive treatment of water for discharge into a reservoir.		Alternative not considered technically feasible so no further research regarding land and operating requirements conducted.

five alternatives included constructed wetland, rock/plant filter, overland flow, chemical precipitation (with or without filtration), and periphyton/fish culture.

A settling basin or sedimentation pond is considered a possible component of the constructed wetland or the rock/plant filter. Construction costs and operation and maintenance costs estimated for four of these alternatives, on the basis of the literature review, are listed in Table VI-2. Data on the cost of constructing and operating a full-scale periphyton/fish culture system are not currently available. However, research conducted by Dr. Drenner of TCU (see Chapter VII) indicates that a periphyton/fish culture system is a potentially viable means of nutrient removal and warrants further studies needed to develop information that can ultimately be used for preliminary design and cost estimating.

RECOMMENDATION OF LABORATORY/PILOT SCALE INVESTIGATIONS

An extensive research of the literature and further calculations were conducted on the four alternatives (identified by APAI) in the preliminary screening and the periphyton/fish culture studies (conducted by TCU) to identify potential treatment efficiencies and more fully estimate costs of construction and operation. This evaluation of the five alternatives indicates three that appear to be the most suitable for further study. The three methods recommended for bench-scale and/or pilot study include: constructed wetland, chemical precipitation, and phytoplankton/fish culture.

TABLE VI-2

COST ANALYSIS FOR MOST VIABLE CANDIDATES

Treatment Alternative	Construction Cost	Operation and Maintenance Cost
Constructed Wetland	$10,000,000/80 MGD	*
Rock/Plant Filter	$45,000,000/80 MGD	$2,900,000/yr for 80 MGD flow**
Overland Flow	$19,500,000/80 MGD	*
w/ Rapid Infiltration Polishing for P	$20,000,000/80 MGD	*
Chemical Precipitation		
w/o Filtration	$10,000,000/80 MGD***	$4,000,000/yr for 80 MGD flow
w/ Filtration	$18,000,000/80 MGD***	$4,000,000/yr for 80 MGD flow
Settling Basin (~60 acre)	$4,000,000	

* - Insufficient data on O & M costs from literature reviewed to estimate.
** - Based on O & M information from several small plants with rock/plant filters (<4 MGD) in Louisiana.
*** - Does not include purchase costs for land (~3500 acres) needed for land application of sludge.

CHAPTER VII

CONCEPTUAL DESIGN AND OPERATION OF LABORATORY\PILOT SCALE INVESTIGATIONS

CONCEPTUAL DESIGN AND PLAN OF OPERATION OF PILOT-SCALE OPERATIONS FOR CONSTRUCTED WETLAND

General

The conceptual design of the pilot-scale operation of the constructed wetland is based on a flow of 0.1 MGD that will be pumped from the Trinity River a distance of approximately 3,000 feet to the head of the constructed wetland. Statistical analyses have been performed on existing Trinity River water quality and flow data from 1980-1989. The results of these analyses are included in Chapter IV of this report. Based on these results, 91 percent of diversion of Trinity River water occurs when the flow in the Trinity River will be less than 3,000 cfs. Identified water quality parameters that will need to be routinely monitored include phosphorus compounds and total phosphorus (TP), nitrogen compounds and total nitrogen (TN), heavy metals, total suspended solids (TSS), and fecal coliform. As discussed in the technical memorandum, "Trinity River Diversion Study, Task 1: Data Acquisition and Review," February 1991, various mechanisms working within a constructed wetland are capable of significantly reducing the concentration of each of these parameters.

Conceptual Design

A plan view of the conceptual constructed wetland is shown in Figure VII-1. A settling pond at the head of the constructed wetland will enable the pumping energy of the river water to be dispersed and will allow settling of suspended sediment from the water before it enters the constructed wetland. This will prevent clogging of the wetland cells with a rapid buildup of silt, and will also provide some removal of phosphorus and metals that adsorb to settling sediment particles. The pond can also be used as a reservoir of water to maintain water levels in the wetland when pumping from the river is not deemed necessary. The excavated material from the pond may be used to construct the berms throughout the wetland to minimize costs. The detention time necessary to provide

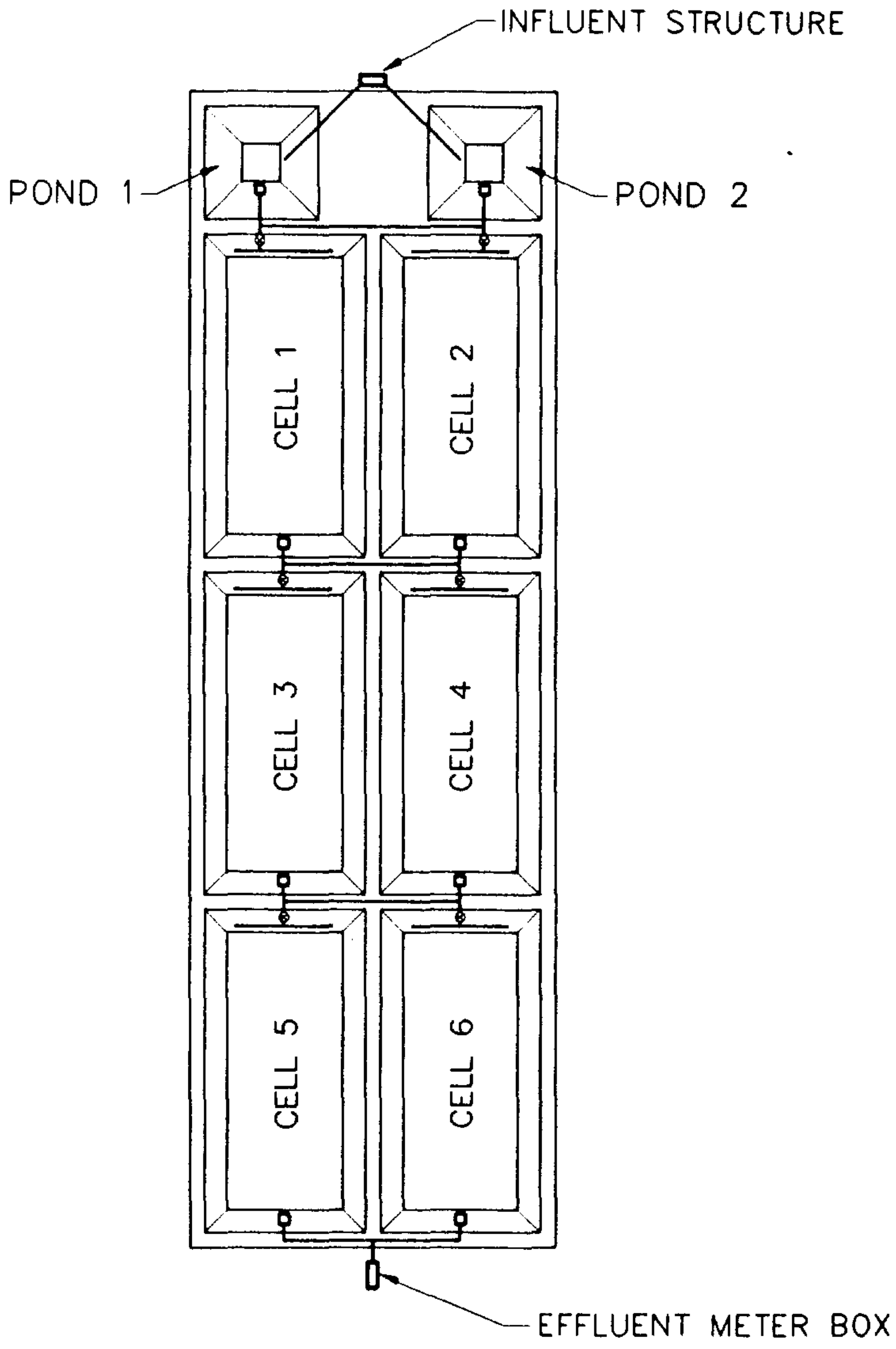
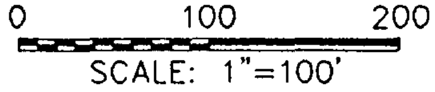


FIGURE VII–1
PLAN VIEW OF CONSTRUCTED WETLAND



sufficient settling of sediment load carried by the river water will be a minimum of 24 hours. A design incorporating two ponds, each capable of providing 24 hour detention time for the entire 0.1 MGD flow and with the installation of piping and valves to allow isolation of either of the ponds, will enable the system to continue operating while maintenance dredging of accumulated sediments is performed on one of the ponds. The approximate size of each pond which would provide 24 hour detention time for the 0.1 MGD flow and an estimated 22 percent storage volume would be 0.075 acre and 5 feet deep.

The flow from the pond will enter the constructed wetland through an outlet structure for the pond that will allow diversion of the water to one or more cells of the wetland. This outlet structure will also need to provide draining of the pond when necessary. The flow and depth of water through the wetland cells will be controlled by telescoping valves at the outlets and gated valves at the inlets that will allow each cell to be independently isolated. This control mechanism will allow individual cells to be drained to provide easier maintenance of the cell and its vegetation, as well as oxidizing and compacting sediments. The cell could then be reflooded and allowed to stabilize before it is brought back on-line.

Effective nutrient removal in constructed wetlands has been shown to peak within a 5-7 day detention time. An average depth of 18 inches across the wetland cells and a 7-day detention time for the proposed 0.1 MGD was used to determine the approximate size of the wetland cells. Detention time may be varied by controlling the water depth in the individual cells. Water depths may be adjusted to mimic natural hydrologic cycles and in response to climatic events. For instance, water depths may be increased during cold months to moderate local temperature and decreased when heavy rainfall events are forecast. By controlling and managing flows through the wetland system, adverse effects from extreme flushing events and short-term winter conditions may be prevented.

The berms around the perimeter of the settling pond and the wetland and within the wetland should be adequate to allow for ease of maintenance and upkeep of the berms and should provide sufficient freeboard to allow depth adjustment of the water within the wetland cells. It is estimated that the berms around and within the wetland will be 3 feet high and 8 feet wide at the top with slopes of 3:1. The berms around the ponds will be similar with inside slopes of 4:1 and outside slopes of 5:1.

Plant Selection

Plant selection should be made from the variety of aquatic plants found in the local environment as well as possible outside sources of plants adapted to similar climates and soils. Since the modeling that has been performed identifies significant pumping of water during the winter months of December, January and February, the selection should involve the consideration of cold-tolerant plants that remain active through the winter months. Both soft-stem bulrush and soft rush have been indicated in the literature as effective in removal of nitrogen and phosphorus. Bulrushes and reeds have been indicated as more effective in the removal of nitrogen compounds than cattails primarily because the cattail has the shallowest root zone of the three, most of its root biomass being confined to the top 30 cm of substrate while the root zone of the bulrushes and reeds extends down to >60 cm and 76 cm respectively. The penetration of the root zone is imperative for the transport of oxygen into the sediments. Bulrushes have also been indicated as being more cold tolerant than cattails, remaining active later in the winter season. The final selection of plants will depend on performance of various species tested in the pilot study.

Plan of Operation

Management to establish and maintain the wetland area will consist of adjusting water depth in the individual cells to provide an ideal environment for the aquatic plants chosen as well as an appropriate detention time for effective contaminant removal. Harvesting the emergent portions of the plants once or twice a year may be necessary. The necessity for harvesting will be evaluated during the pilot study. If shown to be necessary, harvesting will require isolation and drying of individual cells before the use of mechanical harvesting equipment.

Various sampling points should be established at inlet and outlet points to determine the effective removal efficiencies for the water quality parameters of concern. Critical sampling points will be at the inlet and outlet of the settling pond, intermediate points within the wetland, and at the outlet of the wetland. The location of the sampling points should also allow evaluation of removal efficiencies of various plant communities within individual wetland cells. The proposed sampling schedule would include analysis of two samples per week from each of 10 sampling sites, an estimated 20 samples per week.

Costs

A preliminary estimate of equipment, personnel, and consulting costs for the construction of the pilot-scale wetland is included in Table VII-1. Once the specifications for the final design are completed, the information will be submitted to the District for their review to determine what portions of the construction the District will undertake.

The data available are insufficient to calculate preliminary estimates of the costs for operation of the constructed wetland. It is envisioned that one staff person will be able to monitor the pump stations and water depth in the wetland cells and perform routine maintenance as required. The costs for the analysis of the samples will depend on whether the samples are analyzed in-house. These costs are more fully described in Chapter VIII.

LABORATORY-SCALE INVESTIGATIONS OF PHOSPHORUS REMOVAL

General

Phosphorus is recognized as a primary element responsible for eutrophication in lakes. Analyses conducted for this report indicate that levels of phosphorus in the Trinity River can have an impact on water quality in Richland-Chambers and Cedar Creek Reservoirs. During periods that the diversion of Trinity River water is anticipated, dissolved phosphorus in the Trinity River could be expected to be between 3.0 and 4.0 mg/L.

TABLE VII-1

ESTIMATED COSTS OF CONSTRUCTION FOR CONSTRUCTED WETLAND

No.	Description	Quantity	Unit Cost	Opinion of probable cost
1	0.10 MGD Single Electric-Powered Pump Mobile Lift Station (L.S.)			
	Equipment, Setup & Testing	1 L.S.	$10,000.00	$ 10,000.00
	Electrical		6,000.00	6,000.00
	Access Road	1,000 L.F.	10.00	10,000.00
	Total			$ 26,000.00
2	Force Main	3,000 L.F.	15.00	$ 45,000.00
	Valve and Connection Point for Mobile L.S.	1		2,000.00
	Total			$ 47,000.00
3	Influent Control Structure	1	15,000.00	$ 15,000.00
4	Settling Basin Excavation	1210 c.y.	3.00	$ 3,630.00
5	Constructed Wetland Berms	2210 c.y.	5.00	$ 11,050.00
6	Lift Stations from Settling Ponds to Constructed Wetland			
	Wet well	2	1,500.00	$ 3,000.00
	Submersible Pump	2	3,000.00	6,000.00
	6" PVC Pipe	300 L.F.	8.50	2,550.00
	6" Gate Valve	2	300.00	600.00
	Electrical	2	1,250.00	2,500.00
	Total			$ 14,650.00
7	Flow Control Structures for Wetland Cells			
	Dock	6 @ 9 S.F.	100.00	$ 5,400.00
	Telescoping Valve	6	1,500.00	9,000.00
	6" PVC Pipe	840 L.F.	8.50	7,140.00
	6" Gate Valve	6	300.00	1,800.00
	Total			$ 23,340.00
8	Effluent Metering Structure	1	8,700.00	$ 8,700.00
9	Planting	3,211	3.11	$ 10,000.00
	Subtotal			$159,370.00
	Engineering, Surveying, Materials Testing			50,000.00
	Contingencies @ 15%			23,905.50
	Grand Total			$233,275.50

Removal of dissolved and particulate phosphorus has been accomplished for many years using chemical coagulation and precipitation practices. Phosphates can be removed by chemical precipitation with metal ions such as calcium, aluminum, and iron. As the chemistry of phosphate removal is quite different for certain reagents used and often depends on the chemistry of the raw water to be treated, jar tests are normally run to determine the optimum dose and effectiveness of various chemicals in removing phosphorus from raw water. APAI recommends that such tests be performed on samples of Trinity River water at the Richland-Chambers offices of the District. The following is a summary of the design, operation and cost of such tests. The costs of the tests are based on conducting 4 to 8 tests. After initial evaluation of the tests, additional replicates of the tests may be conducted as determined necessary.

Jar Test Procedures

The recommended jar tests will involve the use of six agitators set to operate at the same speed, which may be varied from 10 to 100 rpm. The agitators should be suitable for 600 ml to 2 liter laboratory beakers. APAI recommends that tests be performed using lime [$Ca(OH)_2$] to provide a calcium dose of approximately 150 mg/l, ferric chloride [$FeCl_3(6H_2O)$] to provide a ferric iron dose of about 15 mg/l, alum [$Al_2(SO_4)_3$ $(14H_2O)$] to provide an aluminum dose of about 20 mg/l, and a combination of alum and lime to give aluminum and calcium doses of 30 mg/l and 20 mg/l each. As chemical precipitation is sensitive to pH and alkalinity, the tests should include a means to monitor and control pH. The following procedure should be followed in performing each test.

1. Obtain 2 liter sample of Trinity River water.

2. Test raw water for pH, total suspended solids, alkalinity, total phosphorus, dissolved phosphorus, total ortho-phosphorus, and selected heavy metals.

3. Add desired sample volume to each of the six beakers used in the jar test.

4. Start mixers to run at maximum speed.

5. Add reagents rapidly to beakers and in increasing dosages from left to right. Successive dosages may be varied considerably in initial experiments. Stir at maximum rpm for one minute.

6. Reduce stirring rate to 20 to 70 rpm and stir for 15 to 20 minutes.

7. Through the slow mixing period, the samples should be observed carefully and observations recorded on a data sheet. Time of floc appearance, size of floc, and nature of floc should be recorded.

8. At the end of the slow mixing period, shut off stirrer and allow the floc to settle for 15 to 30 minutes. Observe the settling carefully and report the settling as inches of clear water above the floc at 5 minute intervals or more frequently if the floc settles rapidly.

9. Withdraw samples of supernatant liquid and test for those parameters listed in item 2, above.

10. Run additional tests as necessary to determine optimum dosage of reagent(s).

Costs

The following is a preliminary estimate of equipment, personnel, and consulting costs for before mentioned jar tests.

<u>Equipment</u>	
Multiple, Six-Place, Variable Stirring Apparatus	$1,500
Glassware	350
Precipitation Agents	150
Water Testing Equipment	
pH Meter	1,000-2,000
TSS Analysis*	5,000
Phosphorous Analysis*	8,000

Personnel	
10 Man-days (4-8 tests)	3,200
Consulting/Lab Costs	
Consultant	1,500
Independent Laboratory Analyses	2,700
Total	$23,400-24,400

*Itemization of equipment and reagents can be found in Table VIII-1.

PROPOSED PERIPHYTON/FISH BENCH-SCALE STUDIES

General

Literature reviewed during the course of this study suggest that periphyton (attached algae) may have potential in removing nutrients from Trinity River water prior to its discharge to Richland-Chambers or Cedar Creek Reservoirs. However, nutrients that accumulate in periphyton may eventually be released from the periphyton if the periphyton layer becomes thick enough to form an anaerobic interior film. Several studies have shown that the thickness of the periphyton and nutrient release can be reduced by grazers that feed on periphyton. It is therefore likely that phosphorus and nitrogen can be removed from Trinity River water using a periphyton fish system in which fish are used to graze the periphyton and convert the nutrients in periphyton to fish feces which can be removed from the system. The following is a summary of the design, operation, and cost of experiments proposed by TCU to evaluate the feasibility of this process. A copy of the TCU Research Proposal for these experiments has been included as Appendix D.

A series of three experiments are proposed that focus of the following questions:

1. How do different densities of blue tilapia affect periphyton biomass at eutrophic nutrient concentration?

2. What effect do blue tilapia and water velocity have on nutrient uptake by a periphyton system?

3. How efficiently does the periphyton-tilapia system remove nutrients from Trinity River water?

Experiment 1: How do different densities of blue tilapia affect periphyton biomass at eutrophic nutrient concentrations?

This experiment will be conducted at Texas Christian University (TCU) and involve 12 tanks. Tentatively, the experiment will consist of 6 treatments (0, 5, 10, 20, 30 and 40 tilapia per tank), each with duplicate replication. The experiment would be conducted for a 2 week period. Tanks will be drained at the end of the experiment to evaluate tilapia effects on periphyton attached to the walls of the tanks.

Experiment 2: What effect do blue tilapia and water velocity have on nutrient uptake by a periphyton system?

This experiment will be conducted in the new facility of cone-bottomed tanks. A factorial design will be used in which 2 levels of tilapia (presence and absense) are cross-classified with 2 levels of mixing (low and high) using airlifts. The density of tilapia will be based on the results of Experiment 1. Nutrients in the water, periphyton and feces collected during the experiment will be analyzed to assess the use of tilapia to remove nutrients, and how tilapia and water velocity interact to affect periphyton.

Experiment 3: How efficiently does the periphyton-tilapia system remove nutrients from Trinity River water?

In this experiment, water will be hauled by truck by the Western Transport Company from the Trinity River near Richland Chambers Reservoir and held at TCU. TCU has successfully transported water to TCU from as far away as Lake Wichita at Wichita Falls and Stillhouse Hollow Reservoir south of Waco. Following a settling period, river water will be pumped through the cone-bottomed tank system to examine nutrient removal efficiency for phosphorus and nitrogen. For this experiment, the 12 tanks will be divided into 4 sets of 3 tanks. Water flow between the 3 tanks in a set will be achieved by linking the tanks via siphon tubes. Tentatively, TCU plans to use two treatments: 1) periphyton only and 2) periphyton grazed by tilapia. The density of tilapia will be based on the results of Experiment 1. Analysis of nutrients in the input and output of river water from the tanks as well as tilapia feces collected during the experiment will allow assessment of the nutrient removal efficiency of the periphyton-tilapia system.

Costs

A cost of $19,949 has been proposed by TCU for performing Experiments 1 and 2. In addition, it is recommended that the District set aside an additional $4,000 for engineering assistance. This would bring the total cost of Experiments 1 and 2 to $23,949. The cost of Experiment 3 has not been determined as whether to perform Experiment 3 will depend on the outcome of Experiments 1 and 2.

CHAPTER VIII
PROPOSED SAMPLING AND TESTING PROGRAMS

SAMPLING AND TESTING FOR PILOT/LABORATORY SCALE STUDIES

Constructed Wetland

Sampling points will need to be established at the inlet and outlet points of the wetland cells. Critical sampling points will include the outflow of the influent control structure, the inflow to the first wetland cells, intermediate points within the wetland, and the outflow of the constructed wetland. A maximum of ten sampling points has been estimated. The proposed sampling schedule would include analysis of two samples per week from each sampling site, an estimated 20 samples per week. Since the evaluation of the performance of the constructed wetland will continue for several years, estimates of the costs for equipment and reagents necessary to perform the laboratory analyses at a laboratory facility set up by the TCWCID have been itemized and included in Table VIII-1. These costs can thus be compared to the costs of analysis of the samples by an independent laboratory which are itemized in Table VIII-2.

The analyses proposed for the samples include total suspended solids (TSS), total phosphorus, ortho-phosphate, ortho-phosphorus, total nitrogen, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, heavy metals and fecal coliform. The sampling schedule and required analyses will need to be reevaluated periodically during the operation of the pilot study.

A screening of the Trinity River water at the point of diversion should be performed at the outset of the pilot study to determine the presence of any toxic organics, particularly the organic compounds identified in the technical memorandum, "Trinity River Diversion Study, Task 1: Data Acquisition and Review", February 1991. If toxic organics are identified from the river water in concentrations exceeding surface water quality criteria, a schedule for sampling and analysis of the inflow and outflow of the constructed wetland can be designed that will be cost efficient.

TABLE VIII-1

ITEMIZED COST ESTIMATE FOR IN-HOUSE LABORATORY ANALYSIS

TOTAL SUSPENDED SOLIDS (TSS)/TOTAL VOLATILE SUSPENDED SOLIDS (TVSS)

	Item	Quantaties	Approximate Costs
1.	Muffle Furnace (TVSS)	1	$1,100.00
2.	Gooch Crucibles (36x21 mm) 7/8" Bottom	24	130.00
3.	Glass - Fiber Filter Disks	500	37.00
4.	Drying Oven	1	720.00
5.	Desiccator	1	135.00
6.	Flask, Suction	12	285.00
7.	Crucible Holders	12	65.00
8.	Desiccant (5 lb capacity)	4	200.00
9.	Vacuum Pump	1	390.00
10.	PVC Manifold	1	460.00
11.	Analytical Balance	1	2,500.00
		Total	$6,022.00

FECAL COLIFORM

	Item	Quantaties	Approximate Costs
1.	Nutrient Pad Kits	100	$ 175.00
2.	Incubator 35 ± .5°C	1	570.00
3.	Filter Holding Assembly	See Phosphorus Analysis	
4.	Wide Field Dissecting Microscope	1	600.00
5.	Forceps - Round Tipped	20	10.00
6.	95% Ethyl Alcohol		60.00
		Total	$1,415.00

TABLE VIII-1
ITEMIZED COST ESTIMATE FOR IN-HOUSE LABORATORY ANALYSIS
(Continued)

PHOSPHORUS
"PERSULFATE DIGESTION"

1.	Hot Plate 30x50 cm	1	$ 285.00
2.	Glass Scoop	12	125.00
3.	Phenolphthalein Solution	6L	95.00
4.	Sulfuric Acid (37N)	6x500 ml	440.00
5.	Ammonium Persulfate $(NH_4)_2\ S_2O_8$ or	6x100 g	115.00
	Potassium Persulfate $K_2S_2O_8$	6x500 g	465.00
6.	Sodium Hydroxide (1N)	4L	35.00
		Subtotal	$1,560.00

PHOSPHORUS ANALYSIS
VANADOMOLYBDOPHOSPHORIC ACID COLORIMETRIC METHOD

1.	Spectrophotometer	1	$3,250.00
2.	Volumetric Flasks	12-50 ml 12-100 ml	120.00 135.00
3.	HCl (.5N)	4x4 L	105.00
4.	H_2SO_4 (.5N)	4x4 L	95.00
5.	Activated Carbon	4x4 lb	250.00
6.	Erlenmeyer Flasks	48-250 ml	105.00
7.	Microanalysis (Glass) Filter Holder	3 @	350.00 ea.
8.	Filter Paper Whatman #42 90 mm	500	65.00
9.	Ammonium Molybdate	6 @ 500 g	700.00
10.	Ammonium Metavanadate	No information	
11.	Anhydrous KH_2PO_4	6x500	190.00
		Subtotal	$6,065.00
		Total	$7,625.00

TABLE VIII-1
ITEMIZED COST ESTIMATE FOR IN-HOUSE LABORATORY ANALYSIS
(Continued)

NITROGEN

NH_3-N

1.	Orion 920 Meter (Ion-selective)	See pH meter under equipment for jar test procedures	
2.	Orion Ammonia Electrode	1	$ 500.00
3.	Standardizing Solution (Anhydrous NH_4Cl)	500 g	23.00
4.	NaOH (Ion) 400 g NaOH + 800 ml H_2O Dilute to 1L	See Phosphorus "Persulfate Digestion"	
5.	Magnetic Stir Plate	1	525.00
		Total	$1,048.00

NO_3-N

1.	Orion Nitrate Electrode	1	$ 563.00
2.	Saturated K_2SO_x Solin	6x500 g	170.00
3.	Buffer Solution		
	a) $Al_2(SO_4)_3 \cdot 18\ H_2O$	500 g	95.00
	b) H_3BO_3	6x500 g	150.00
	c) H_2NSO_3H (Sulfamic Acid)	6x100 g	135.00
	d) .1N NaOH	See Phosphorus "Persulfate Digestion"	
		Total	$1,113.00

TABLE VIII-1
ITEMIZED COST ESTIMATE FOR IN-HOUSE LABORATORY ANALYSIS
(Continued)

NO_2-N			
1.	Sulfanilamide Reagent 5 g + 50 ml Conc HCl + 300 ml H_2O	6x100 g	$ 180.00
2.	N-(1-Naphthyl)-Ethylenediamine Dihydrochloride Solution 500 mg/500 ml H_2O	100 g	180.00
3.	HCl 1:3	See Phosphorus Analysis	
4.	Sodium Oxalate (0.05N) 3.3 g $\underline{Na_2C_2O_4}$/L H_2O	500 g	70.00
5.	Ferrous Ammonium Sulfate 0.05N 19.607 g $Fe(NH_4)_2\ (SO_4)_2 \cdot 6\ H_2O$ + 20 ml Conc H_2SO_4 -> Dilute to 1L	500 g	65.00
6.	0.05 N $KMnO_4$ 1.6 yr $KMnO_4$/L Distilled H_2O	500 g	35.00
7.	$NaNO_2$	500 g	50.00
		Total	$ 580.00
ORG-N			
1.	Digestion/Distillation Unit	1	$8,000.00 ($5,000-10,200)
2.	Mercuric Sulfate Solution (HgO)	100 g	70.00
3.	6N H_2SO_4	See Phosphorus "Persulfate Digestion"	
4.	K_2SO_4	500 g	45.00
5.	NaOH (Solid Form) 500 g SIC + 25 g Dilute to 1L	5 Kg	100.00
6.	$NaS_2O_3 \cdot 5\ H_2O$	6x500 g	95.00
7.	N_aOH (6N)	6x1L	90.00
8.	Borate Batter 88 ml 0.1N NaOH + 500 ml (0.025M Sodium-tetraborate {9.5 g $Na_2B_4O_7 \cdot 10\ H_2O$/L}) Dilute to 1L	500 g	25.00
		Total	$ 8,425.00
		Grand Total	$25,000.00

TABLE VIII-2

APPROXIMATE COSTS OF INDEPENDENT LABORATORY ANALYSIS

Test	Approximate Individual Costs
Total Suspended Solids	$ 12.50
Total Phosphorus	$ 12.50
Ortho-Phosphate	$ 12.50
Ortho-Phosphorus (included under Ortho-Phosphate)	
Total Nitrogen	$ 40.00
Ammonia-Nitrogen	$ 15.00
Nitrite-Nitrogen	$ 12.50
Nitrate-Nitrogen	$ 12.50
Total Kjeldahl Nitrogen	$ 17.50
Priority Pollutant Metals (includes Antimony, Arsenic Beryllium, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Silver, Thallium, Zinc, Total Metal Preparation)	$190.00
Coliforms	$ 15.00
pH	$ 5.00
Alkalinity	$ 10.00
Pesticide Scan - Chlorinated	$ 65.00
Pesticide Scan - Organophosphorus	$ 65.00
Herbicide Scan - Chlorinated	$ 75.00
Herbicide and Pesticide Scan - Chlorinated	$135.00

Chemical Precipitation of Phosphorus

An outline of the jar test procedures for the laboratory-scale study for phosphorus removal was provided in Chapter VII. For each water sample tested, the critical parameters of the raw water which require analysis include pH, total suspended solids, alkalinity, total phosphorus, dissolved phosphorus, and total ortho-phosphorus. Following the procedures outlined for chemical precipitation, the supernatant liquid should be tested for the same parameters listed above for the raw water. An itemized estimate of the laboratory costs for the analyses is also provided in Chapter VII. Total estimated cost to perform the jar tests including laboratory analyses is approximately $25,000.

Periphyton/Fish Bench-Scale Studies

A series of three experiments to be conducted at TCU has been outlined in Chapter VII. The proposed total cost including an allowance of $4,000 for engineering assistance of Experiments 1 and 2 is $23,949. This cost includes sampling and analysis of any water samples to be performed at TCU. The cost of Experiment 3 will be determined depending on the outcome of Experiments 1 and 2.

TRINITY RIVER SAMPLING AND TESTING

A review of available water quality data was undertaken to ascertain whether sufficient data exists to adequately address the concerns of the impacts of a proposed diversion of Trinity River water into Richland/Chambers and Cedar Creek Reservoirs for ultimate potable use. It was desired to establish the relationship between various water quality parameter concentrations and streamflow in the river. Sufficient data have been identified to develop these relationships for most nutrients, solids, and bacteriological parameters. However, insufficient data exist for metals and pesticides or other toxic organics to establish good relationships of these with streamflow.

It is recommended that a long-term sampling program on the Trinity River be implemented in the Trinidad area to gather additional data for metals and toxic organics under a variety of streamflow conditions. A regular once per month sampling program supplemented with special event sampling to capture approximately two high-flow events should be implemented for heavy metals. An independent laboratory will perform analysis for priority pollutant metals including antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, zinc, and total metal preparation for approximately $190.00. The cost for analyzing a sample for individual metals ranges from $10-$30 per metal depending upon the metal. If specific problem metals are identified, routine analysis may be limited to those metals to limit cost.

A screening program to identify organics of potential concern should be implemented with approximately two special sampling events each for high-flow and low-flow periods. An independent laboratory cost for a priority pollutant organic scan including acid extractable and base neutral organics, pesticides extractables, purgeable organics, plus herbicides and organophosphate pesticides analysis is approximately $800.00. After potential toxic organic problems are identified, a routine sampling schedule may be set up and sample analysis limited to the identified problem organics.

SAMPLING AND TESTING FOR LAKE MODEL VERIFICATION

The District's current water quality monitoring program maintains several sampling stations on Cedar Creek and Richland-Chambers Reservoirs and their tributaries. Water quality sampling is also performed on the wastewater treatment facilities in these watersheds, the water supply pipeline, and balancing reservoirs. Table VIII-3 is a listing of the different parameters sampled/analyzed at each of these facilities and recorded in the District's water quality database.

The District's current water quality sampling program has been in place since 1989. Table VIII-4 presents the dates over the last two years on which samples were taken at the reservoirs, tributaries and wastewater treatment plants in the Cedar Creek and Richland-Chambers watersheds. Each date in Table VIII-4 indicates that at least one sampling station for that facility was visited, but

TABLE VIII-3

TCWCID NO. 1
WATER QUALITY SAMPLING PARAMETERS

Reservoirs General	Reservoir Intakes Additional	Reservoir Intensive Survey	Tributaries	WWTP	Pipeline	Pipeline & Reservoir Biological	Balancing Reservoirs May-Sept Bi-Weekly	Rainfall
Chl 'a'	Calcium	$CBOD_5$	Chl 'a'	$CBOD_5$	Chl 'a'	Zooplankton	Chl 'a'	TSS
TSS	Magnesium	$CBOD_{20}$	$CBOD_5$	TSS	Free Chlorine	Community & Algae	Algae	NH_3-N
NH_3-N	Sodium	Color	TSS	VSS	Total Chlorine			NO_3-N+NO_2-N
NO_3-N+NO_2-N	Potassium	VSS	VSS	NH_3-N	Calcium			TKN
Soluble TKN	Sulfate	Silica	NH_3-N	NO_3-N+NO_2-N	Magnesium			Total-P
TP	Chlorides		NO_3-N+NO_2-N	TKN	Sodium			PO_4-P
PO_4-P	TTHMFP		TKN	TP	Potassium			Alkalinity
TOC	Algae		TP	PO_4-P	Sulfate			pH
DOC			PO_4-P	TOC	Chlorides			
Alkalinity			TOC	Fecal Coliform	Alkalinity			
Iron Dissolved			Alkalinity	Cadmium Dissolved	TSS			
Manganese Dissolved			Fecal Coliform	Chromium Dissolved	VSS			
Lead Dissolved			Lead Dissolved	Lead Dissolved	NH_3-N			
Fecal Coliform			Copper Dissolved		NO_3-N+NO_2-N			
TDS			Zinc Dissolved		TKN			
			TDS*		TP			
			Oil & Grease*		PO_4-P			
					TOC			
					DOC			
					COD (May-Sept.)			

*Richland-Chambers tributaries only

TABLE VIII-4

TCWCID NO. 1 WATER QUALITY
FOR CEDAR CREEK AND RICHLAND-CHAMBERS WATERSHEDS
1989-1990

		CEDAR CREEK			RICHLAND-CHAMBERS	
	Reservoir	Tributaries	WWTPs	Reservoir	Tributaries	WWTPs
No. Sampling Stations	11	9		7	3	
	2/13/89	3/29/89	2/17/89	2/22/89	3/29/89	2/17/89
	2/24/89	4/15/89	4/5/89	3/17/89	4/15/89	5/31/89
	3/8/89	3/8/90	5/31/89	5/11/89	3/8/90	6/28/89
	4/12/89	3/14/90	6/28/89	6/14/89	3/15/90	7/5/89
	4/14/89	3/30/90	7/5/89	7/19/89	3/30/90	8/2/89
	5/5/89		8/2/89	8/16/89	9/11/90	9/22/89
	5/18/89		9/22/89	9/15/89	10/16/90	11/1/89
	6/8/89		10/25/89	11/1/89		11/2/89
	6/21/89		2/1/90	11/20/89		12/8/89
	7/12/89		2/22/90	1/19/90		2/1/90
	7/24/89		3/9/90	2/14/90		3/9/90
	8/9/89		5/30/90	3/15/90		3/30/90
	8/24/89		6/27/90	4/11/90		5/30/90
	9/6/89		7/30/90	5/10/90		6/27/90
	9/20/89		9/6/90	6/6/90		7/30/90
	10/12/89		10/5/90	7/11/90		9/6/90
	11/8/89		11/9/90	8/15/90		10/5/90
	12/6/89			11/13/90		11/9/90
	2/8/90			12/5/90		
	5/7/90					
	8/9/90					
	10/31/90					

not necessarily all stations. For the stations that were visited on these dates, values have been recorded in the water quality database for almost every parameter listed in Table VIII-3, and sometimes for additional parameters. The District's plan for the 1991 sampling program proposes the collection of monthly samples on the tributaries and wastewater treatment plants and quarterly samples on the reservoirs. It appears that the District's current sampling programs for their reservoirs and reservoir watersheds are adequate. No recommendations are made to alter these current programs.

Additional water quality data has also been collected by the District at four locations on tributaries in the Richland-Chambers watershed previous to the construction of the reservoir. Much of the same type of data was recorded for these stations as is listed for tributaries in Table VIII-3. These data were collected from 1982 through 1988.

As the District's Regional Water Supply Plan completed in 1990 also recommends the construction of Tehuacana Reservoir by the year 2042, the District should consider developing an ongoing water quality monitoring program for Tehuacana Creek similar to the current program in place for Cedar Creek and Richland/Chambers watersheds within the next two to three years.