TECHNICAL MEMORANDA

Water Reclamation Research Project

TEXAS WATER DEVELOPMENT BOARD

AND

CITY OF ABILENE, TEXAS

TWDB CONTRACT NO. 55-61027

MAY 1988

Freese AND Nichols, INC. CONSULTING ENGINEERS

CH2M HILL

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ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 1

RESEARCH PROJECT
OBJECTIVES, GOALS AND APPROACH

Principal Author: David C. Lewis, P.E.

Technical Memorandum No. 1 (TM-1), Research Approach, addresses:

- Authority and Acknowledgments
- Statement of Problem, Opportunity, and Brief History
- Overall Objectives
- Project Format
- Study Approach

AUTHORITY AND ACKNOWLEDGMENTS

This project was conducted in accordance with the general contract between the City of Abilene (COA) and Texas Water Development Board (TWDB) dated August 7, 1986, and specific subcontracts between COA and Freese and Nichols, Inc.; Freese and Nichols, Inc. and CH2M HILL; and COA and Baylor College of Medicine. Authorization to proceed was December 10, 1986. A copy of the general contract agreement between COA and TWDB is attached as Appendix A.

The Research team extends thanks and appreciation to the numerous agencies and personnel who assisted us during this research project. The following agencies deserve special credit:

- American Water Works Association (AWWA)
- Groundwater Foundation
- Texas Water Development Board (TWDB)
- Texas Department of Health (TDH)

In 1986, Abilene agreed to participate in the Colorado River Municipal Water District's Stacy Reservoir Project, effectively securing water rights for the last available surface water supply of acceptable quality for Abilene.

In 1985, Abilene developed the "Water Management Plan". This water conservation plan addresses the effectiveness of pricing, regulations, and education on water demand in Abilene. In May 1986, a drought contingency plan was approved and amended to the City ordinances.

In 1984, Abilene commissioned Freese and Nichols, Inc. (FN) to conduct a study of alternative water supply sources. The study evaluated the possibility of using brackish water (saltwater) or reclaimed wastewater as a water resource. The study concluded that the use of brackish water is not economically feasible at this time, but the use of reclaimed wastewater was possible. In 1985, the Abilene City Council authorized the City staff to begin planning an advanced wastewater treatment plant pilot project.

OVERALL OBJECTIVES

The overall objective of this project is to identify a system of treatment processes that could be implemented by the City of Abilene to increase its water supply without detrimental effects on water quality. Specific goals and objectives developed for the project are as follows:

Acceptable Effects of the Discharged Water on the Water Quality of the Reservoirs

The discharge water (WWTP effluent) shall not cause any adverse effects on the water quality which would alter its current attainable beneficial use, such as potable water supply, recreation, fisheries, and irrigation.

Public Acceptance

Public officials and selected community representatives shall be apprised of the objectives, goals, findings, and recommendations of the research project.

A public meeting to present the research project shall be held to start the public involvement and participation in any follow-up project.

Non-potable Water Supply Reuse

Non-potable water reuse options that reduce demands on the potable water system shall be investigated.

PROJECT FORMAT

In order to use the total resources of the research team, a technical memorandum approach was used in report preparation and project management. Technical memoranda (TM's) deal with specific issues and allow presentation of data in a format that relates to the specific issue, resulting in a more focused approach. As a set, the TM's comprise a complete report. They also provide the basis for the summary report, which presents a more concise account of the key project issues for a broad and often non-technical audience.

A list of TM's for this project is:

TM No.	Description	Author(s)
8B	Bench-scale testing - Nitrification/ Dentrification	T. Simpkins
9	Recommended Plan	D. Lewis
10	Evaluation of financing options	J. King R. Longoria
11	Non-potable system(s)	R. Longoria D. Lewis

STUDY APPROACH

Figure 1.1 illustrates the interrelationships of the major project tasks. A more detailed work plan was developed for each task and then assigned to a team member. The primary evaluations and conclusions were developed at project team meetings in which draft TM's or portions thereof were presented and discussed. The meetings were generally one- or two-day sessions including six to ten team members. This approach allowed for a greater interchange of ideas from various team members.

The primary research team members are:

Team Member	Assignment
John Cook, P.E.	Principal-in-Charge
David Lewis, P.E.	Project Manager
Bob Chapman, P.E.	Technical Advisor
Carl Hamann, Ph.D.	Water Treatment Specialist

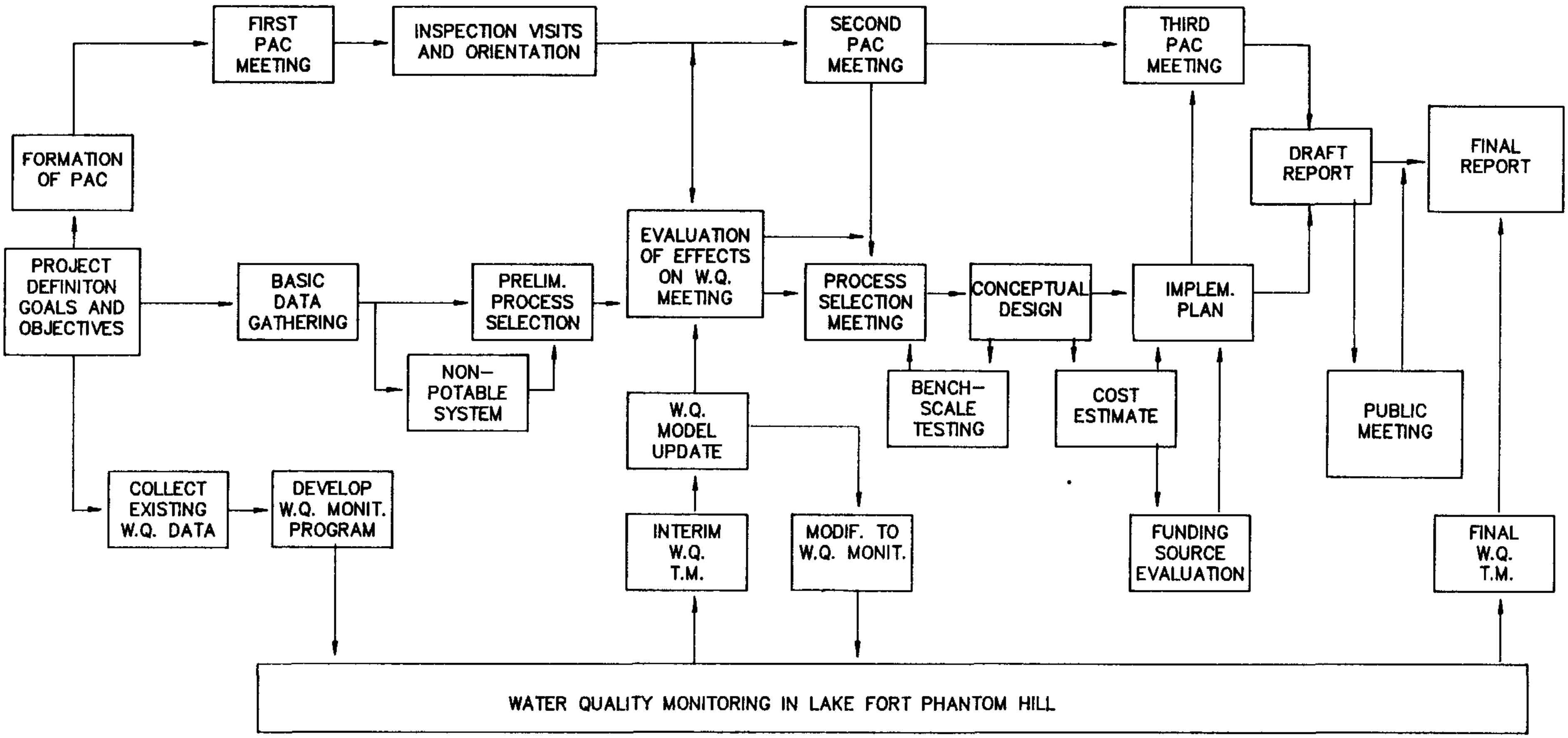

FIGURE 1-1
GENERAL PROJECT
FLOW CHART

- Texas Water Commission (TWC)
- United States Geological Survey (USGS)
- Environmental Protection Agency (EPA)
- Research Foundation of AWWA
- City of Abilene

The Research team particularly wishes to recognize the staff of the City of Abilene (COA) Water and Wastewater Department who assisted in the collection of water quality data and with bench scale testing, and extend a special thanks to Cindy Manning, Assistant to the Director of Water Utilities, who assisted in travel arrangements and meetings.

TM-2 describes and acknowledges the efforts of the members of the Public Advisory Committee (PAC) for their efforts.

STATEMENT OF PROBLEM, OPPORTUNITY, AND BRIEF HISTORY

The City of Abilene's growth over the last 50 years has required the development of new water resources. Abilene has committed itself to continued growth. While economic and population growth may not be directly tied to water demand, it is strongly interrelated. Without new water resources, Abilene's growth and the life-style of its residents would be seriously affected. In the early 1980's, a drought nearly exhausted Abilene's water supplies. In response to this situation, Abilene committed itself to providing water supplies in sufficient quantity and quality to meet future water demands without sacrificing growth or quality of life. In order to accomplish this goal, Abilene has developed and begun implementing a three-part appraoch. Its objectives are to:

1. Develop surface water resources to the maximum extent practical.
2. Develop and implement an effective water conservation program.
3. Evaluate alternative water supply sources.

Acceptable Water Quality for Discharges into Public Drinking Water Reservoirs, Specifically Lake Fort Phantom Hill

Discharges to Lake Fort Phantom Hill shall comply with state and federal water quality regulations. In addition, the discharge shall not cause aesthetic problems with the lake. The discharge to the lake should produce a water resource compatible with production of a potable drinking water of equal or greater quality than Abilene's present water resources.

Acceptable Operational Constraints in Selection of Unit Treatment Processes

Unit treatment processes selected shall be consistent with the City of Abilene's operation and maintenance capabilities. It is recognized that advanced treatment systems will require additional training and possibly new personnel. Selection of unit processes should take into account existing operational constraints.

Risk Involving Public Health

Unit treatment processes selected shall maintain or reduce the current public health risks associated with the potable water supply and wastewater treatment and disposal.

Acceptable Costs for Construction and Operation of Water Reclamation Facilities

Water reclamation shall be implemented only if it is determined to be cost-effective in comparison to other alternatives.

TM No.	Description	Author(s)
1	Project objectives and goals, statement of problem, methodology	D. Lewis
2	PAC activities, meetings, comments and recommendations	R. Longoria
3	Basic data development: population projections, hydrology, water demand, existing water rights, WWTP and WTP capabilities	R. Longoria B. Chapman D. Lewis
4	Water quality data: historic, developed, monitoring program, assessment	D. Gattis B. Nickerson
5	Water quality model	K. Iceman
6	Water quality criteria and goals	B. Chapman
7	Process selections and conceptual design and cost estimates	R. Longoria B. Chapman D. Lewis
7A	Process Selection, Sizing, and Location	D. Lewis R. Longoria
8A	Bench-scale testing - High lime and alum coagulation	R. Longoria

Team Member	Assignment
Ray Longoria, P.E.	Task Leader
J. L. Melnick, M.D.	Virology Study Leader
Ted Metcalf, Ph.D.	Virology Study Leader
Terry Foster, Ph.D.	Parasitic Study Leader
Barbara Nickerson	Water Quality/Monitoring Task Leader
Tom Simpkin, Ph.D.	Wastewater Treatment Specialist
Glen Daigger, Ph.D.	Wastewater Treatment Specialist
Ken Iceman, P.E.	Water Quality Modeling Specialist
Jim Nichols, P.E.	Quality Control Task Leader
Ken Miller, P.E.	Quality Control Task Leader

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 2

PUBLIC ADVISORY COMMITTEE ACTIVITIES AND MEETINGS

Principal Author: Raymond R. Longoria, P.E.

Technical Memorandum No. 2 (TM-2), PAC Activities addresses:

- Public Advisory Committee (PAC) Formation and Responsibility
- Summary of PAC Meetings and Comments
- Summary of PAC Water Reclamation Plant Tours
- Public Meeting

INTRODUCTION

Despite all the technologic and economic elements that comprise a water reclamation research project, it is foremost a public involvement project. A project of this type requires non-wavering public support and funds to be successful. Two avenues were provided for public participation: a select Public Advisory Committee was formed, and a public meeting providing a forum for the whole community to discuss the project was planned.

PUBLIC ADVISORY COMMITTEE FORMATION AND RESPONSIBILITY

Public Advisory Committee (PAC) members, representing various segments of the community, were nominated by the City and approved by the Texas Water Development Board.

The seven-member Public Advisory Committee included:

Jackie Cox	-	Private citizen, geologist
Jeanette Davis	-	Private citizen, former State Board of League of Women Voters
George Dawson, M.D.	-	General practitioner in family medicine
Dr. Terry Foster	-	Fairleigh Dickinson Laboratories, Inc., a local research laboratory performing grant research
Bill Hollowell, P.E.	-	Professional engineer, Tippett and Gee, Inc.
Harold Nixon	-	Current City Councilman and businessman
Dr. Clark Stevens	-	Retired biology professor, Abilene Christian University

Ms. Davis was elected chairperson at the initial meeting and presided at the remaining meetings.

The purpose of the committee was to act as an advisory group to the research project team, providing comments and guidance during the project. The organization's major responsibilities were to provide a public forum for the exchange of ideas, disseminate accurate information to the public and channel the concerns of the Abilene citizens to the research project team. A copy of the PAC Chapter (Public Advisory Committee Duties, Responsibilities and Schedule) is included at the end of this Technical Memorandum.

SUMMARY OF PAC MEETINGS AND COMMENTS

Although only four meetings were identified in the scope of the project, a total of six formal PAC meetings were held. All meetings were conducted in Abilene. The dates and subjects of those meetings are described below:

Meeting 1	April 15, 1987	PAC formation and introduction of project goals and objectives.
Meeting 2	July 23, 1987	Baseline physical and water quality data.
Meeting 3	August 23, 1987	Water quality effects and proposed concept plan.
Meeting 4	September 24, 1987	Water quality standards and process alternative evaluation.
Meeting 5	October 15, 1987	Presentation of the draft report.
Meeting 6	January 13, 1988	Presentation of revised final draft report and discussion of Public Meeting format and content.

Copies of meeting minutes are available at the Municipal Building in Abilene.

SUMMARY OF PAC WATER RECLAMATION PLANT TOURS

The project scope required visits by the PAC, and project team to the Denver Metro and the El Paso water reclamation projects. A third visit was also conducted to the Upper Occoquan Sewage Authority water reclamation project, since it more closely resembled the conditions of the Abilene research project. A summary of the plant tours is provided below:

1. Fred Hervey Water Reclamation Plant, El Paso, Texas. Site visit was conducted on May 12, 1987. The El Paso project is an advanced wastewater treatment plant whose water reclamation facility discharges up to 10,000,000 gallons-a-day to help recharge the depleting Hueco Bolson aquifer. Many of the treatment processes used at this plant were under consideration for the Abilene research project. It was estimated the reclaimed water would take in excess of two year to reach the point where water was withdrawn from the aquifer. To date, there is no confirmation the reclaimed water has reached the well field. Roberto Bustamante, the El Paso Sewage System Manager conducted the tour.

2. Denver Potable Water Reuse Demonstration Plant. Site visit was conducted on May 13, 1987. The Denver project, often referred to as the Denver Metro Plant is a demonstration plant producing 1 million gallons per day of potable water. The water is not introduced into the Denver potable water supply. Rather, it is part of a research project generating data to answer the question, "Is reclaimed water safe to drink?" An additional 5-10 year of monitoring remains. This level of testing is necessary since the plan is to introduce the reclaimed water directly into

the potable water system instead of a large aquifer like El Paso, or a large lake such as Occoquan Reservoir in Alexandria, Virginia.

3. Upper Occoquan Sewage Authority Water Reclamation Plant. Site visit was conducted on June 24, 1987. The Upper Occoquan Sewage Authority (UOSA) project most closely resembles the project concept for the Abilene water reclamation research project. Advanced treatment units reclaim water which is then discharged to Bull Run Creek, a tributary to the Occoquan Reservoir. The UOSA plant discharges up to 15 million gallons per day to the reservoir, and is in the process of being expanded. The treatment units were similar to those being considered for the Abilene project. Millard Robbins, the Executive Director of UOSA conducted the tour.

PUBLIC MEETING

A public meeting was held on February 23, 1988 in the City of Abilene Council Chambers. Approximately two dozen citizens were in attendence. The Summary Report was presented by the research team, then the meeting was opened for questions. A summary of the meeting minutes is included at the end of this technical memorandum.

APPENDIX A

PUBLIC ADVISORY COMMITTEE DUTIES, RESPONSIBILITIES AND SCHEDULE

I. PURPOSE OF THE COMMITTEE

The Committee shall act as an advisory group to the City of Abilene and its consultants. The Committee shall review and comment on elements of the study and make recommendations to the City pertaining to the project. The Committee's role shall be an advisory role making recommendations to the City and a communications role reflecting the interests of the community, with decision-making responsibility remaining with the City.

II. STRUCTURE OF THE COMMITTEE

A Chairperson and a Vice-Chairperson shall be elected by a majority vote of the Public Advisory Committee.

The Chairperson shall preside at all meetings of the Committee and shall represent the Committee to the City, it consultants, to State and federal agencies, the media, and the general public.

The Vice-Chairperson shall perform the functions of the Chairperson when that person is unable or unavailable to perform them.

The City shall provide secretarial assistance to the Committee in order to facilitate its work.

III. MEETINGS OF THE COMMITTEE

A. REGULAR MEETINGS

The Committee shall have three regular meetings. The initial orientation meeting will be held at the City Hall in Abilene on Wednesday, March 11, 1987. The remaining meetings will be scheduled on March 11, 1987. Committee meeting shall be open to the general public. Notice of time and place of regular committee meetings shall be given in advance of the meetings. Notice of regular meetings shall be mailed to Committee members and to local media in order to inform the general public. The members of the committee will also be notified by phone a few days before the meeting. All meeting notices shall be accompanied by an announced agenda for the meeting in question.

All material for review and comment by the Committee shall be available to the members sufficiently in advance of the time designated for Committee comment so that adequate review time is provided.

The City staff, its consultants, and staff of appropriate entities (such as the Texas Water Development Board) shall provide necessary information to the Committee to facilitate its advisory function.

B. SPECIAL MEETINGS

Special meetings of the Committee may be called by the Chairperson, the City, or its agent, when special needs require the involvement of or consideration by the Committee. Notice of the time and place of such special meetings shall be given at least three days in advance of the meeting. Committee members shall be advised by telephone, as well as by written notice, of such special meetings.

IV. COMMITTEE ACTIONS

A quorum of the Committees shall be defined at 50% of the Committee membership. A quorum must be present before the Committee can take definitive actions.

Procedural matters may be decided by consensus or by majority vote of the members present.

Comments and recommendations to the City on the final product shall be by majority vote of those present.

V. REPLACEMENT OF COMMITTEE MEMBERS

If, for any reason, a Committee member cannot continue to serve, the City shall appoint a replacement, naming a person from the same category of membership in which the replaced member was designated.

Members absent from more than two consecutive regular Committee meetings without accepted excuse (illness of member or member's family, death in family, or business travel) may be replaced by the City.

VI. AMENDMENTS TO RULES OF PROCEDURE

Changes in these Rules of Procedure may be made by majority vote of the Committee.

No changes in the Rules of Procedure may be made which would be in conflict with the legal requirements of the City or the TWDB.

APPENDIX B

CITY OF ABILENE
WATER RECLAMATION RESEARCH PROJECT
PUBLIC HEARING
TUESDAY, FEBRUARY 23, 1988

Jim Blagg opened the meeting with a brief background of the Reclamation Research Project. He introduced the Public Advisory Committee members in attendance: Jeanette Davis, Dr. Terry Foster, Dr. George Dawson, Harold Nixon and Dr. Clark Stevens. The purpose of the public hearing is to obtain feedback from the citizens of Abilene.

Dwayne Hargesheimer introduced Mike McDevitt with the Texas Water Development Board and briefly described the board's involvement with the project. Dwayne also introduced Dr. T. G. Metcalf from the Baylor College of Medicine as a research team member available to answer questions regarding health concerns.

Dwayne presented an overview of the City of Abilene water supply. He described the area's watersheds and storage and explained the Lake Hubbard reservoir supply. Dwayne detailed the future water supply expected from Stacy. The present water supply is adequate, however, in view of the area's drought history, the Staff feels obligated to pursue all resources at our disposal.

John Cook from Freese & Nichols, Inc. elaborated on the project and needs. He stated that the unconventional water sources are being investigated because it is felt that Abilene's ability to supply water by conventional sources is limited over the long term. This situation is being faced by most municipalities in Texas. The research project explores the possibility of reclaiming wastewater now discharged after treatment around Lake Fort Phantom down the Brazos to Possum Kingdom Reservoir.

Bob Chapman, Assistant Director of Water Engineering for CH2M Hill, Inc. reviewed similar projects from across the nation and explained how other communities are addressing their needs for water supply. Mr. Chapman presented overviews of projects now operating in Denver, CO., Tampa, FL., St. Petersburg, FL., El Paso, TX, and in North Virginia. These projects are producing high quality effluent. Some are receiving support from governmental agencies. Most communities first explored non-potable uses of reclaimed wastewater in an effort to reduce or level out the demand for fresh water supply.

John Cook explained how the study was conducted. David Lewis (Freese & Nichols, Inc.) was project manager, Ray Longoria (Freese & Nichols, Inc.) was project engineer. Assistance came from other staff members of Freese & Nichols, Inc. and CH2M Hill, Inc. Virology work was supported by Baylor College of Medicine. Technical memorandums provided a discourse on each of the key elements of the study and were assembled into the project report. Information was reviewed by the research team in a quality control effort to critique scientific findings. City Staff and the Public Advisory Committee were met with several times. The Water Development Board role was financial support of the research project and review of the report. The Texas Water Development Board has no future commitment beyond this point. A summary report of the project has been prepared.

David Lewis discussed water quality findings. Water quality was a key element and a driving force for the project team. The research team inventoried historic data, implemented a water quality monitoring program, and developed water quality standards which were in most cases in excess of standards established by the EPA and the State of Texas. These high standards became the goal of the team. The research team developed a water quality model to show impact of decisions that would be made. Data included biological parameters, chemical parameters, physical parameters, and toxics. Special studies were conducted. Water quality of Lake Fort Phantom Hill is good. Runoff and drainings into Lake Fort Phantom Hill are poor. The lake is well mixed. The lake meets surface water criteria set by the State of Texas for drinking water supplies. The water quality model findings were:

-Lake Fort Phantom Hill is nitrogen/phosphorus limited. It has trouble ridding itself of nitrates. High phosphorus levels in the discharge will create algae blooms. These two parameters must be controlled.

-Under drought conditions: at 3 mgd of reclaimed discharge, water quality will improve. More than 3 mgd would require higher degrees of treatment.

-Levels of treatment were investigated to maintain historical water quality.

Bob Chapman addressed health effects. Chronic effects are long term health effects. Acute effects include viruses and parasites. Safeguards can be provided. Projects in use across the nation do not indicate long term problems. Natural pollutants in fresh water are of more concern to regulatory agencies than wastewater contaminants. Multiple barriers will remove viruses and parasites to assure a safe water supply. Continual monitoring assures efficient process operation.

Ray Longoria described the proposed treatment facility. They faced two evaluations: technical evaluation of the treatment facility and implementation of a process into a workable water reclamation system. The water quality model provided an optimum operation level of 3 mgd. Two selection criteria were reliability and economics. Biological phosphorus with alum coagulation was chosen as the most effective treatment process. The treatment involves preliminary and biological procedures similar to conventional wastewater treatment plants. The difference comes with the tertiary treatment which adds chemicals to enchance solids removal and disinfectants prior to discharge into the receiving stream. Alternatives were developed including enhancement of existing wastewater treatment facilities at Hamby. Development of a non-potable distribution system was investigated. A second alternative involved construction of a tributary plant in conjunction with a non-potable distribution system. The second alternative was chosen primarily because of economic considerations.

John Cook presented project findings:

- -Reclaimed wastewater can be safely produced.
- -A process was identified to produce effluent within governmental standards and to maintain or improve water quality of Lake Fort Phantom Hill.
- -A full scale pilot facility operating at 3 mgd which would have minimal or beneficial effects on Lake Fort Phantom Hill.
- -A turf irrigation system is feasible. Such a system would provide users with a cost savings over use of potable water.
- -All means of increasing water supply (conservation, Stacy, reclamation) should be considered.

If the City elects to proceed with this project, they need to: (1) develop the treatment facility; (2) develop a management and operations program; and (3) begin implementation.

Project recommendation included:

- -3 mgd at the Hamby treatment facility or on a tributary of Lake Fort Phantom Hill;
- -sewer improvements - development of a non-potable distribution system.
- -Determination of water rights.
- -Water quality monitoring should be continued and expanded.
- -Public Advisory Committee role should be expanded.
- -Conservation should be continued.
- -Conventional water treatment and monitoring should continue.
- -Pilot testing should be conducted.
- -Financing alternatives should be investigated.

John elaborated on projected water demands. At this point, the meeting was opened to questions and comments.

Questions and Answers:

Dwayne Hargesheimer encouraged questions from the public. He reminded the audience that Dr. Metcalf was available for questions concerning health concerns as was Dr. George Dawson of the Public Advisory Committee.

A: Citizen expressed opinion that potential toxicity of additives in the water should be studied in more detail. He feels long term health problems can result from inadequate removal of chemicals and the addition of treatment chemicals in the reclamation process. He pointed out that the EPA has recognized over 700 chemicals in the water and has only set acceptable levels on about 40. How will levels of chemicals such as trichloroethylenes be dealt with?

A: Bob Chapman: Many of these issues are being addressed by federal regulations. The compounds you mentioned are of concern. We have the programs in place to deal with them. TCE is an example. It is an extremely volatile compound which will be removed to a great degree by aeration of any conventional wastewater plant. TCEs would be further removed as they move along streams.

Dwayne advised that specific technical questions can be further discussed with the technical support people after the public meeting breaks up.

Q: Will chlorine removal be required by future regulations?

A: John Cook: Chlorine is of a concern. The EPA is moving towards removal of chlorine from wastewater treatment plant discharge. Their concern is not human health but toxicity to aquatic life in the receiving stream. On the potable side, the concern is for human health. A great deal of work is under way. Ray Longoria added that proposed plant would be adaptable to ozone disinfection.

Q: Would there be effective removal of the AIDS virus in the treatment process?

A: Dr. Metcalf: There is absolutely no concern. The AIDS virus is too fragile to survive the environment in a wastewater treatment plant. Dr. Dawson concurred.

Q: Is there cost effectiveness in storage in Lake Fort Phantom Hill reservoir if it is silting?

A: Dwayne Hargesheimer: That may be a problem in the distant future. Projections show no great effect on the current water supply up to the year 2000.

Q: Who will be responsible for monitoring the water and how often will it be monitored?

A: That will be the option of the City Council. Existing projects use satellite groups such as local universities for monitoring. Several options were looked at by the research project. The research team recommends involvement of a quasi-independent group. Recommendation is to monitor at regular intervals varying according to the chemical group being examined.

Q: How does the water quality of effluent from the existing wastewater treatment plant compare to quality of Lake Fort Phantom Hill?

A: John Cook: You are comparing apples and oranges. Quality of water coming from the existing plant is secondary, not suitable for drinking or recreational use. It is presently discharged into an arroyo which dries up or eventually discharges into Possum Kingdom. LFPH is a reservoir of good quality - not great quality. It is safe for human contact and supports diverse fisheries.

Q: Expressed concern about high concentration of organics and pollutants during dry times. Will the public be notified if that reclaimed wastewater creates unsafe levels of regulated compounds? (specifically trihalomethanes).

A: John Cook: THMs are not of immediate health concern as might be something like coliform bacteria. "Who will watch the quality?" is a question we felt important enough to address in the project. Again, we recommend an independent group to monitor quality of the discharge.

Comment-Jeanette Davis: The standards followed by the research project exceeded quality standards set up by regulatory agencies.

Q: Does the total project cost include the pipeline, right-of-way, and construction?

A: Ray Longoria: Construction and implementation were computed as total project cost. Included in the cost comparison of the complete water reclamation system is the cost of sewage collection system improvements needed to get wastewater from point of generation to treatment. This was the big factor that swung us in favor of the west side tributary plant. That option avoids the major expense of moving sewage to the existing northeast location.

Dwayne Hargesheimer: There are technical memorandums available which break down cost projections in detail.

Q: How will sludge be disposed of?

A: Dwayne Hargesheimer: The current permit allows ponding of digested sludge. Water is decanted and used to irrigate. Sludge remains in the pond. After the silting process is completed (60 years), sludge will be dried up and disposed of.

Q: Is there a danger of the water used to irrigate the golf courses contaminating drinking water supply by seeping into water wells?

A: The risk of a home well being contaminated by this project is unlikely because high standards would be applied which would result in near potable discharge.

Q: Comment. Decanted water contains high solids.

A: The situation at the existing wastewater treatment plant is a different matter. There are no nearby wells at the existing facility.

Q: Are there any guarantees against accidental discharge of raw sewage into the creek? What kind of operation maintenance costs will we be looking at?

A: John Cook: The reliability of the process is a key concern. The plant will be designed to be reliable. It will have back up units and multiple units. There is no way to eliminate all risk of release of partially treated wastewater. The risk is minimal. Even extreme situations can be handled.

Comment-Jackie Cox: The length of Elm Creek itself provides a natural barrier to accidental contamination of LFPH.

David Lewis: Overall cost of the facility was increased by 20% to allow for additional safeguard.

Q: Will the plant, if it is built, be shut down from time to time for maintenance?

A: Project design with multiple units allows for shutdown of one unit for repair without incapacitating the entire plant.

Q: Did I understand an earlier overheard comment that 99.7% of the discharge is guaranteed to be free of viruses?

A: Bob Chapman: We were referring to a log reduction of virus or parasites. Several log reductions will take place in the treatment process.

Dr. Metcalf: In terms of virus reduction through the usual treatment, you can count on at least 4 - 6 log reductions prior to disinfection. Disinfection will provide 2 - 3 more log reductions. As we look at the present treatment and the proposed project we see the addition of two processes.

Q: Can I get a list of chemicals used in the proposed project?

A: Yes.

Q: The point is that the new chemicals which will be introduced into the water supply may be dangerous. Over the long term, many people feel that the nations water supply is a major health risk.

A: John Cook disagreed - feels the national water supply is safe. There are greater health concerns such as improper diet, smoking, pesticide use, etc. which have a greater "total body burden" impact.

Comment: Bob Chapman - what we have here is a microcosm of a larger national debate concerning "How Safe is Safe?"

Q: Does water quality change when the lake turns?

A: David Lewis: We found that LFPH does not turn over. In the late fall, we see indications of a tendency toward stratification, but since the addition of a mixing system, actual turnover has not occurred.

Dwayne Hargesheimer: Phantom is sensitive in this area. That was recognized in the study.

Q: During the treatment process, will heavy metals be removed?

A: Yes. Heavy metal accumulations are in removed sludge.

Q: Will industries be restricted as to discharge quality?

A: Dwayne Hargesheimer: There is already enforcement of an industrial waste ordinance. It will continue.

Q: Is monitoring of water quality expensive?

A: David Lewis: $30 to $50 thousand a year are estimated to be needed to monitor quality of LFPH. This does not include cost of daily monitoring at water and wastewater plants. Special studies may be needed periodically. They were not included in these estimated costs. This significant program carries with it significant expense.

Q: With budget cuts, is there any assistance available?

A: Dwayne Hargesheimer: We are not sure at this point. Cost parameters will be considered at time of implementation.

Ray Longoria: This cost of monitoring is incremental. Monitoring is always required for a water supply.

Q: Is the sanitary landfill a threat to our water supply?

A: Dwayne Hargesheimer: The landfill is not situated in the LFPH watershed.

Jim Blagg: Current permits for the State don't allow surface runoff from landfills. It must be impounded.

Q: Will this project be put to voters?

A: That decision would be left up to the Council.

Q: There is no new water. All water is recycled. When will water be available from Stacy Dam?

A: We will have a right to use Stacy water any time after construction is completed.

Q: When will that be?

A: In 1992, the project will be impounding water. It may take 5 years to fill. Transportation facilities will need to be built.

Q: Are we looking at this project in the same time frame?

A: This project was not intended to support current water supply

Q: What is total cost?

A: Ray Longoria: Total estimated cost is $10.5 million based on 1987 costs. This cost is at the recommended production level of 3 mgd.

Q: There are many components in the overall future water supply, conservation, Stacy, reclamation, etc. Some of this project must be built anyway. Is that correct?

A: Dwayne Hargesheimer: Yes. We must build the primary and biological phases irregardless.

Q: When must this building be completed?

A: Dwayne Hargesheimer: We are contemplating improvements now and again in 1992. It would depend on community growth.

Q: Who will take the initiative to advise the public of problems with the water such as taste and odor problems?

A: This is a consumer acceptance factor rather than a health concern.

Dwayne Hargesheimer concluded the meeting. Final documents will be presented to the State in the next 30 days and the project will wrap down. The Staff and Research Team will be available after the meeting for follow-up.

Dwayne Hargesheimer
Director of Water Utilities

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 3

BASELINE DATA DEVELOPMENT

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GENERAL

Assembly of baseline data was required as a prerequisite to completing the various tasks in the Water Reclamation Research Project. The data and information was obtained from existing sources and is presented in fact sheet format.

A list of the fact sheets assembled in this technical memorandum is presented below:

FACT SHEET	
A	Existing and Projected Population
B	Existing Quantity and Quality Models of Lake Fort Phantom Hill
C	Historical Water Quality - Lake Fort Phantom Hill
D	Potable Water Reduction and Usage
E	Wastewater Flows and Quality
F	Wastewater Treatment Plant Capacity
G	Water Treatment Plant Capacity
H	Water Rights (Permits and Contracts)
I	Historical Climatological Data
J	Current Water Conservation Measures
K	Design Criteria of Similar Reuse Projects
L	Summary of Literature on Public Health Impacts

A. FACT SHEET ON EXISTING AND PROJECTED POPULATION

HISTORICAL POPULATION

Table A-1 gives historical population figures for the City of Abilene and Taylor County from 1900 to 1986. The reported census population in 1980 was 98,315 people, and a census estimate made in 1984 is 106,790. The population estimated by the City Planning Department for 1985 is 108,541.

The increase in population from 1970 to 1980 represented a 9.6 percent increase, or 0.9 percent per year. The increase in population from 1980 to 1985 suggests a 2.0 percent growth rate.

Based on the above information, a more recent estimate was made by the City of Abilene's Planning Department. The estimate was for the wastewater study area shown on Exhibit A, which is broader than the existing City limits. The estimate of total population for 1986 was 113,000. Of this total, 112,659 were estimated to be served by City sewer.

PROJECTED POPULATION

The City's Planning Department prepared a population projection for the year 2005. This is presented in "City of Abilene, Population Projection", July 1986. The City's Planning Department anticipated the 2 percent per year growth seen in the 1980's to continue through 2005. This yields a 2005 total population of 166,792, with 165,865 estimated to be served by sewer in that year. Of the approximately 54,000 population increase, about 30,000 or about 60 percent is estimated for the southwest quadrant of the City.

A one percent per year increase would result in a year 2005 population of 136,500 with approximately 136,000 served by City sewer. Figure 1-A gives a plot of the historical, and projected populations at 1 and 2 percent growth. The population increase is expected to fall within the limits of these values.

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Table A-1

Abilene and Taylor County
Historical Populations

Year	Abilene Population	Abilene Annual Growth	Taylor County Population	Taylor County Annual Growth	Percent of Taylor County in Abilene
1900	3,411		10,499		32.5%
		10.4%		9.6%	
1910	9,204		26,293		35.0%
		1.1%		-0.9%	
1920	10,274		24,081		42.7%
		8.5%		5.5%	
1930	23,175		41,023		56.5%
		1.4%		0.7%	
1940	26,612		44,147		60.3%
		5.5%		3.7%	
1950	45,570		63,370		71.9%
		7.1%		4.8%	
1960	90,368		101,078		89.4%
		-0.1%		-0.3%	
1970	89,653		97,853		91.6%
		0.9%		1.3%	
1980	98,315		110,932		88.6%
		2.5%		2.5%	
1981*	100,778		113,744		88.6%
		2.0%		2.0%	
1982*	102,767		115,989		88.6%
		3.8%		3.8%	
1983*	106,700		120,429		88.6%
		0.1%		2.2%	
1984	106,790		123,100		86.8%
		1.6%		-0.4%	
1985*	108,541		122,506		88.6%
1986*	113,000	4.1%	-	-	-

*Population for 1981, 1982, 1983, 1985 and 1986 are from the Planning and Community Development Department and the Water Utilities Department of the City of Abilene. The 1984 population was estimated by the U. S. Census, and figures for other years are from U. S. Census Report.

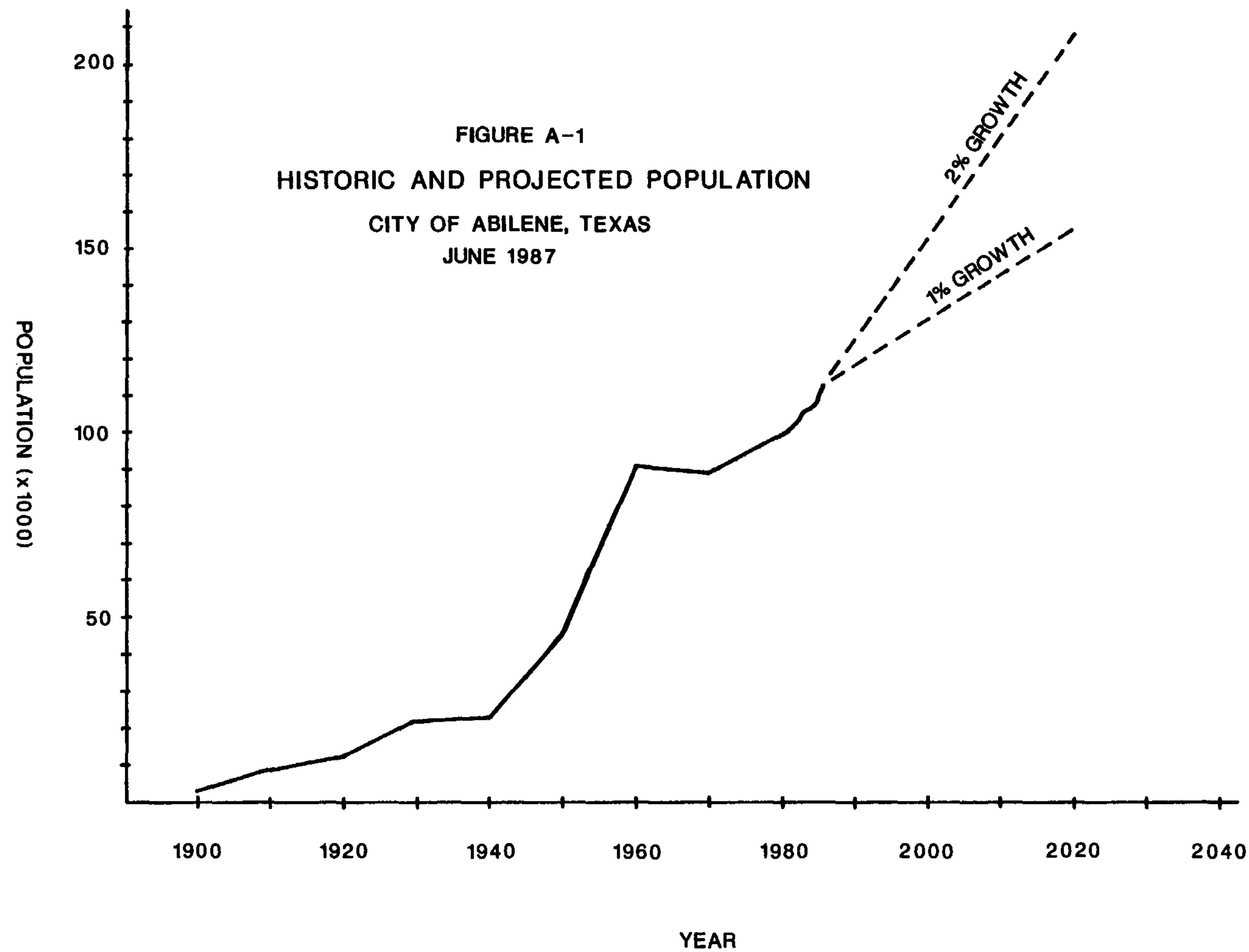


FIGURE A-1
HISTORIC AND PROJECTED POPULATION
CITY OF ABILENE, TEXAS
JUNE 1987
2% GROWTH
1% GROWTH
200
150
100
50
POPULATION (x1000)
1900
1920
1940
1960
1980
2000
2020
2040
YEAR

B.2 Fact Sheet on Existing Models of Lake Fort Phantom Hill

Since 1976, Freese and Nichols has conducted a number of studies of Lake Fort Phantom Hill to analyze reservoir yield, water quality, pumping cost and operation as a system with Hubbard Creek Reservoir. The computer models of the lake used in these studies are described below.

1. 1976 - Report on Lake Fort Phantom Hill Yield: This report investigated the yield of Lake Fort Phantom Hill and the effect of increased reservoir capacity on yield. (The study found that increasing the capacity of the lake would not increase the yield significantly.) The study used a computer model to conduct a monthly mass balance of reservoir inflows, evaporative losses, withdrawals for water supply and spills. The data used by the model include historical monthly evaporation rates, historical monthly inflows (adjusted for current conditions), and area and capacity information.

2. 1980 - Study of Coordinated Operation of Existing Raw Water Supply Sources and Study of Long Range Water Supply: These studies investigated the operation of Lake Fort Phantom Hill in coordination with Hubbard Creek Reservoir. A computer model was developed for the studies to conduct a mass balance operation study of the two reservoir systems. The model was used to determine the yield of the system and to analyze the total dissolved solids levels for water in Lake Fort Phantom Hill, water in Hubbard Creek Reservoir and water supplied to Abilene. A second computer model was developed to analyze the cost of pumping for various operating strategies with the two-reservoir system.

3. 1984 - Evaluation of the Use of Brackish Water and Reclaimed Wastewater for Long-Range Water Supply: This study investigated the total dissolved solids levels and costs for various alternative sources of water supply. The computer models used were based on those developed in 1980 and described in Item 2 above.

Summary

Existing models of Lake Fort Phantom Hill have been used to analyze reservoir yield, water quality in terms of total dissolved solids, pumping cost and operation as a system with Hubbard Creek Reservoir. All the models described were developed by Freese and Nichols for specific studies and are based on a monthly mass balance of water and salts.

The quality modeling conducted for Lake Fort Phantom Hill shows that concentrations of total dissolved solids in the lake should remain at acceptable levels. In a system operation study using 1940-1985 inflows and estimated 1990 demands, the total dissolved solids concentration in Lake Fort Phantom Hill averaged about 385 mg/l, ranging from 189 mg/l to 725 mg/l. High concentrations of TDS were associated with drouths, and lower levels coincided with high inflow and spills.

A table showing the demand of the West Central Texas Municipal Water District is given on the attached table. Approximately 1,000 acre-feet/year is met by Lake Abilene. The remainder is a combination of Lake Fort Phantom Hill, Hubbard Creek Reservoir and the scalping from the Clear Fork of the Brazos River.

West Central Texas Municipal Water District
Projection of Normal Water Use by Member Cities

- Values in Acre-Feet per Year -

	1985 Actual Use	Projected Normal Use 1990	1995	2000
Abilene	21,375	26,400	28,300	30,200
Albany	681	700	700	700
Anson	608	700	700	700
Breckenridge	1,531	1,800	1,900	2,000
Total	24,195	29,600	31,600	33,600

C. FACT SHEET ON HISTORICAL WATER QUALITY

Historical water quality and the findings of the current water quality testing program are contained in the Technical Memorandum on Water Quality Assessment - Lake Fort Phantom Hill, Abilene, Texas.

D. FACT SHEET ON WATER USAGE AND WATER PRODUCTION

The City of Abilene Water Utility Department provides potable water for the City, including residential/commercial usage, and major industrial customers and also sells water to various cities and water corporations in the area.

Water supply is principally from Lake Fort Phantom Hill, Hubbard Creek Reservoir and Lake Abilene. The City also has water rights to other sources. The City's water rights are identified in Fact Sheet H.

Three water treatment plants operated by the City produce the potable water from the raw supply water. These are described further in Fact Sheet G.

Water Customer Information

The City has both raw and treated water customers. Raw water customers include the Abilene Country Club and Fairway Oaks Country Club which purchase water from Lake Kirby for irrigation. Treated water customers include City of Abilene residents, businesses and industries, and several major water wholesale customers. As of June, 1987 the City had 34,010 customers excluding the major users. The major users are as follows:

Dyess Air Force Base
City of Merkel
City of Potosi
View-Caps Water Supply Corporation
City of Hawley
City of Hamby
S.U.N. Water Supply Corporation
City of Blair
Steamboat Mountain Water Supply Corporation

The major users account for only about 13 percent of the total average day usage, or about 3.0 mgd.

Water Production

Average water production information from 1978 to 1986 is given in Table D.1. Since the City supplies large industrial customers and water corporation, the data reflects Abilene residential use separately from total usage. The 1985 Abilene, Texas Upper Pressure Planes Water Distribution System Analysis by Freese and Nichols identified the average day per capita demand at 178 gpcd without major users and 208 gpcd including them.

This is the average usage over an entire year. Flows within the year vary significantly and are highly dependent upon the weather and time of day. Figures D.1 and D.2 illustrates this relationship for Abilene. Flows that are useful in design of water treatment and distribution facilities include the peak day usage and the maximum hour usage. These are generally given as ratios. For Abilene the recent historical ratio of Peak-Day to Average-Day is 1.89 and the ratio of maximum-hour demand to peak-day demand was 1.60. The 1.89 peak-day/average-day ratio is lower than the previously identified ratio in the 1978 Water System Report. This appears to reflect a decrease in peak usage due to the recently adopted water conservation program. If this trend continues the lower ratio should adequately predict future water needs. A summary of the flows is given below.

Summary of Current Water Demands
City of Abilene

	Excluding Major Users		Total Including Major Users	
	MGD	gpcd	MGD	gpcd
Average-Day Demand	19.02	178	22.18	208
Peak-Day Demand	-	-	41.86	393
Maximum-Hour Demand	-	-	63.43	595

Using the historical per capita flows an estimated 2005 population of 136,500 and an assumed increase in usage of 10 percent by the major users, the estimated future water requirements (year 2005) are as follows:

Summary of Year 2005[1]
Water Demands
City of Abilene

	Excluding Major Users		Total Including Major Users	
	MGD	gpcd	MGD	gpcd
Average-Day Demand	23,62	178	27.6	208
Peak-Day Demand	-	-	56.3	425
Maximum-Hour Demand	-	-	83.0	626

[1]Extrapolated from estimate through year 2000 made in 1985 Abilene, Texas Upper Pressure Planes Water Distribution System Analysis.

Table D.1

Historical Average Water Use Characteristics
City of Abilene

Year	Population	Average Day Use Excluding Major Users (MGD)	Average Day Use Excluding Major Users (gpcd)	Average Day Use Major Users	Total Average Day Use (MGD)	Total Average Day Use (gpcd)
1978	97,449	17.2	177	2.5	19.7	202
1979	98,101	17.0	174	2.3	19.3	197
1980	98,315	20.0	204	2.8	22.8	232
1981	100,778	18.4	183	2.7	21.1	209
1982	102,767	18.1	176	2.8	20.9	203
1983	106,700	19.0	178	3.2	22.2	208
1984	106,790	18.8	176	3.2	22.0	206
1985	109,720	-	-	-	19.8	180
1986	113,000	-	-	-	19.6	173
Avg.	-	-			-	

ABILENE

SEASONAL PATTERN OF WATER USE

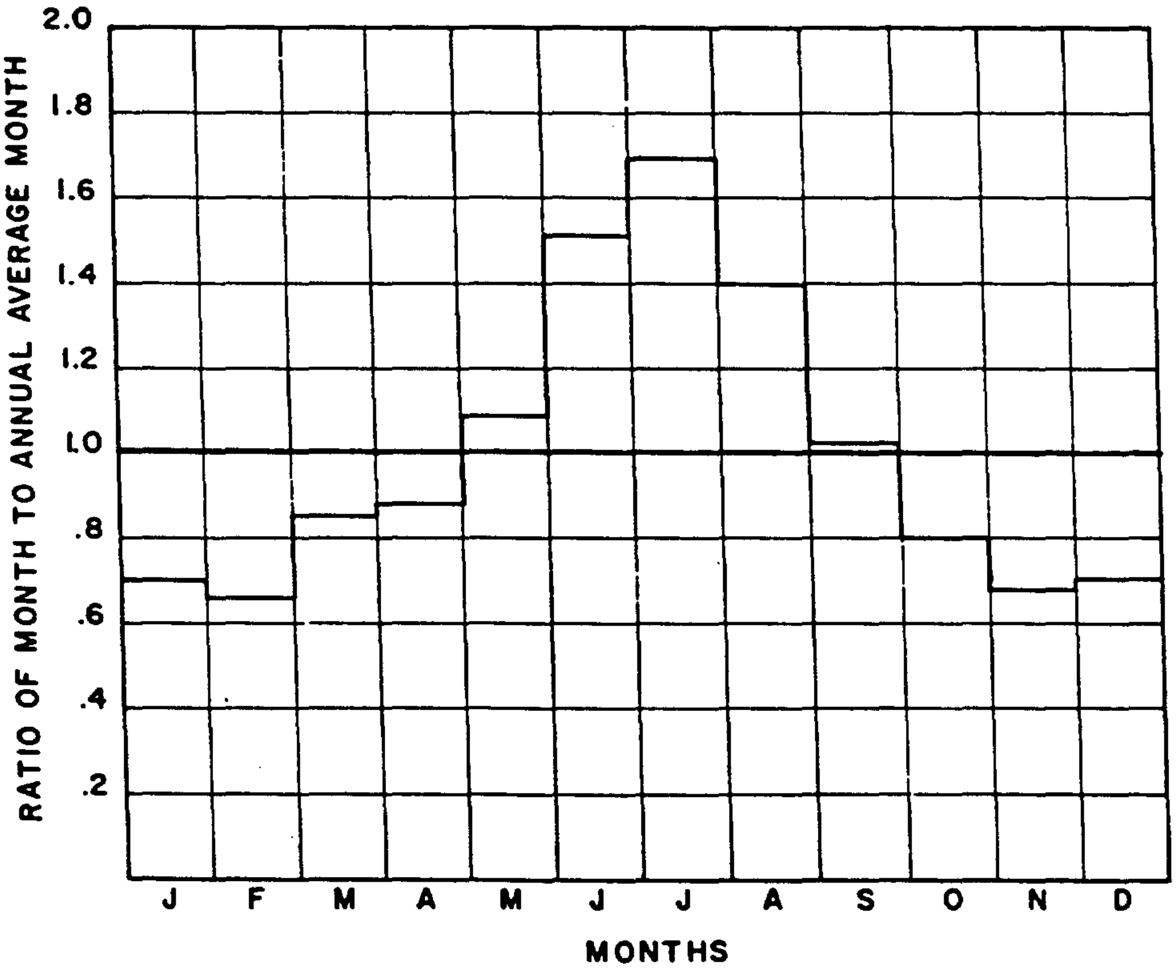


FIGURE D.1

PEAK DAY HOURLY PATTERN OF WATER USE

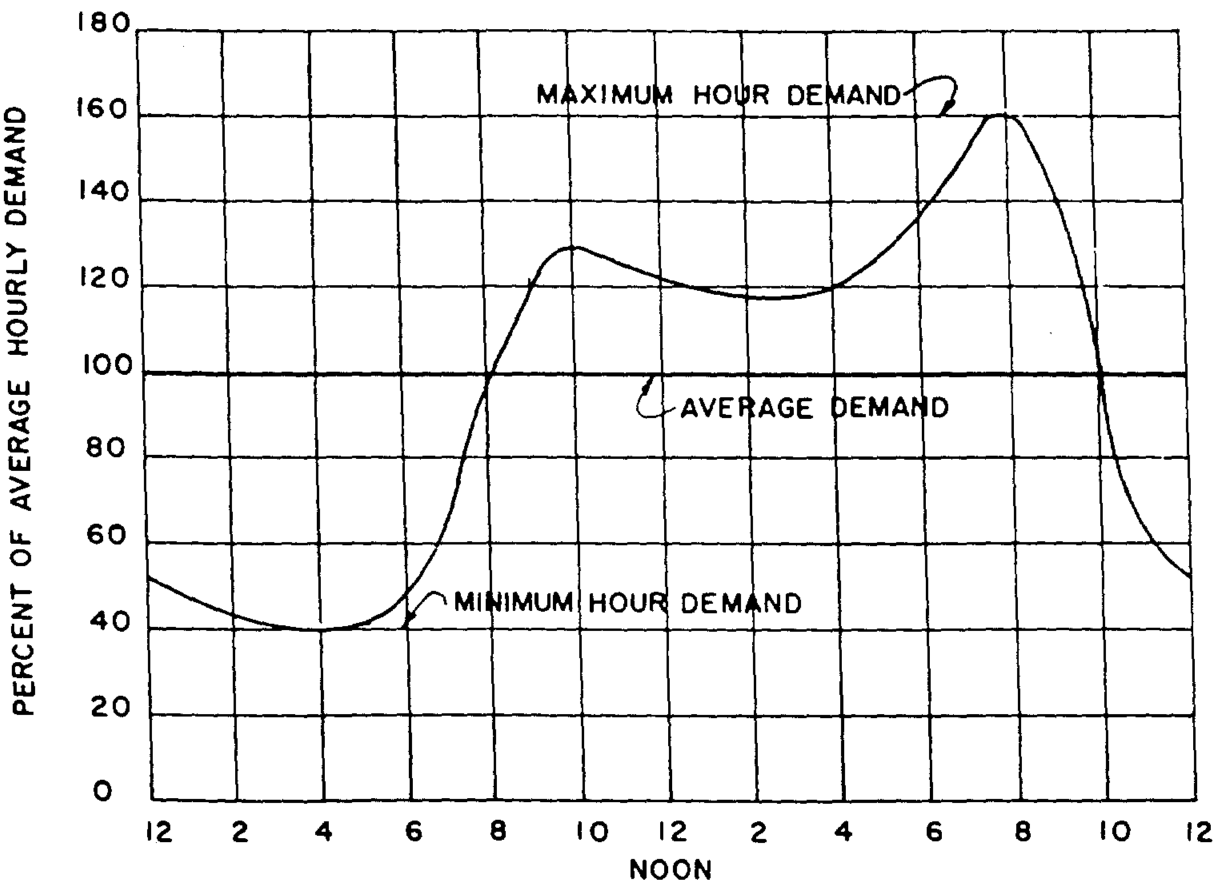


FIGURE D.2

E. FACT SHEET ON WASTEWATER FLOWS AND WASTEWATER QUALITY

Wastewater Quantity

The Average annual daily flows measured at the Hamby Wastewater Treatment Plant since 1978 are given in Table E.1. This represents the total flow into the plant form all sources; domestic, industrial and inflow/infiltration.

1. Domestic Wastewater. Includes residential (houses, nursing homes, apartments, dormitories), institutional (schools, libraries, public buildings) and commercial (restaurants, retail stores, office buildings, etc.) wastewater.

2. Industrial Wastewater. Wastewater flow generated by industries as identified by the City of Abilene Industrial Waste Ordinance. A listing of these industries and their average daily flow is given in Table E.2.

3. Inflow/Infiltration. Inflow is the unintentional direct entry of surface stormwater runoff into the wastewater sewer system. Infiltration is the unintentional entry of groundwater into the sewers from the surrounding soil.

Figure E.1 shows the trend of total wastewater flows since 1978. The total rainfall in each year is also shown. The affect of rainfall, via inflow/infiltration can be seen on this figure.

In the Wastewater Collection System Analysis, City of Abilene, May 1987 by Freese and Nichols, projections of future wastewater flows were estimated. The estimates were based on review of the historical wastewater flow data, and population projections estimated by the City of Abilene Planning Department. A summary of the results is presented below. The total wastewater flows are presented graphically in Figure E.2.

	1986	2005
Sewered Population	112,659	165,865
Per Capita Flow (gpcd)	100	100
Industrial Flow (mgd)	1.64	1.80
Total Average Annual Flow (mgd)	12.99	19.0
Maximum Month Average Flow (mgd)	14.3	20.9
Peak 2-Hour Flow (mgd)	44.0	66.0

The maximum-month flow, rather than the annual average flow, is generally used for process sizing of treatment facilities. The peak 2-hour flow is the maximum flow expected to be sustained for a 2-hour period and occurs with enough frequency to be significant. Sewer lines and treatment plant hydraulics are typically sized to handle the peak 2-hour flow.

Wastewater Quality

Wastewater quality data is available only for the flow received at the plant. Quality data is not available for wastewater in the system or from specific dischargers.

The wastewater treated at the Hamby Wastewater Treatment Plant is characterized as a moderately strong waste that is primarily domestic wastewater. During periods of high rainfall the incoming sewage is diluted to a level categorized as weak.

The average values of key wastewater parameters at the Hamby Wastewater Treatment Plant and national average values are presented in Table E.3.

Table E.1

Historical Wastewater Flows
and Number of Customers

Year	Average Annual Total Daily Flow (MGD)	Sewered Population
1978	10.47	97,449
1979	11.50	98.101
1980	12.38	98.315
1981	13.23	100,778
1982	13.12	102,767
1983	13.09	106,700
1984	13.48	106,790
1985	11.88	109,908
1986	12.99	112,659

TABLE E.2

Average Annual Industrial Point Source Wastewater Flows
City of Abilene, Texas

Industry	Discharge[1] (gal/day)
Texas Instruments	40,083
Victor Equipment	13,110
Humana Hospital	41,008
Baird Bakeries	12,252
State School	136,081
ACCO (Mill & Ref.)	18,134
Martin Linen	13,742
Gooch Packing	210,820
Abilene Linen	23,028
Coca-Cola	19,781
U.S. Brass	101,241
Hendrick's Hospital	94,596
Crown Cork & Seal	211,129
Abtex	34,321
General Dynamics	232,734
Borden's Milk	12,603
Dyess AFB	699,233
Martin Sprockett	4,159
Bandag, Inc.	18,162
Band Instrument Plating	20,501
	1,956,718

[1]Estimated from average yearly water consumption.

Table E.3

Water Quality Characteristics
City of Abilene, Texas

Constituent	Average Abilene Untreated Wastewater	Typical Composition of Untreated Domestic Wastewater
BOD_5	236	220
Total Suspended Solids	191	220
Volatile Suspended Solids (TSS)	145	165
Total Dissolved Solids (TDS)	-	500
Total Organic Carbon (TOC)	71	160
Chemical Oxygen Demand (COD)	460	500
Ammonia-Nitrogen (NH_3-N)	26	25
Phosphorous	-	8
Alkalinity	150	100

AVERAGE MONTHLY WASTEWATER FLOW
and ANNUAL RAINFALL at HAMBY WWTP
(1978-1986) ABILENE, TEXAS

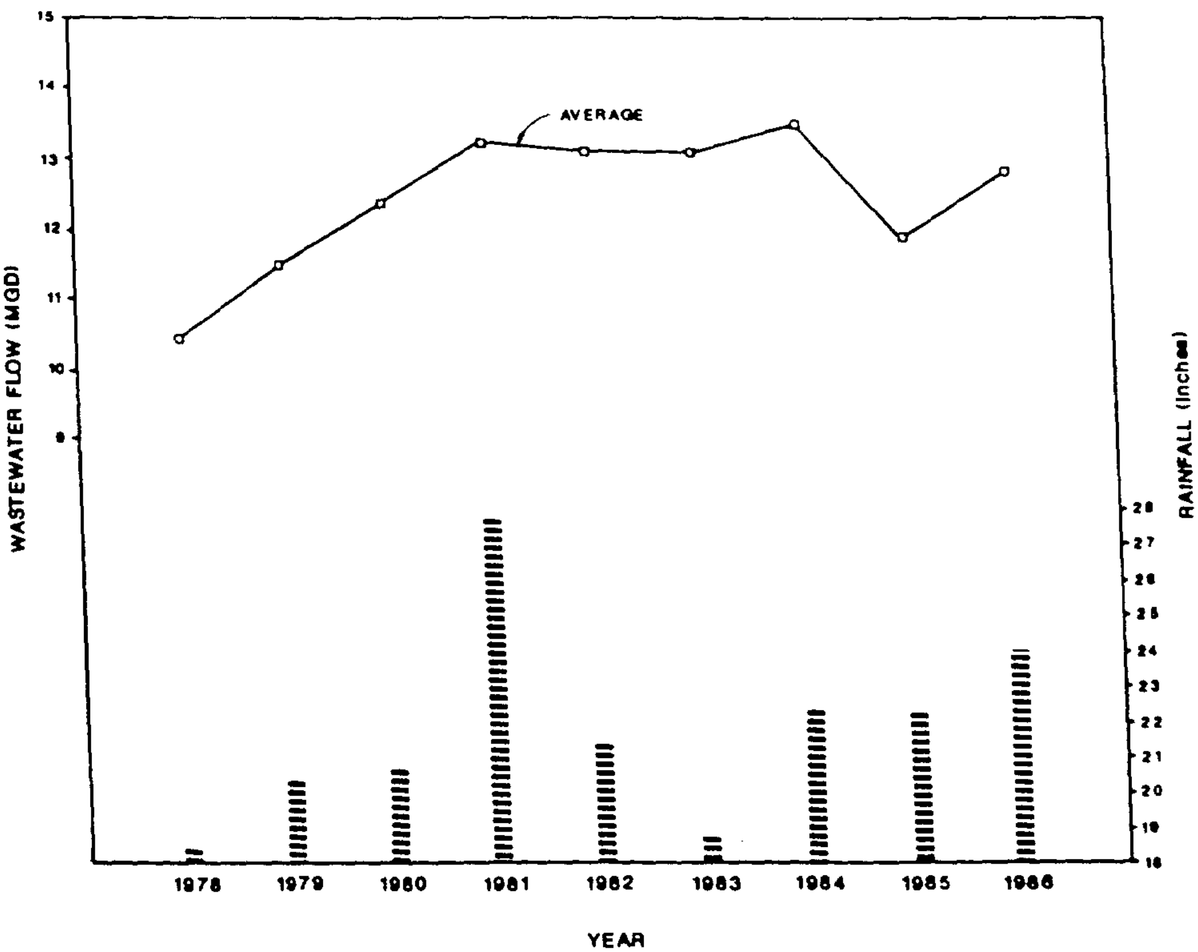


FIGURE E-1

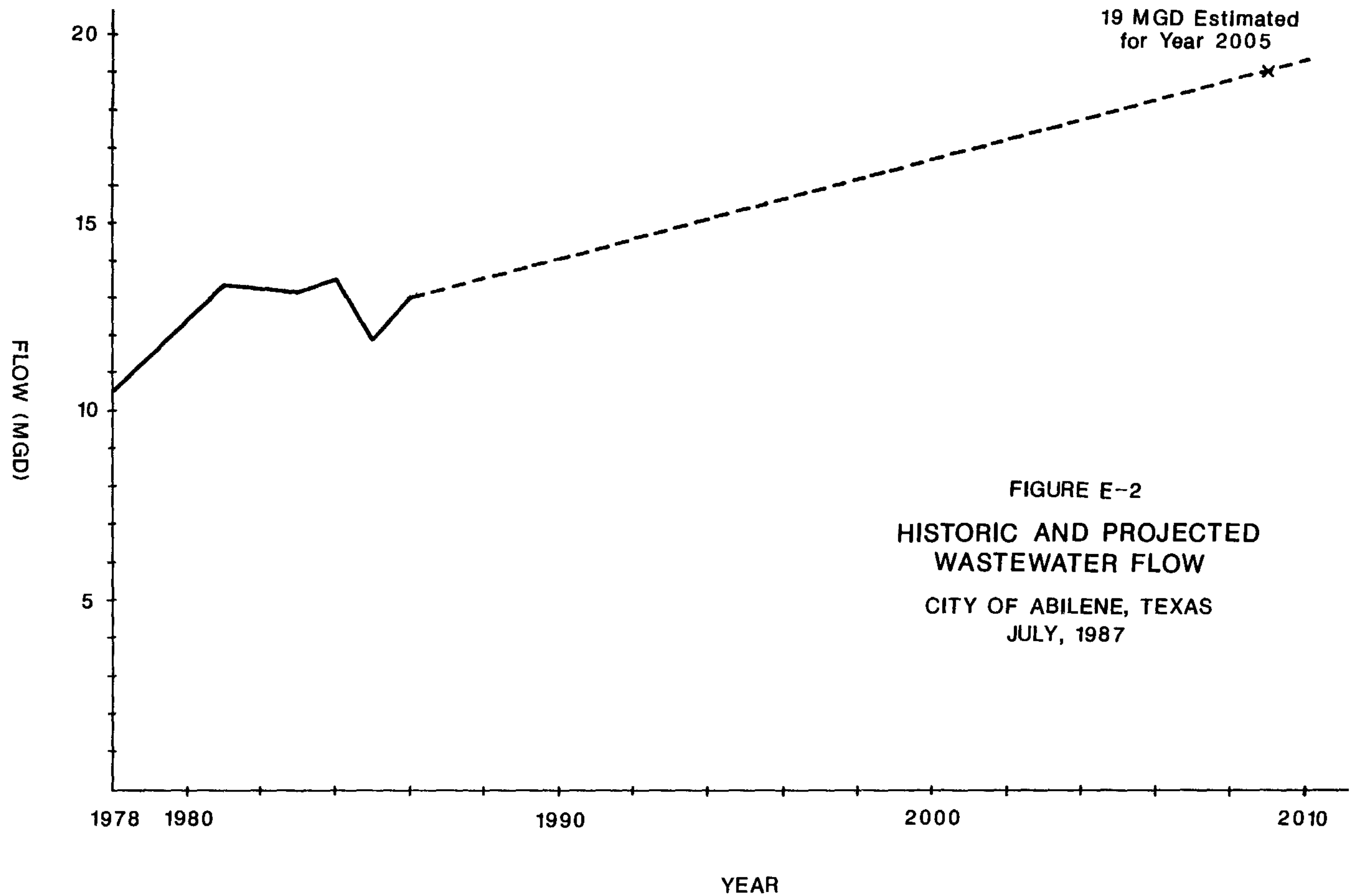


FIGURE E-2

HISTORIC AND PROJECTED WASTEWATER FLOW

CITY OF ABILENE, TEXAS
JULY, 1987

F. FACT SHEET ON WASTEWATER TREATMENT PLANT CAPABILITIES

The City of Abilene Wastewater Treatment Plant (also referred to as Hamby WWTP) handles the entire wastewater flow from the City of Abilene. The Plant is a conventional activated sludge plant rated at 13.4 mgd daily flow/24 mgd peak flow. Discharge is to Freewater Creek which flows into Deadman Creek around the eastside of Lake Fort Phantom Hill and eventually to the Brazos River. A part of the treated effluent also is used for irrigation as weather permits. Effluent Set II governs effluent quality. This requires an effluent quality of 20 mg/l BOD_5, 20 mg/l TSS and a chlorine residual of 1.0 mg/l.

Design loadings are described in Table F.1

Table F.1

Design Loadings for Abilene WWTP

Q_D - Design Average Flow/Actual	13.4/13.0 mgd
Q_p - Design Peak Flow/Actual	24/18.0 mgd
Average Influent BOD_5	267 mg/l
Average Influent TSS	225 mg/l
Average Influent COD	518 mg/l
Average Ammonia-Nitrogen	26 mg/l

Unit Operation and Process

Preliminary treatment is accomplished at Buck Creek Lift Station. Preliminary treatment consists of the removal of large inorganic debris by screening and removal of small dense inorganic material via gravity grit removal. All wastewater is then pumped approximately 5 miles to the Hamby Plant using a combination of centrifugal wastewater pumps. The firm capacity of the Buck Creek Lift Station is 24 mgd. Two 1 MG aerated equalization basins at Buck Creek serve to dampen the peak flows to Hamby Wastewater Treatment Plant. The peak flow to the treatment facility is limited to the effective 24 mgd capacity of Buck Creek Lift Station.

Hamby Wastewater Treatment Plant is sized for 13.4 mgd at design average flow and 24 mgd at peak flow. Wastewater receives primary and secondary treatment and disinfection before being discharged to Freewater Creek. Primary treatment consists of removal of settleable solids in primary clarifiers. This stage reduces the total suspended solids an average of 64 percent and the BOD_5 an average of 23 percent.

Secondary treatment consists of conventional activated sludge basins, with fine bubble dome diffusers for aeration and mixing, and final clarifiers. The majority of the organic material (both suspended and dissolved) is removed in this process. The removal of suspended solids and BOD_5 across this process averages 64 and 88 percent respectively.

Disinfection consists of chlorination of secondary effluent to provide a 1.0 mg/l chlorine residual after a 20 minute detention time.

The overall removal efficiency at the plant including disinfection is 91 percent and 94 percent for TSS and BOD_5, respectively. Removal of ammonia-N averages 68 percent. This equals to effluent quality of 17 mg/l TSS and 14 mg/l BOD_5 and 8.6 NH_3-N.

Facilities at the Buck Creek Lift Station and Hamby Wastewater Treatment Plant are described in Table F.2 and shown in Figure F.1.

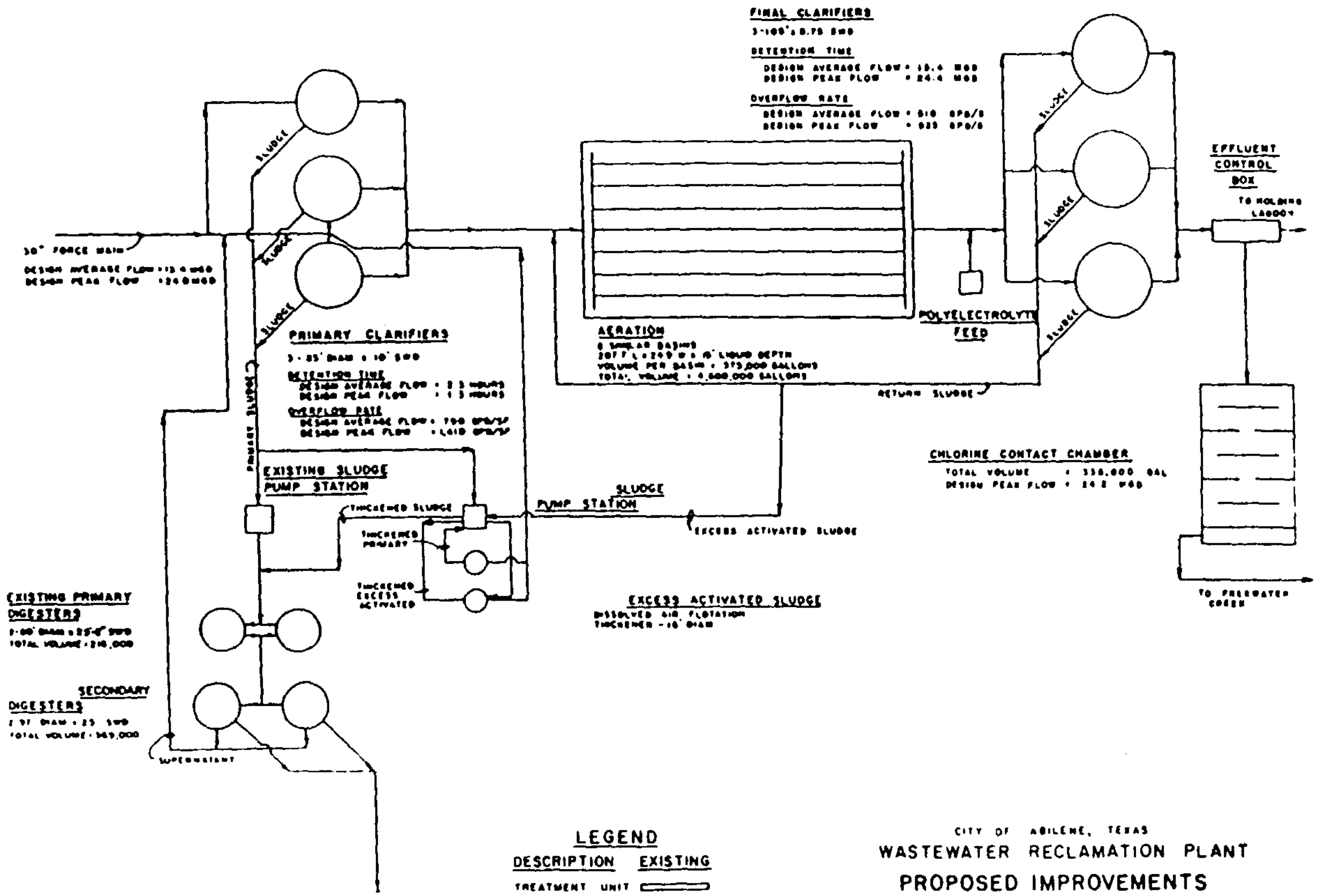
Table F.2

Unit Process and Operation Description
Buck Creek Lift Station and Hamby Wastewater Treatment Plant

Buck Creek Lift Station	Rated (per unit)
Preliminary Treatment	
° Two mechanically cleaned bar screen chain and sprocket	17 mgd
° Two grit chambers (with grit classifier) detritor type	20 mgd
Pumping Equipment*	
° Four (4) motor-driven pumps	(2) 8 mgd (1) 12 mgd (1) 17 mgd
° One (1) engine-driven pump (Standby)	9 mgd
Equalization Basins	
° Two (2) concrete lined basins	1 MG
° Two (2) aeration centrifugal blowers	N/A
Hamby Wastewater Treatment Plant	
Primary Treatment	
° Three circular plow type clarifiers 85 ft. diameter, 10 ft. SWD	10.2 mgd
Secondary Treatment	
° Eight single pass conventional activated sludge. 208' x 25' x15'	16.6 mgd (Total)
° Four PD blowers. One large and one small blower are engine driven	(2) 7,500 scfm (2) 3,500 scfm
° Uniformly spaced ceramic dome diffusers w/gas cleaning system	N/A
Final Clarifiers	
° Three circular, peripheral feed plow type clarifiers. 105 ft diameter, 8.75' SWD.	10.4

*Due to the limitations of the force main, the maximum flow achievable with multiple pumps is approximately 24 mgd.

Disinfection	
° Chlorine solution injection, two 2,000 ppd chlorinators, one 1,000 ppd chlorinator.	N/A
° Two rectangular baffled chlorine contact chambers, 28 ft. x 103 ft., 8 ft. SWD. Total volume of 336,000 gallons.	12.1 mgd
Sludge Handling	
° Two DAFT. 45 x 16 x 9.75. Design based on 6% @ 7 tons/day	7 tons/day
° Anaerobic Digesters Two fixed cover 95 ft. diameter x 25 ft. Two floating cover 80 ft. diameter x 25 ft.	Equivalent population of 116,000 (Total)
° Ponds. Existing ponds are used for sludge disposal.	N/A
Irrigation	
° Approximately 400 acres on ponds with varying depths.	N/A
° Permitted for 4,400 acre-ft./yr. to land application	



CITY OF ABILENE, TEXAS

WASTEWATER RECLAMATION PLANT

PROPOSED IMPROVEMENTS

SCHEMATIC FLOW DIAGRAM

FIGURE F. 1

G. FACT SHEET ON WATER TREATMENT PLANT CAPABILITIES

General

The City of Abilene is served by three surface water treatment plants: the Northeast Water Treatment Plant, the Grimes Water Treatment Plant and the Abilene Water Treatment Plant.

The Northeast and the Grimes Water Treatment Plant produce in excess of 90 percent of the potable water for Abilene in a given year. Both are supplied principally from Lake Fort Phantom Hill, with up to 15.5 mgd available from Hubbard Creek Reservoir when necessary. The Abilene Water Treatment Plant is supplied by Lake Abilene. A summary of the raw water quality for these supplies is given in Tables G-1, G-2 and G-3.

The Northeast Water Treatment Plant is a lime softening facility. The other two are turbidity removal facilities. Disinfection is provided using chlorine and ammonia to produce chloramines. Since the Abilene Water Treatment Plant does not receive water supply from Lake Fort Phantom Hill it is not discussed in detail.

Northeast Water Treatment Plant

Northeast Water Treatment Plant was placed in service in 1971. The plant uses lime to soften the lake water using solids contact clarifiers. It has a rated capacity of 24 mgd.

The unit operation data is as follows:

- ° Sedimentation; three solids contact clarification units, 80 ft. diameter, 14.5 ft. SWD; lime and polymer addition.
- ° Filtration; six gravity filters (multi-media coal, sand, garnet, and gravel).
- ° Disinfection; chlorine and ammonia and storage in 5 MG clear well.
- ° Sludge handling; sludge lagoons.

Overall plant performance is considered satisfactory.

Grimes Water Treatment Plant

Grimes Water Treatment Plant was placed in service initially in the 1940's. Several expansions have been made. The plant removes turbidity and color but softening is not provided. It has a rated capacity of 25 mgd.

The unit operation is as follows:

- ° Sedimentation; two solids contact clarification units, feed polymer, aluminum sulfate and sodium hydroxide.

° Filtration; eight dual media gravity filters (sand and coal).

° Disinfection; chlorination and ammonia and storage in on-site clear wells.

° Sludge handling; disposal to the sanitary sewer system.

Overall plant performance is considered satisfactory. The site is congested and is land locked limiting additional expansion. Additionally a hydraulic restriction at the solids contact unit limits the current plant flow to 25 MGD. Plant can be increased to overall rated capacity of 38 MGD by making improvements to the raw water delivery system, renovating the conventional clarification units and renovating additional existing gravity filters, and increasing the high service pumping capacity.

Abilene Water Treatment Plant

The Abilene Water Treatment Plant was placed in service initially in the 1920's. It has a rated capacity of 3 MGD. Since Abilene Water Treatment Plant will not take flow from Lake Fort Phantom Hill it will not be discussed in detail.

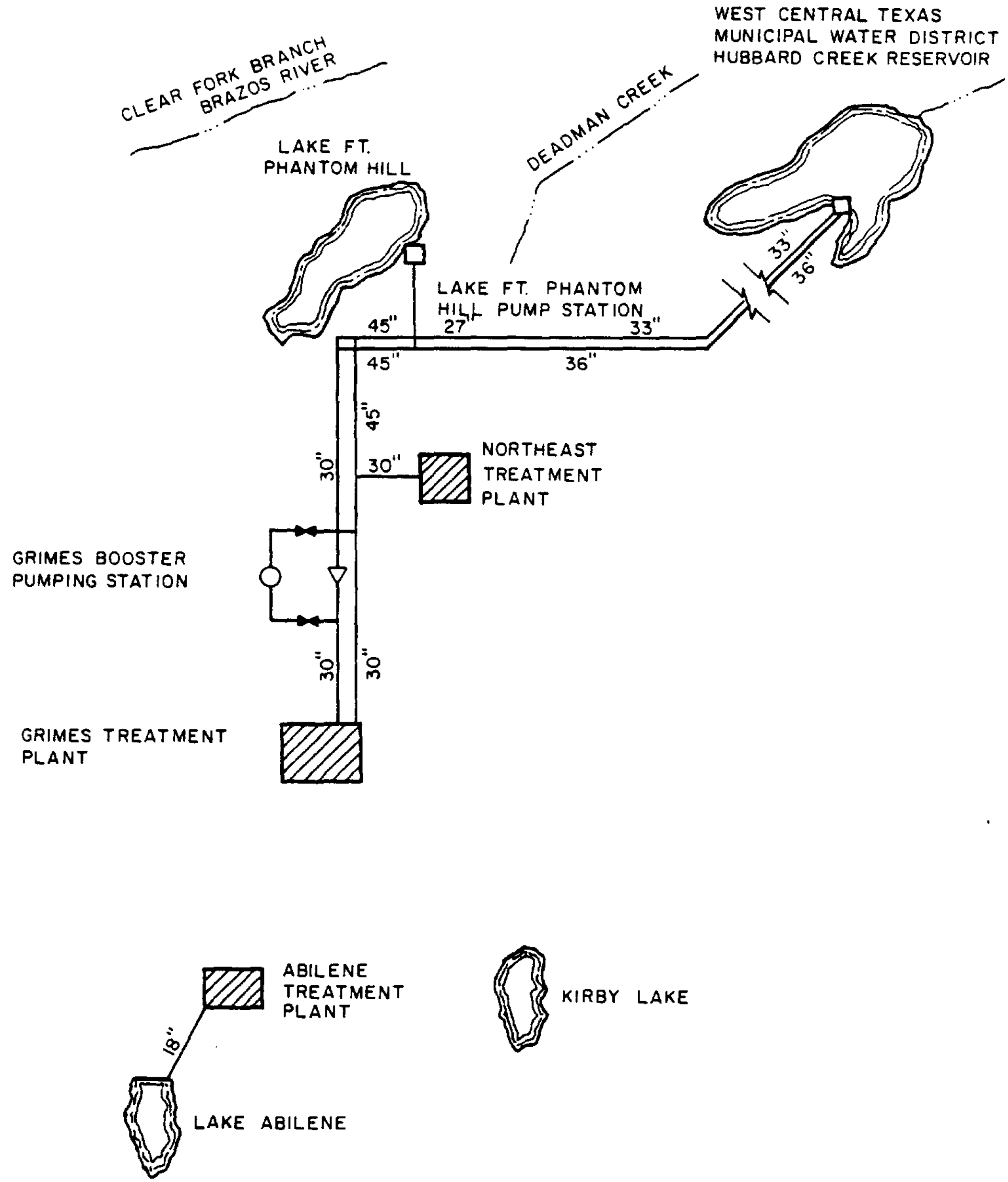


FIGURE G.1

POTABLE WATER SUPPLY & TREATMENT FACILITIES

Table G-1

Summary

Abilene Raw Water Quality
Lake Fort Phantom Hill

Test Performed	Lake Fort Phantom Hill Max.	Min.	Avg.
pH	8.48	8.0	8.23
Alkalinity	180.0	121.0	149.45
Hardness	250.0	174.0	250.00
TDS	653.0	432.0	527.00
NO_3-N	20.59[1]	0.005	2.42
SO_4	115.0	55.0	84.51
Cl	149.4	84.0	125.21
Ca	67.8	36.9	49.93
Na	106.4	47.3	85.04
Mg	37.0	17.3	27.77

[1] Appendix C of 1978 Abilene, Texas Municipal Water System Analysis listed a NO_3-N value of 20.59 for November 1977. Review of data suggests this was an analytical error. The next highest value observed was 1.705 mg/l.

Table G-2

Summary

Abilene Raw Water Quality
Lake Hubbard

Test Performed	Lake Hubbard Max.	Min.	Avg.
pH	8.6	7.48	7.99
Alkalinity	123.0	70.0	100.67
Hardness	364.0	204.0	312.55
TDS	1026.0	700.0	863.00
NO_3-N	0.736	0	0.28
SO_4	75.4	39.8	58.11
CL	392.7	106.7	310.65
Ca	266.7	35.0	109.73
Na	236.0	33.9	133.84
Mg	29.8	12.6	25.48

Table G-3

Summary

Abilene Raw Water Quality
Lake Abilene

Test Performed	Lake Abilene Max.	Min.	Avg.
pH	8.5	8.1	8.28
Alkalinity	180.0	122.0	155.73
Hardness	280.0	176.0	240.55
TDS	576.0	328.0	429.20
NO_3-N	0.731	0.058	0.34
SO_4	91.8	31.6	59.86
CL	113.1	54.0	82.40
Ca	69.2	30.4	45.74
Na	64.6	32.6	46.53
Mg	44.8	15.8	29.50

H. Fact Sheet on Water Rights (Permits and Contracts)

The City of Abilene currently obtains water supplies from a number of sources, including Lake Abilene, Lake Fort Phantom Hill, the Clear Fork of the Brazos River, Deadman Creek and Hubbard Creek Reservoir (owned by the West Central Texas Municipal Water District). In the future, the City plans to obtain water from Stacy Reservoir, which is now being built by the Colorado River Municipal Water District.

Summary of Surface Water Supply for Abilene

1. Abilene currently obtains about 1,000 acre-feet per year from Lake Abilene under Permit 253. This is the dependable yield of the reservoir.

2. Abilene diverts water from the Clear Fork of the Brazos River into Lake Fort Phantom Hill by pumping under Permit 1481C. Abilene also diverts water from Deadman Creek into Lake Fort Phantom Hill by gravity under Permit 1726.

3. Abilene diverts water for municipal supplies from Lake Fort Phantom Hill under Permit 1249A.

4. Even with diversions from the Clear Fork and Deadman Creek, Lake Fort Phantom Hill cannot supply all municipal use for the City of Abilene. When Lake Fort Phantom Hill is low, Abilene decreases diversions from the lake and receives the necessary additional supply of water from the West Central Texas Municipal Water District.

5. In the future, Abilene plans to obtain additional water from Stacy Reservoir, now under construction on the Colorado River.

The water rights and contracts under which Abilene obtains its surface water are discussed below:

Rights Held by Abilene Used for Municipal Water Supply

1. Permit 1481C - Diversions from Clear Fork Brazos River: Permit 1481C allows the City of Abilene to divert up to 30,000 acre-feet per year from the Clear Fork into Lake Fort Phantom Hill for later use for municipal, industrial and domestic purposes. The diversions can be made at a rate of up to 1,006 cfs, and special conditions in the permit limit diversions to times of high flow. The 30,000 acre-feet per year from the Clear Fork are included in and not in addition to the permitted use from Lake Fort Phantom Hill.

2. Permit 253 - Lake Abilene: Permit 253 allows the City of Abilene to impound 11,868 acre-feet of water in Lake Abilene and to use up to 1,675 acre-feet per year for municipal purposes.

3. Permit 1249A - Lake Fort Phantom Hill: Permit 1249A allows the City of Abilene to impound 73,960 acre-feet of water in Lake Fort Phantom Hill and to use up to 20,690 acre-feet per year for municipal purposes and 10,000 acre-feet per year for industrial purposes.

4. Permit 1726 - Diversion from Deadman Creek: Permit 1726 allows the City of Abilene to divert up to 3,000 acre-feet per year from Deadman Creek into Lake Fort Phantom Hill by gravity. The permit also allows Abilene to redivert the water from Lake Fort Phantom Hill for municipal use. The 3,000 acre-feet per year is in addition to Abilene's permitted use from Lake Fort Phantom Hill under Permit 1249A.

Other Water Rights Held by Abilene

1. Permit 1051A - Lake Kirby: Permit 1051A allows the City of Abilene to impound 8,500 acre-feet in Lake Kirby and to use 3,765 acre-feet per year for municipal purposes and 1,120 acre-feet per year for irrigation. The lake is not now used for municipal water supply, but the authorization is maintained as an emergency backup source.

2. Certified Filing 173A - Lakes Cameron and Lytle: Certified Filing 173A allows Abilene to impound 62 acre-feet in Lake Cameron and use it for recreational purposes. The filing also allows Lake Cameron and Lake Lytle (maintained by West Texas Utilities) to be used as emergency standby power plant cooling water.

3. Permit 4266 - Irrigation with Treated Effluent: Permit 4266 allows Abilene to use up to 4,330 acre-feet of treated sewage effluent for irrigation on its own land and the land of others to whom the City sells effluent.

West Central Texas Municipal Water District

The West Central Texas Municipal Water District holds Permit 1890A, which allows it to impound 317,750 acre-feet in Hubbard Creek Reservoir and to divert and use up to 56,000 acre-feet per year (44,800 municipal; 6,000 mining; 2,000 irrigation; 2,000 domestic and livestock; 1,200 industrial). Hubbard Creek Reservoir is used to supply water to Albany, Anson and Breckenridge, as well as to Abilene. Abilene currently has a contract with the West Central Texas MWD to receive up to 15.5 MGD from Hubbard Creek Reservoir in any given day. Upon the completion of a parallel water transmission line from Hubbard Creek Reservoir to Abilene, the City will be entitled to receive up to 31.0 MGD in any given day, with the average diversion limited to 15.5 MGD.

Stacy Reservoir

The Colorado River Municipal Water District holds Permit 3866A, which authorizes it to impound up to 554,340 acre-feet in Stacy Reservoir and to divert and use up to 103,000 acre-feet per year for municipal purposes and 10,000 acre-feet per year for industrial purposes. Abilene is currently paying a portion of the development cost of Stacy Reservoir in order to obtain 15,000 acre-feet per year of the reservoir's municipal supply. The Texas Water Commission has authorized the diversion of this water from the Colorado River Basin to the Brazos River Basin.

I. FACT SHEET ON HISTORICAL CLIMATOLOGICAL DATA

Abilene is located in the very western edge of north central Texas in the low rolling plains. The approximate elevation is 1,750 feet. The normal annual rainfall is 23-inches, with most of the precipitation occurring in the spring, during April, May and June,a and in the fall during September and October. Thunderstorms account for most of the rainfall.

Temperature extremes for Abilene range from 9° in 1947, to 111° in 1943. The mean maximum monthly temperature in July is 94°, while the mean minimum temperature in January is 33°. Average monthly temperature and total monthly precipitation for Abilene from1976 to 1985 is shown in Table I-1.

CLIMATOLOGICAL DATA
Abilene, Texas

Average Temperature
(Total Precipitation)

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Jan	42.4 (0.02)	35.7 (1.22)	34.5 (0.62)	35.6 (0.72)	45.2 (0.77)	44.8 (1.20)	44.8 (1.00)	42.6 (2.28)	39.5 (0.98)	37.2 (0.53)
Feb	56.0 (0.08)	50.9 (0.08)	38.7 (1.26)	44.9 (1.10)	47.9 (0.72)	49.4 (1.06)	44.7 (1.20)	47.0 (0.12)	49.9 (0.46)	44.4 (1.50)
Mar	56.5 (0.25)	56.8 (2.35)	55.0 (0.17)	56.7 (5.16)	54.8 (0.69)	54.9 (2.36)	58.3 (0.43)	54.9 (1.95)	55.3 (0.47)	57.5 (2.86)
Apr	64.8 (3.70)	62.4 (3.11)	70.3 (1.00)	64.2 (1.72)	63.9 (0.17)	68.3 (3.52)	62.9 (0.38)	60.6 (0.54)	63.6 (0.20)	66.7 (0.90)
May	68.2 (1.04)	73.4 (0.44)	76.3 (1.50)	69.8 (1.86)	72.1 (5.00)	71.6 (1.48)	72.1 (6.87)	70.8 (1.42)	75.3 (0.42)	73.8 (4.03)
Jun	78.9 (0.68)	81.3 (1.71)	83.3 (1.24)	79.0 (2.89)	84.4 (1.14)	80.3 (2.73)	78.8 (3.98)	76.7 (3.86)	83.1 (1.70)	77.9 (1.78)
Jul	77.7 (4.27)	83.8 (1.82)	89.0 (0.72)	83.7 (1.55)	89.4 (0.24)	85.8 (1.69)	84.1 (1.50)	82.8 (2.57)	83.7 (0.97)	81.6 (1.71)
Aug	81.6 (1.47)	83.4 (2.54)	82.3 (6.70)	82.2 (1.55)	86.1 (1.62)	83.3 (0.63)	85.6 (1.12)	85.2 (0.10)	83.1 (3.24)	84.9 (3.66)
Sep	7.35 (3.97)	82.6 (0.09)	77.3 (2.36)	77.7 (0.01)	77.7 (6.30)	78.0 (1.74)	77.6 (1.09)	77.9 (0.87)	73.1 (3.55)	75.7 (1.28)

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Oct	56.9 (6.24)	66.9 (2.15)	66.9 (1.49)	71.6 (0.53)	64.9 (0.71)	66.2 (10.68)	65.9 (0.74)	69.1 (3.25)	63.8 (5.15)	65.7 (2.43)
Nov	45.6 (0.63)	54.6 (0.57)	55.3 (0.94)	50.9 (0.65)	52.6 (1.62)	57.4 (0.43)	54.4 (1.72)	57.0 (1.77)	52.7 (2.11)	54.6 (1.56)
Dec	42.5 (0.18)	48.7 (0.19)	43.3 (0.28)	47.7 (2.62)	49.3 (1.69)	48.8 (0.25)	45.8 (128)	34.2 (0.77)	48.8 (3.08)	41.4 (0.03)
Annual	62.1 (22.53)	65.0 (16.27)	64.4 (18.28)	63.7 (20.36)	65.7 (20.67)	65.7 (27.77)	64.6 (21.31)	63.2 (19.50)	64.3 (22.33)	63.5 (22.27)

J. FACT SHEET ON CITY OF ABILENE WATER CONSERVATION PLAN

History

In 1983, Abilene's water conservation program, consisting mainly of extensive public eduction, was developed and implemented. This was followed in 1984 by the adoption of a Water Conservation Ordinance. The severe weather of 1984 and 1985 required activating mandatory water conservation measures. Some revisions, and a name change to the Drought Contingency Plan became effective in 1985. In 1986 the Drought Contingency Plan was incorporated into the broader scoped Water Management Plan.

Description of Plan

The overall goal of the City of Abilene Water Management Plan is to guide the development, management, conservation and protection of the City's water resources. Two of the specific goals are to reduce the average-day and the peak-day water usage. Reduction of the average-day usage decreases the water supply needs. Reduction of the peak-day rate decreases the water treatment facility needs.

The City's water management plan is broken down into supply management and demand management.

Supply management includes:

1. Improvement of metering ability and accuracy.
2. Systematic program of leak detection and repairs.
3. Management of watersheds feeding water supply sources.
4. Evaporation suppression.

Demand management includes:

1. Price structuring to promote conservation.

2. Issuing enforcement restrictions on water use, such as those in the Drought Contingency Plan and strict plumbing code requirements.

3. Education and demonstration programs emphasizing conservation such as:

    - Public Information and Education Programs
    - Xeriscape. Low Water Demand Landscaping Workshops.
    - Residential Water Conservation Retrofit Program.
    - City Building Retrofit Program.
    - Commercial/Industrial Water Conservation and Workshop.

A Water Conservation Advisory Committee and a Xeriscape Advisory Committee have been formed and serve to promote the goals and objectives of the Waste Management Plan.

Program Effectiveness

A Reduction of annual water usage starting in 1983 is evident from reviewing the historical flow records. Figure J.1 demonstrates this graphically. Although much of the decrease in 1985 can be attributed to the weather and the loss of some industries, it does appear that the water conservation measures have produced the desired result. The ratio of peak-day/average-day since 1982 has consistently been less than 1.89. Prior to 1982 the historical data would have suggested a higher ratio.

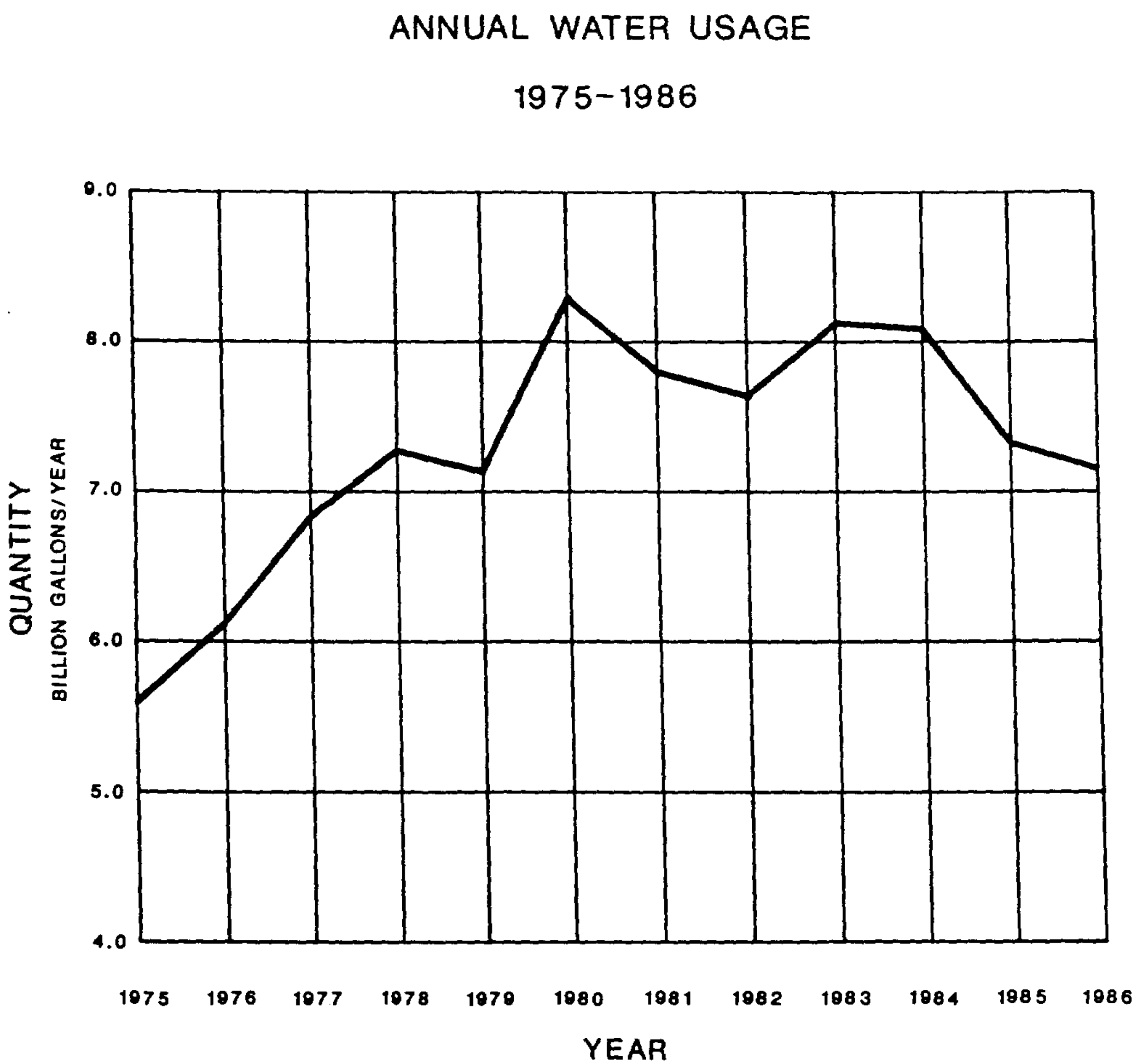

ANNUAL WATER USAGE
1975-1986
QUANTITY
BILLION GALLONS/YEAR
9.0
8.0
7.0
6.0
5.0
4.0
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
YEAR

FIGURE J.1

K. FACT SHEET ON SIMILAR RECLAMATION PROJECT'S DESIGN CRITERIA AND TREATMENT LEVELS

Design criteria and treatment levels was reviewed for the following projects:

- Upper Occoquan Water Supply System
- Denver Water Re-Use Project
- El Paso Water Reclamation Project
- Tampa Reuse Project
- Water Factory 21, So. California

Design Criteria and treatment levels differed between these projects, but generally the following items were addressed:

- Need for redundancy in process treatments and design.

- High level of treatment for
  - Nutrients
  - Metals
  - Biological organisms

- Independent review of operations and water quality data.

- Extensive monitoring program of the facility and receiving waters.

The most complete policy was by Upper Occoquan Water Supply District. A copy is attached for information purposes.

" Current Revised Policy "

Commonwealth of Virginia
STATE WATER CONTROL BOARD

Policy for Waste Treatment and Water Quality Management in the Occoquan Watershed

Adopted: July 26, 1971 in Minute 10.

Effective: August 29, 1971.

Revised: December 12, 1980 in Minute 20.

Effective: March 4, 1981.

SUBPART A. INTRODUCTION

I. Purpose and Authority

To provide a policy for interim and long-term solutions to the Occoquan Watershed's pollution problems. The policy was adopted pursuant to authority vested in the Board by Section 62.1-44.15 of the State Water Control Law, Code of Virginia 1950, as amended.

II. Water Quality Standard

This "Occoquan Policy" also constitutes Special Standard "g" in the Board's Water Quality Standards for Sections 7, 7a, 7b, 7c, and 7d of the Potomac River Basin's Potomac River Subbasin, which sections are delineated geographically in the "Basin and Section Description" portion of the Water Quality Standards publication. In addition, the text of this policy is referred to under subparagraph 5.01 g., entitled "Occoquan Watershed Policy," of the Water Quality Standards.

III. Background

During the 1960s there was a great deal of concern generated about the large amount of treated sewage effluent being discharged in the Occoquan Watershed, since the receiving streams feed the Occoquan Reservoir, a drinking water supply for over 600,000 people in Northern Virginia.

In response to this, the State Water Control Board commissioned the firm of Metcalf & Eddy to study the problems of the Occoquan Reservoir and to recommend a course of action to preserve the Occoquan as a valuable water resource for future generations.

The results of the Metcalf & Eddy study stated that point source pollution was the primary cause of water quality degradation in the Occoquan Watershed and that a high degree of waste treatment would be necessary to prolong the life of the drinking water supply.

In 1971 the State Water Control Board adopted a *Policy for Waste Treatment and Water Quality Management in the Occoquan Watershed* (the Occoquan Policy) which outlined a course of action to control point source pollution in the watershed.

The Occoquan Policy provided for the construction of regional high-performance treatment facilities in the watershed and a monitoring program to obtain water quality data both before and after construction of any of the high-performance plants.

The Occoquan Watershed Monitoring Program (OWMP or monitoring program) was established in 1972 which gathered an extensive amount of information and found that water quality problems in the Occoquan Watershed were related directly to point source pollution and to non-point source pollution.

In 1978, a regional high-performance treatment facility (the Upper Occoquan Sewage Authority—UOSA) was placed in operation. This facility eliminated eleven major point sources of pollution in the watershed.

Shortly after UOSA began operations, costs and charges for sewage treatment in systems tributary to UOSA increased rather sharply. To date a significant part of those high costs have been associated with large amounts of infiltration and inflow being sent by the user jurisdictions to the regional facility for treatment.

In an attempt to control non-point source pollution the Commonwealth of Virginia adopted an erosion and sediment control law in 1973. In accordance with this law all of the watershed jurisdictions have adopted erosion and sediment control ordinances. In addition, a number of best management practices (BMP) handbooks were written and published in 1979 by the Board. In mid-1980 Fairfax County adopted a BMP ordinance.

In 1978, the Water Control Board contracted the firm of Camp Dresser & McKee (CDM) to reevaluate certain aspects of the Occoquan Policy. Their report was presented to the Board and to the local communities in 1980 and recommended that few changes be made to the policy.

As a result of the CDM report, input from the local communities and the Board's staff, an updated version of the Occoquan Policy was drafted.

IV. References

1. *A Comprehensive Pollution Abatement Progam for the Occoquan Watershed,* Metcalf & Eddy Engineers, March 18, 1970.

2. Record of Public Hearing on March 31, 1971, concerning State Water Control Board's Occoquan Policy.

3. *Occoquan Policy Reevaluation, Phase III Report,* Camp Dresser & McKee, June 1980.

4. Record of Public Hearing on November 20, 1980, concerning amendments to the Occoquan Policy.

SUBPART B. LONG-RANGE POLICY

I. Number and General Location of Regional Treatment Plants

A. The number of high-performance regional plants which shall be permitted in this watershed is not more than three, but preferably two, generally located as follows:

1. One plant in the Fauquier County/Warrenton area.

2. One plant in the Manassas area to serve the surrounding area in Prince William, Fairfax, and Loudoun Counties.

3. All point source discharges will preferably be located at least 20 stream miles above the Fairfax County Water Authority's raw water intake. In no case shall a plant be located less than 15 miles above the raw water intake.

B. This shall not limit the consideration of land disposal systems for waste treatment in the watershed, provided such systems shall have no point source discharge to State waters and shall have the approval of the State Water Control Board.

II. Regional Plant Capacity Allocations for the Occoquan Basin

A. The initial allotment of plant capacity for the Upper Occoquan Sewage Authority treatment facility shall be approximately 10 MGD, based on all effluent being from high-performance plants meeting the requirements of Sections IV, V, and VI below and all those treatment facilities belonging to the City of Manassas, the City of Manassas Park, the Greater Manassas Sanitary District, and Sanitary District 12 of Fairfax County being abandoned.

B. Incremental increases in the regional plant capacity may be approved by the State Water Control Board (Board) based on the results of a monitoring program which shows that current and projected discharges from the high-performance plants do not create a water quality or public health problem in the reservoir. Such incremental increases shall not exceed 7.5 MGD at any one time. The Board advises that since severe infiltration/inflow stresses the performance reliability of the regional treatment plant(s), jurisdictions must pursue I/I correction within their individual systems.

III. Prerequisites for Preliminary Plant Approval

Prerequisites before the State Water Control Board gives approval to preliminary plans for a regional high-performance plant are:

1. A monitoring program for the receiving waters shall be in effect.

2. The Authority who is to operate the proposed plant shall enter into a written and signed agreement with the Board that the Authority shall meet the administrative requirements of Section VI. of this subpart.

Shortly after UOSA began operations, costs and charges for sewage treatment in systems tributary to UOSA increased rather sharply. To date a significant part of those high costs have been associated with large amounts of infiltration and inflow being sent by the user jurisdictions to the regional facility for treatment.

In an attempt to control non-point source pollution the Commonwealth of Virginia adopted an erosion and sediment control law in 1973. In accordance with this law all of the watershed jurisdictions have adopted erosion and sediment control ordinances. In addition, a number of best management practices (BMP) handbooks were written and published in 1979 by the Board. In mid-1980 Fairfax County adopted a BMP ordinance.

In 1978, the Water Control Board contracted the firm of Camp Dresser & McKee (CDM) to reevaluate certain aspects of the Occoquan Policy. Their report was presented to the Board and to the local communities in 1980 and recommended that few changes be made to the policy.

As a result of the CDM report, input from the local communities and the Board's staff, an updated version of the Occoquan Policy was drafted.

IV. References

1. *A Comprehensive Pollution Abatement Progam for the Occoquan Watershed,* Metcalf & Eddy Engineers, March 18, 1970.

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3. *Occoquan Policy Reevaluation, Phase III Report,* Camp Dresser & McKee, June 1980.

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SUBPART B. LONG-RANGE POLICY

I. Number and General Location of Regional Treatment Plants

A. The number of high-performance regional plants which shall be permitted in this watershed is not more than three, but preferably two, generally located as follows:

1. One plant in the Fauquier County/Warrenton area.

2. One plant in the Manassas area to serve the surrounding area in Prince William, Fairfax, and Loudoun Counties.

3. All point source discharges will preferably be located at least 20 stream miles above the Fairfax County Water Authority's raw water intake. In no case shall a plant be located less than 15 miles above the raw water intake.

B. This shall not limit the consideration of land disposal systems for waste treatment in the watershed, provided such systems shall have no point source discharge to State waters and shall have the approval of the State Water Control Board.

II. Regional Plant Capacity Allocations for the Occoquan Basin

A. The initial allotment of plant capacity for the Upper Occoquan Sewage Authority treatment facility shall be approximately 10 MGD, based on all effluent being from high-performance plants meeting the requirements of Sections IV, V, and VI below and all those treatment facilities belonging to the City of Manassas, the City of Manassas Park, the Greater Manassas Sanitary District, and Sanitary District 12 of Fairfax County being abandoned.

B. Incremental increases in the regional plant capacity may be approved by the State Water Control Board (Board) based on the results of a monitoring program which shows that current and projected discharges from the high-performance plants do not create a water quality or public health problem in the reservoir. Such incremental increases shall not exceed 7.5 MGD at any one time. The Board advises that since severe infiltration/inflow stresses the performance reliability of the regional treatment plant(s), jurisdictions must pursue I/I correction within their individual systems.

III. Prerequisites for Preliminary Plant Approval

Prerequisites before the State Water Control Board gives approval to preliminary plans for a regional high-performance plant are:

1. A monitoring program for the receiving waters shall be in effect.

2. The Authority who is to operate the proposed plant shall enter into a written and signed agreement with the Board that the Authority shall meet the administrative requirements of Section VI. of this subpart.

IV. Design Concept for High-Performance Plants on the Occoquan

A. Plant design requirements are:

1. The design of the high-performance sewage treatment plants discharging to the Occoquan Watershed shall meet all the requirements specified herein as well as those specified in the most recent edition of the Commonwealth of Virginia Sewerage Regulations.

2. The basic sewage plant design concept for the regional plants discharging to the Occoquan Watershed shall be based on the Upper Occoquan Sewage Authority Wastewater Reclamation Facility.

B. Changes in plant design requirements will be made according to these criteria:

1. Changes to the plant design described herein shall only be acceptable if the change does all of the following:

a. Improves or equals the plant performance and final effluent quality.

b. Increases or equals plant reliability and maintainability.

c. Has a demonstrated performance in a plant of at least 5 to 10 MGD size for an operating period of not less than one, but preferably two years.

2. Before such changes are incorporated in the plant, specific written approval shall be obtained from the Board.

3. Changes to the plant design solely to reduce cost and which jeopardize plant performance and reliability will not be approved.

V. Plant Performance Requirements

A. The plant performance requirements for high-performance plants discharging to the Occoquan Watershed are given in Table I.

B. The regional sewage authority must accumulate at least two seasons of operational data regarding the process reliability and effectiveness of the nitrogen removal facilities. In the case of the existing regional Sewage Authority (UOSA), those two seasons of data may be accumulated in two stages. The first stage may be gathered during the shakedown period of the nitrogen removal facilities (at or near the 10.9 MGD flow) while the second stage may be gathered at or near the 15 MGD flow.

C. Full-time operation of the nitrogen removal facilities is to be dependent upon the ability of the Occoquan Reservoir to maintain an ambient nitrate concentration of 5.0 mg/l as N or less in the vicinity of the Fairfax County Water Authority intake point. It is recommended that the Fairfax County Water Authority and the owner of the regional Sewage Authority enter into an agreement whereby both parties can be kept informed as to the need for operation of the nitrogen removal facilities.

TABLE I

MINIMUM EFFLUENT QUALITY REQUIREMENTS* FOR ANY REGIONAL SEWAGE TREATMENT PLANT IN THE OCCOQUAN WATERSHED

	COD Mg/l	Suspended Solids Mg/l	Nitrogen Mg/l	Phosphorus Mg/l	MBAS Mg/l	Turbidity JTU	Coliform Per 100 ML Sample
Final Effluent Requirements	10.0	1.0	1**	0.1	0.1	0.5***	Less than 2
Typical Percent Removals *(These are for information only: not requirements)*	98%	99.5%	97%	99.5%	99%	100%	100%

*As measured on a weekly average unless otherwise noted. Since these are minimum requirements, the normal average would be expected to be substantially better.

**Total nitrogen during operation of nitrogen removal by ion exchange; unoxidated nitrogen (as TKN) at all other times. Refer to Subpart B, Section V for further information.

***Measured immediately prior to chlorination.

VI. Administrative and Technical Requirements for the Control of the Sewer System Tributary to a Regional, High-Performance Plant in the Occoquan Watershed

A. The owner to whom the permit is issued for operation of a regional plant shall meet the general and administrative requirements covered below. These requirements shall also be contractually passed on by the owner to any parties and/or jurisdictions with which the owner may contract for the processing of waste water.

These requirements are not applicable to the existing small, independent discharges in the watershed.

B. The high-performance regional treatment plant shall be manned by an appropriate number of trained and qualified operating, maintenance and laboratory personnel and manned continuously 24 hours a day, 7 days a week throughout the year.

C. The owner shall include, as part of his preliminary and final plans and specifications which are submitted to the State Water Control Board for approval, a detailed statement indicating how each of the technical and administrative requirements in this policy has been met. Any proposed deviation from any of these requirements shall be clearly identified and technically justified, and shall require formal State Water Control Board approval. These submittals shall also include:

1. Simplified fluid system diagrams which clearly identify the following:

a. The average and peak capacity of each unit.

b. The number of units of each type needed to handle the normal average flow and the peak of flow.

c. The number of spare units and their capacity for both average and peak flow cases shall also be identified.

In addition, a brief narrative summary description shall be submitted to identify what has been done to ensure that each unit and major subsystem can be maintained and expanded without release of effluent that does not meet the minimum standards.

2. A simple one-line power distribution system diagram showing how outside power is brought into the plant and how power is distributed within the plant proper shall be submitted. This diagram shall also show as a minimum:

a. Ratings and characteristics of electrical components such as transformers, circuit breakers, motor controllers, etc. making up the system.

b. Protective devices such as thermal overloads, under frequency, or under voltage relays.

c. Voltages supplied by all buses.

d. Normal circuit breaker and switch conditions. (Notes shall also be provided as required to cover abnormal, casualty, and emergency operating modes.)

e. How electrical loads are combined into switch gear and load center. (The use of cubicle outlines in phantom or dotted line is suggested.)

D. The final submittal of plans and specifications for the plant to the State Water Control Board shall include a systematic failure mode and effects analysis on the mechanical and electrical portions of the plant so as to demonstrate that a single failure of a mechanical or electrical component will not interrupt the plant operations which are necessary to meet the effluent requirements of Table I of this policy.

E. Pumping stations on the collection systems which are located in the Occoquan Watershed and are tributary to a regional treatment works shall:

1. Have stand-by pumping units.
2. Have at least one "on-site" backup power supply.
3. Have at least one "off-site" power supply.
4. Be designed so that no single failure of a mechanical or electrical component could degrade pumping capability.
5. Have pumps and valves arranged so that these units can be removed and replaced without the by-passing of sewage.
6. Have flow measure devices with provisions for recording flow.
7. Have retention basins of a minimum one-day capacity.

If these pumping stations are remote and unmanned, an alarm system shall be provided at manned stations to indicate that problems are developing and to direct maintenance assistance to the affected pumping station. The owner of each pumping station shall be required to obtain a State Water Control Board certificate.

A waiver may be sought from requirement 7. above, particularly in new collection systems exhibiting no I/I problems. However, the jurisdiction requesting such a waiver must submit documentation to the Water Control Board for review that the sewer system tributary to the pump station meets the criteria established by the Virginia Sewerage Regulations for infiltration/inflow and any other such information that the Board may require.

F. The major junctions in the collection system (e.g., at least at the 1 to 2 MGD collection points) shall have continuous recording flow measuring devices to help in the early identification of problem portions of a collection system in the event of unexplainable high flows (e.g., excessive infiltration). Also, such flow measuring devices and isolation valves shall be provided between jurisdictions as well as any others who contract for services of the regional plant. The flow measuring devices and isolation valves between jurisdictions shall be under the control and responsibility of the owner to whom a plant certificate is issued.

G. Each regional sewage treatment plant shall have a pretreatment program approved by the Board.

H. Waste being processed in any existing small plants shall have the first priority on treatment capacity and such capacity shall be specifically reserved for them in the new high-performance regional plants. New developments are to have second priority.

I. If any of the various administrative procedures of the owner or of jurisdictions served by the plant prove ineffective under actual operating conditions, the State Water Control Board shall have the right to place new requirements on the owner and jurisdictions and to require any necessary action by these parties to physically correct the damage done to the reservoir due to ineffective implementation of the administrative requirements covered herein.

J. The owner's interceptor and collection systems of the jursidictions in the Occoquan Watershed shall be designed, installed, inspected, and tested by the respective owner to limit infiltration to 100 gal/inch-dia/mile/day as a maximum. The test results shall be certified and submitted to the Board.

K. Whenever the owner enters into an agreement with a jurisdiction for services of a regional plant, the owner shall be responsible for seeing that such jurisdictions have ordinances and rules to meet all the applicable requirements covered by this policy. These ordinances and rules shall meet the owner's approval and the owner shall monitor and spot-check to see that the jurisdictions are effectively implementing their ordinances and rules to meet the requirements covered herein. The Board, at its discretion, can request the owner to submit to the Board for its approval the ordinances and rules that will be used to meet the Board's requirements covered herein.

Further, anytime a user violates any of the administrative or technical requirements of the contract between the user and the owner which can affect the plant operations, hydraulic loading, or effluent quality or which affect the reservoir's water quality due to urban run-off (e.g. siltation), the owner shall not allow the user to discharge additional waste water to the owner's plant until the problem has been resolved to the owner's satisfaction.

L. Up-to-date as-built drawings and manuals shall be available at least once a year for State Water Control Board inspection and review. These documents shall include as a minimum:

1. Up-to-date as-built electrical and fluid system diagrams.
2. Detailed as-built and installed drawings.
3. Normal operating and casualty procedures manual.

The documents shall be updated at least once a year to reflect all changes and modifications to the plant.

M. The design engineer shall have the responsibility of meeting the proposed effluent quality as shown in Table I. To demonstrate that the plant as designed by the engineer can meet the effluent standards, the plant is to be operated under the supervision of the design engineer for a minimum of one year of continuous operation after the "debugging" period.

SUBPART C. EXPANSION OF EXISTING PLANTS IN THE OCCOQUAN WATERSHED

I. One of the objectives of the Occoquan Policy is to reduce water quality problems in the Occoquan Watershed due to pollution from point sources. To date the means of accomplishing this objective have been the construction and utilization of a high-performance regional plant—the Upper Occoquan Sewage Authority (UOSA)—and the elimination of eleven low-performance treatment plants in favor of the UOSA facility. The eleven low-performance treatment plants constituted the major point sources of pollution in the Occoquan Watershed; however, there are a number of smaller sewage treatment facilities which are still discharging. These facilities were not connected to the regional facility for at least one of the following reasons: (a) a collector system to the regional plant was not constructed in close enough proximity to provide service, and/or (b) the small facility was outside of the service area for the regional plant. At some point in the future, these remaining plants may wish to expand and increase their flows.

II. Existing waste treatment facilities may be expanded to receive increased sewage flows; however, the degree of treatment must also be upgraded so that there will be no increase in the quantity of pollutant loadings to the receiving stream. A no-discharge land-application system may be considered in lieu of upgrading a facility.

III. Plants exceeding approved design performance levels will not be allowed additional capacity until the owner has installed additional treatment and demonstrated by means of a minimum of three months of performance data that the plant has been brought to within approved design performance levels and can accept additional waste loads without exceeding such approved design performance levels.

IV. No expansion shall be approved until the owner gives a written agreement to the State Water Control Board stating that the facility will connect to a regional facility when the appropriate conveyance facilities become available.

V. Proposed interim expansion of plants shall be reviewed with the appropriate regional Sewage Authority and its concurrence obtained to assure that such expansions are coordinated with the Authority regional plans and can be readily incorporated into the regional system. The appropriate regional Sewage Authority concurrence shall be obtained before the State Water Control Board approval is given.

VI. The plans and specifications for expansion of collection and interceptor systems shall be reviewed with the appropriate regional Sewage Authority and its concurrence obtained before they are submitted to Board and State Department of Health for approval. Any proposed expansion of collection and interceptor systems shall meet the technical and administrative requirements of Subpart B., Section VI., and the jurisdiction proposing such an expansion shall submit a formal letter to the Board stating that its expansion will meet the requirements of Section VI.

SUBPART D. OCCOQUAN WATERSHED MONITORING PROGRAM (OWMP)

Due to the critical nature of the receiving waters, intensive monitoring will be required to ensure that plants achieve desired performance levels at all times, and the effects of point sources and non-point sources on the receiving waters are measured and projected.

I. Watershed Monitoring Subcommittee

A. In order to ensure that performance levels are maintained and that the effects of point sources and non-point sources on receiving waters are known, a Watershed Monitoring Subcommittee shall be established and shall be convened at least twice each calendar year. A Subcommittee of this type must necessarily be composed of high-caliber personnel knowledgeable in the field of water and waste water treatment and management. Accordingly, the Subcommittee shall consist of three ex-officio members or their designated representatives as follows:

1. Executive Secretary, State Water Control Board.
2. Director of State Department of Health's Division of Water Programs.
3. Director of Virginia Soil and Water Conservation Commission.

and three other members or their designated representatives as follows:

4. A representative of the Environmental Protection Agency.
5. A representative of a State university in Virginia.
6. A nationally recognized consultant in the water and waste water treatment field.

B. The ex-officio members shall select and submit to the State Water Control Board for approval the names of the other members of the Subcommittee. The Subcommittee shall elect a Chairman and such chairmanship shall be rotated on a biennial basis.

C. From time to time the Subcommittee may seek additional expert advice.

II. Monitoring Subcommittee's Responsibilities

The Watershed Monitoring Subcommittee shall have the following responsibilities:

1. To ensure that there is adequate monitoring of the regional plant effluent and process control testing at the regional plant.

2. To develop a water quality monitoring program for the Occoquan Reservoir and its tributary streams to ensure that there is a continuous record of water quality available. To further ensure that projections are made to determine the effect of additional waste loading from point sources as well as non-point sources.

3. To ensure that the stream monitoring program is separate and distinct from plant process control testing and effluent monitoring.

4. To review data collected from the monitoring program and submit to the Board and the various jurisdictions reports on the status of plant performance and water quality in the watershed every six months. All reports by Occoquan Watershed Monitoring Program (OWMP) or Occoquan Watershed Monitoring Laboratory (OWML) personnel concerning evaluation of Occoquan monitoring data must be approved by the Occoquan Watershed Subcommittee prior to release or publication.

5. To report to the Board immediately significant changes in plant performance or water quality due either to point source or non-point source pollution.

6. To maintain close liaison with the Fairfax County Water Authority in order to ensure satisfactory raw water which can be adequately treated at the Authority's facilities.

7. To establish the Occoquan Watershed Monitoring Laboratory (OWML) to conduct sampling and analyses to fulfill the above responsibilities.

III. Provision for Restructuring of the OWMP

A. The Occoquan Watershed Monitoring Program (OWMP) and the Occoquan Watershed Monitoring Laboratory (OWML) were established in accordance with the above provisions. This was done on July 1, 1972. Since that time a large body of information regarding the functioning of the Occoquan Reservoir system has been accumulated. Major point sources have been consolidated into and eliminated by a high-performance sewage treatment facility (UOSA). As growth increases in the watershed, this trend is expected to continue.

B. The work performed by OWML has indicated that the key to water quality is a two-part issue. Those parts are point source pollution and non-point source pollution. Point source discharges in the watershed are currently regulated by the Board's NPDES Permit program. Non-point sources of pollution are currently being addressed by State and local voluntary and mandatory control programs. However, in the future it may be necessary that additional mandatory programs be adopted.

C. Recently, several jurisdictions have expressed concern about the continuance of the OWMP in regard to monitoring non-point source pollution. Therefore the Subcommittee should re-evaluate its program direction and means of funding to more adequately reflect the concerns and needs of its supporting jurisdictions, specifically to direct more attention to the effects of non-point source pollution on the Occoquan Reservoir. A program restructuring shall take place to account for shifts in monitoring trends and funding by December 31, 1982, or the regional Sewage Authority must assume the monitoring program.

IV. Financing the OWMP

A. It is recommended that the cost of the OWMP be split equally between water supply and sewage uses. This would mean that the Fairfax County Water Authority would have to fund half of the OWMP budget while the counties of Fairfax, Prince William, Loudoun, and Fauquier and the cities of Manassas and Manassas Park would be responsible for jointly funding the other half. That portion of the OWMP budget funded by the counties and cities would be divided so that each jurisdiction would be charged in proportion to its allotted sewage capacity in the Occoquan Watershed. The budget shall be reviewed by the jurisdictions prior to approval by the Subcommittee.

B. Written agreements shall be obtained from each of the jurisdictions which shall commit them to supply the above funds yearly to finance the OWMP. This monitoring program is for their protection and benefit. If for some reason a county or city does not wish to retain its sewage allotment in the Occoquan Watershed and/or will not fund the monitoring program, then its allotment can be divided up among the remaining participating jurisdictions, with their portion of the cost of the monitoring program rising accordingly.

C. If Federal funds and assistance can be obtained, the cost to the counties and the Fairfax County Water Authority will be reduced proportionally. The funding of the program without Federal funds is to be assumed, so as not to further delay or complicate the initiation of this program.

D. The State Water Control Board staff coordinator will be responsible for controlling the funding of the OWMP.

L. FACT SHEET ON PUBLIC HEALTH IMPACTS ASSOCIATED WITH WASTEWATER REUSE

Attached is an overview of public health issues related to public confidence, disease risk, control strategies and the overall reliability of reclamation project prepared by John M. Gaston. Since this subject is so large, no attempt will be made to represent all the data.

Introduction

In developing and promoting a successful wastewater reclamation program, a variety of issues must be considered by both regulatory and developmental agencies. Central to this program are the public health issues that relate to public confidence, disease risk, control strategies, and the overall reliability of the reclamation project. These issues, if properly addressed, will increase the chances for a successful reclamation project. This analysis will examine the public health risks extant in wastewater reclamation projects and the mitigating steps that may be employed to reduce those risks. For the purposes of this exercise, reclaimed wastewater is defined as treated sewage from domestic, commercial, and industrial sources. This reclaimed water, as a result of appropriate treatment, is suitable for a direct beneficial use or a controlled use that would not otherwise occur.

Risk Identification

What Kind of Risks?

If we assume that the public health risks that may occur because of the use of reclaimed wastewater will be directly related to the quality of that wastewater, we may then identify those risks from exposure. Dismissing, for the purposes of this discussion, the risks associated with the ingestion (direct) of treated wastewater, we may assume that whatever risks are present come about as a result of contact with the treated wastewater or secondary contact with associated items. This contact may result in some form of disease transmission. Various investigators (Clark, 1981), (Majeti, 1981), (Cooper, 1981), have identified specific diseases that may be transmitted by untreated (or inadequately treated) wastewater. These include (in no special order):

- Infectious hepatitis
- Typhoid
- Other *Salmonella*
- Parasitical: *E. Hystolytics*
- *Shigella*
- Enteric virus related diseases
- Skin rash, infection
- Eye inflammation
- Respiratory infections
- Earache or infection

Organisms associated with these diseases do occur in wastewater and the possibility of disease transmission is real.

What Factors Influence the Risk?

Assuming that the entire population is not going to be completely and constantly exposed to raw untreated wastewater, we may attempt to identify those exposure and disease risk factors that will influence the population at risk. This listing, and similar factors, have been tested in public involvement surveys (Bruvold, 1976 and 1981).

- Duration of Exposure: The risk from contact with reclaimed wastewater would, we assume, be directly related to the time and duration of exposure. A single, casual contact should have far less risk than an ongoing daily exposure. In a survey of waste treatment plant workers (Clark, 1981) no specific relationship was established, but the following two points were noted:

  1. "Gastrointestinal illness rates were higher in the inexperienced wastewater exposed workers than in the experienced workers and controls."

  2. "Antibody titers to coxsackievirus B5 were significantly higher for one subgroup of wastewater workers, the spray irrigation nozzle cleaners, when compared to either other wastewater workers or to the road commission workers. This suggests that there may be a risk of viral infection only in those with the greatest and more direct exposure to wastewater."

  These two points would suggest that the disease risk would be highest in that portion of the population with frequent and direct exposure.

- Method of Exposure: Because of the information on duration of exposure, we may also assume that there may be difference in disease risk as it relates to the method of exposure. At one end of the scale would be complete submersion in wastewater. The opposite case would be no exposure or perhaps walking in an irrigated field and the resultant secondary contact with the damp soil. Aerosol exposure from spray may also carry disease organism and the hazard of respiratory infection.

  From these two factors we may draw the following assumptions:

  High Risk | Low Risk

- Method: Complete Submersion>Aerosol Contact>Secondary Exposure

- Duration: Constant Exposure>Worker Contact>Casual Exposure.

- Population at Risk: Certain portions of the population may be more at risk than average. If children or high risk groups are exposed to disease organisms, the chances of infection are greater than if a healthy adult is exposed. This factor may be a consideration in selection of potential reclamation sites and in determining the degree of treatment necessary for specific projects. If the entire population is to be exposed (park irrigation in an urban area) the treatment requirements will be higher than if only a specific portion of the population is at risk (golf course).

- Degree of Treatment: The degree of treatment provided relates directly to the disease risk from microbiological agents. Some State agencies have established specific criteria for treatment as it relates to use (Ongerth, 1982). The summery in Table 1 shows the criteria as established by the State of California.

These requirements also relate specifically to the cost of reclaimed water and the overall economic analysis of the project. Currently, one of the most controversial requirements in these criteria relates to the need for "filtered effluent" when irrigating parks, playgrounds, and school yards. This requirement has also been extended to include golf courses with homes built in and around the landscape area. In this case the different requirement relates to irrigation of yards at the home versus golf courses that only provide for golfers and not homes.

Risk Mitigation

The following factors should be considered when analyzing wastewater reclamation projects. Tradeoffs between the various factors may be possible depending upon the population at risk, the proposed use and treatment provided.

Treatment Reliability: The size and sophistication of the reclamation plant is a factor in the uses for the product water. These reliability features include:

- Optional sources for use when treatment upsets occur.

- Online or realtime monitoring of the treated water quality.

Table L-1

Description of Minimum Required Wastewater Characteristics

Use of Reclaimed Wastewater	Primary[b]	Secondary and Disinfected	Coagulated, Filtered[c] and Disinfected	Coliform MPN/100 ml Median (daily sampling)
Irrigation				
Fodder crops	X			No requirement
Fiber	X			No requirement
Seed crops	X			No requirement
Produce eaten raw, surface irrigated		X		2.2
Produce eaten raw, spray irrigated			X	2.2
Processed produce, surface irrigated	X			No requirement
Processed produce, spray irrigated		X		23
Landscapes: golf course, cemeteries, freeways		X		23
Landscapes: parks, play-grounds, schoolyards			X	2.2
Recreational impound-ments				
No public contact		X		23
Boating & fishing only		X		2.2
Body-contact (bathing)			X	2.2

[a] Wastewater Reclamation Criteria, Calif. Adm. Code, Title 22, Div. 4, Environmental Health, 1978.

[b] Effluent not containing more than 0.5 ml/liter/hr settleable solids.

[c] Effluent not containing more than 2 Turbidity Units.

- Flexibility of treatment design to permit operation under upset conditions.

- Alarm features to indicate loss of power, process failure or plant shutdown.

- Standby power supply, multiple treatment units, emergency storage or disposal options, or other reliability features.

Exposure and Access Control: A reduced degree of treatment may be acceptable if the exposure and access to the reclaimed wastewater is closely controlled. An example of this requirement might be the primary effluent irrigation of cotton. Under normal circumstances this use would not require close supervision or access control. The irrigation would proceed with primary effluent (undisinfected), and the access conditions would be governed by soil moisture, and the date of harvest. If, however, the cotton field were directly adjacent to homes, the irrigation with undisinfected primary effluent may not be acceptable because of the following factors:

- Ready access to children, and the disease risk from damp soil, and irrigation water that exists from undisinfected primary effluent.

- Aesthetic considerations relative to odors and vectors that would impact the adjacent houses.

In this case unless the access could be closely controlled (fencing, etc.), and the aesthetic concerns addressed, this would not be an acceptable use for the reclaimed primary effluent.

Environmental Concerns and Public Involvement: Public education programs are essential in developing a healthy climate for reclamation programs. An extensive study of ten project areas (Bruvold, 1981) showed that three conditions must be met in order to ensure public support: (1) safeguard public health (2) protect the environment, and (3) conserve water. Some projects may meet one requirement, but fail to meet others and thus be rejected by the public. In a specific example, oxidation pond effluent was used in California to supplement source waters for rice fields (ponds). Initial reaction was that this was an appropriate use for the reclaimed wastewater for the following reasons:

1. Public access was limited or non-existent,

2. The rice is a processed food crop and secondary disease transmission is not a problem, and

3. The rice field discharge location is not in a sensitive area.

Following startup of the project an unexpected problem occurred and caused all the rice irrigation projects to be cancelled. Because of the nutrient content in the oxidation pond effluent extensive algae growth occurred in the rice fields, and because of the presence of the rice stalks, the standard mosquito control measures were not effective. This resulted in massive breeding of *Culex tarsalis* mosquitoes and the increased threat of encephalitis. The additional treatment required for nutrient removal made the project too costly and removed rice fields from the cost effective category of reclaimed wastewater.

Specific Project Analysis

Individual wastewater reclamation projects may be analyzed to assess the public health risk on a case-by-case basis.

The highest risk factors include:

- Sensitive population at risk---children, etc.
- Extensive and frequent exposure to the reclaimed wastewater.
- Little or no waste treatment to reduce disease organisms.
- Multiple modes of contact---direct, spray, secondary (food contamination).
- No reliability features to reduce adverse impacts from treatment failures, etc.

Conversely, the lowest risk factors include:

- Closely controlled access to the reclamation reuse area.
- Limited exposure and duration.
- Limited population at risk.
- Advanced waste treatment to eliminate or limit disease organisms.
- Alternate disposal and treatment units.

The balance between the two positions may be obtained for specific projects with tradeoffs established to ensure public health protection. For instance, it may be possible to control exposure and access to a reuse area if treatment is not sufficient to protect the public, or additional treatment may make up for unlimited access. In either case public support is essential and the project must be cost effective. If treatment and access (exposure) requirements make the project more expensive than "other" water costs, the project will operate at a loss and will be in jeopardy from a financial standpoint.

Direct Potable Reuse

Several projects have been proposed to provide reclaimed wastewater for potable reuse. Some are in existence for indirect reuse utilizing groundwater recharge and as a supplement to surface water sources (Beresford, 1983), but direct reuse projects have not progressed beyond the planning stage. State and Federal regulations have not been developed for these uses and it is unlikely that criteria will be developed in the near future. Generally, this also corresponds with the risks that the public are willing to accept.

In consumer attitude surveys (Bruvold, 1976), the majority of the public are unwilling to accept reclaimed wastewater for drinking, commercial food preparation, home food preparation, or home/commercial canning. The acceptability of other uses, not involving ingestion, varies with greater acceptance of lesser contact uses. This would seem to correspond with the comments of R. Handler (1979):

> "It has become a function of government to determine whether a given technological benefit is worth the attendant risk where such exists; it also assesses whether the cost of mitigating or eliminating such risk are justified by the latter's nature and magnitude. A sensible guide would surely be to reduce exposure to hazard wherever possible, to accept substantial hazard only for great benefit, minor hazard for modest benefit, and no hazard at all when the benefits seems relatively trivial."

ABILENE RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 4

WATER QUALITY ASSESSMENT

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INTRODUCTION

The City of Abilene, Texas is evaluating the feasibility of using treated wastewater effluent to supplement their existing municipal water supply, Lake Fort Phantom Hill. One part of that evaluation is to consider existing water quality of the lake to predict the effects of the introduction of treated effluent on future water quality. This report summarizes the current water quality of Lake Fort Phantom Hill relative to current standards and criteria. The analysis is based on sampling data collected by the City of Abilene, the Texas Water Commission (TWC) and the U.S. Geological Survey (USGS). The City's data provided the longest continuous record with the greatest parametric coverage.

Lake Fort Phantom Hill is located in Jones County, approximately 10 miles northeast of Abilene. The lake is operated by the City of Abilene as a municipal water supply. When full, it has a surface area of approximately 4,000 acres and storage capacity of approximately 69,000 acre-feet. It receives runoff from a 470 square mile watershed, some of which is controlled by Lake Abilene and other upstream impoundments. Part of the watershed is drained by Elm Creek and Cedar Creek. In addition, up to 30,000 acre-feet per year of supplemental diversions can be pumped into the lake from the nearby Clear Fork Brazos River during high flow periods when the quality of the Clear Fork is suitable for municipal use. Occasionally, water also is diverted into the lake from Deadman Creek, a neighboring stream to the east.

Fort Phantom Hill dam is an earthfill structure with a top width of 25 feet, maximum height of 84 feet and length of 3,740 feet. The spillway is natural ground with a concrete control weir. The spillway has a crest length of 800 feet, crest elevation of 1,635.9 feet above mean sea level (msl) and is located 0.7 miles from the east end of the dam. The service outlet consists of a concrete tower with gated openings and a four by seven-foot conduit. Impoundment of water began in October 1938.

During the 1960's, the City of Abilene was experiencing taste and odor problems with Lake Fort Phantom Hill water. As a solution to this problem, a mechanical aeration system was installed in the lake and is used during the summer months to mix the lake waters and to help prevent further taste and odor problems.

APPLICABLE WATER QUALITY STANDARDS AND CRITERIA

Water quality in Lake Fort Phantom Hill was evaluated in comparison to the "Texas Surface Water Quality Standards" (TWC, 1985), and "Drinking Water Standards Governing Drinking Water Quality and Reporting Requirements for Public Water Supply Systems" (Texas Department of Health [TDH], 1987). The surface water quality standards are established by the TWC to maintain the quality of water in the state and protect the water uses deemed desirable for each classified water quality segment. Lake Fort Phantom Hill is designated as Segment 1236 and its designated uses include contact recreation, high quality aquatic habitat, and public water supply (TWC, 1985). The applicable criteria are presented in Table 4-1.

The Texas Water Commission is currently reviewing its water quality standards for possible revision beginning in 1988. A recent draft of those standards indicates a proposal for this segment to lower the chloride criteria to 130 mg/l, raise the sulfate criteria to 150 mg/l, and lower the total dissolved solids criteria to 550 mg/l. This reflects a continued review of dissolved inorganic constituent data to base the criteria on historical trends.

The Texas Drinking Water Standards are designed "to assure the safety of public water supplies with respect to bacteriological, chemical and radiological quality" (TDH, 1987). The drinking water standards

Table 4-1

Current Surface Water Criteria for Lake Fort Phantom Hill

Constituent	Criteria
Chloride	Annual mean not to exceed 200 mg/l
Sulfate	Annual mean not to exceed 100 mg/l
Total dissolved solids	Annual mean not to exceed 600 mg/l
Dissolved oxygen	Not less than 5.0 mg/l
pH	Range from 6.5 to 9.0
Fecal coliform	30 day geometric mean not to exceed 200 colonies/100 ml
Temperature	Not to exceed 34° C

Source: Texas Water Commission

were developed in compliance with requirements of the Federal Safe Drinking Water Act (PL 93-523 as amended) and the Environmental Protection Agency's (EPA) "Interim Primary Drinking Water Regulations." The applicable standards are presented in Table 4-2.

The primary drinking water standards are established to protect human health, while the secondary levels are designed to minimize non-health related problems such as taste and odor. It should be noted that the point of compliance for the drinking water standards is after treatment, so that comparison of these standards with raw untreated water may not always be appropriate. In particular, turbidity and bacterial population are substantially eliminated with proper water treatment.

Table 4-2

Texas Drinking Water Standards

Primary Standards:

Constituent	Standard (mg/l)
Arsenic	0.05
Barium	1.0
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate	10.0
Selenium	0.01
Silver	0.05
Fluoride	4.0
Eudrin	0.0002
Lindum	0.004
Methoxychlor	0.1
Toxephene	0.005
2,4-D	0.1
2,4,5-T	0.01
Turbidity	1 NTU
Coliforms	1/100 ml
Strontium - 90	8 pCi/l
Total trihalomethanes	0.10 mg/l

Secondary Levels:

Constituent	Level
Chloride	300 mg/l
Color	15 color units
Copper	1.0 mg/l
Fluoride	2.0 mg/l
Foaming agents (MBAS)	0.5 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Odor	3 threshold odor number
pH	7.0 or greater
Sulfate	300 mg/l
Total dissolved solids	1,000 mg/l
Zinc	5.0 mg/l

Source: Texas Department of Health, Division of Water Hygiene.

HISTORICAL WATER QUALITY SAMPLING DATA

City of Abilene (1976-1987)

Thirty-two water quality parameters were analyzed by the City of Abilene in water samples from Lake Fort Phantom Hill during the sampling period 1976-1987. The period from 1976-1987 was chosen for evaluation to represent a recent time period which included both wet and dry years. The City's sampling data are summarized in Table 4-3. Table 4-4 presents the average values of the samples collected by the City between 1976 and 1987 compared with the applicable surface water quality criteria for Lake Fort Phantom Hill. All water samples were collected within one meter of the water surface near the City's intake structure. Since thermal and water quality stratification is prevented during the summer months of most years by mechanical aeration in the vicinity of the intake tower, and the lake is naturally mixed during the rest of the year, these near-surface samples are assumed to be representative of the water column. Table 4-5 compares the sample concentrations to the applicable drinking water standards. A correlation matrix of all sampling parameters for the 1976-1987 Abilene data is presented in Appendix A. Only correlation coefficients of approximately 0.50 or greater with probability levels (p) less than 0.05 were considered to be significant.

Texas Water Commission (1976-1986)

The Texas Water Commission reported a number of lake profile samples collected from the two sites in Lake Fort Phantom Hill during the period 1976 through 1986. One of the sampling sites was located at mid-lake near the dam, and the other site was located near the West Texas Utilities Company cooling water outfall, approximately two-thirds of the distance up-lake from the dam to the head of the reservoir (see Figure 4-1). Selected sampling data from these sites are summarized in Tables 4-6 and 4-7 and provide an areal and vertical comparison of water quality at different sites in the lake. Temperature and dissolved

Table 4-3

Statistical Summary of Water Sampling Data Collected by the City of Abilene from Lake Fort Phantom Hill between 1976 and 1987

Parameter	Mean	Std. Deviation	No. Samples
Ammonia N, mg/l	0.30	0.54	73
Bromide, mg/l	0.46	0.86	88
Cadmium, Total mg/l	0.001	0.002	88
Calcium, Total mg/l	61	19	124
Chloride, mg/l	94	23	131
Conductivity, umhos/cm	674	142	101
Copper, Total mg/l	0.01	0.04	88
Dissolved Orthophosphate P, mg/l	0.05	0.13	105
Dissolved Oxygen, mg/l	8.9	2.1	89
Fecal Coliform, #/100 ml	38	57	81
Fluoride, Total mg/l	0.29	0.14	129
Hardness, Total mg/l as $CaCO_3$	232	29	131
Iron, Total mg/l	0.23	0.31	84
Lake Surface Elevation, Ft msl	1,627	5	114
Lead, Total mg/l	0.003	0.008	88
Magnesium, Total mg/l	22	10	123
Manganese, Total mg/l	0.01	0.04	60
Nickel, Total mg/l	0.01	0.01	88
Nitrate N, mg/l	0.18	0.32	112
Nitrite N, mg/l	0.01	0.03	97
pH, S.U.	8.4	0.2	131
Potassium, Total mg/l	8.6	3.8	74

Table 4-3, Continued

Parameter	Mean	Std. Deviation	No. Samples
Silica, Total mg/l	4.3	2.8	90
Silver, Total mg/l	0.01	0.01	47
Sodium, Total mg/l	64	22	100
Sulfate, mg/l	94	40	129
Temperature, °C	19.1	8.0	98
Total Alkalinity, mg/l as $CaCO_3$	143	21	131
Total Dissolved Solids, mg/l	466	105	81
Turbidity, turbidity units	37	36	89
Zinc, Total mg/l	0.05	0.19	87

Table 4-4

Summary of City of Abilene Data (1976-1987) Compared to Surface Water Criteria

Constituent	State Criteria	Lake Samples: Mean	Std. Dev.	No. Samples
Chloride (mg/l)				
Annual mean not to exceed	200	94	23	131
Sulfate (mg/l)				
Annual mean not to exceed	100	94	40	129
Total Dissolved Solids (mg/l)				
Annual mean not to exceed	600	466	105	81
Dissolved Oxygen (mg/l)				
Not less than	5.0	8.9	2.1	89
pH range	6.5-9.0	8.3	0.2	131
Fecal Coliform (#/100 ml)				
Thirty-day geometric mean not to exceed	200	38*	57	81
Temperature (Degrees C)				
Not to exceed	34	19.1	8	98

*Value reported is actually the arithmetic mean of 81 samples collected during the period 1976 to 1987 and, therefore, is not comparable to the fecal coliform criterion.

Table 4-5

Texas Drinking Water Standards for Public Water Supplies Compared to City of Abilene Mean Sampling Values from Lake Fort Phantom Hill Between 1976 and 1987

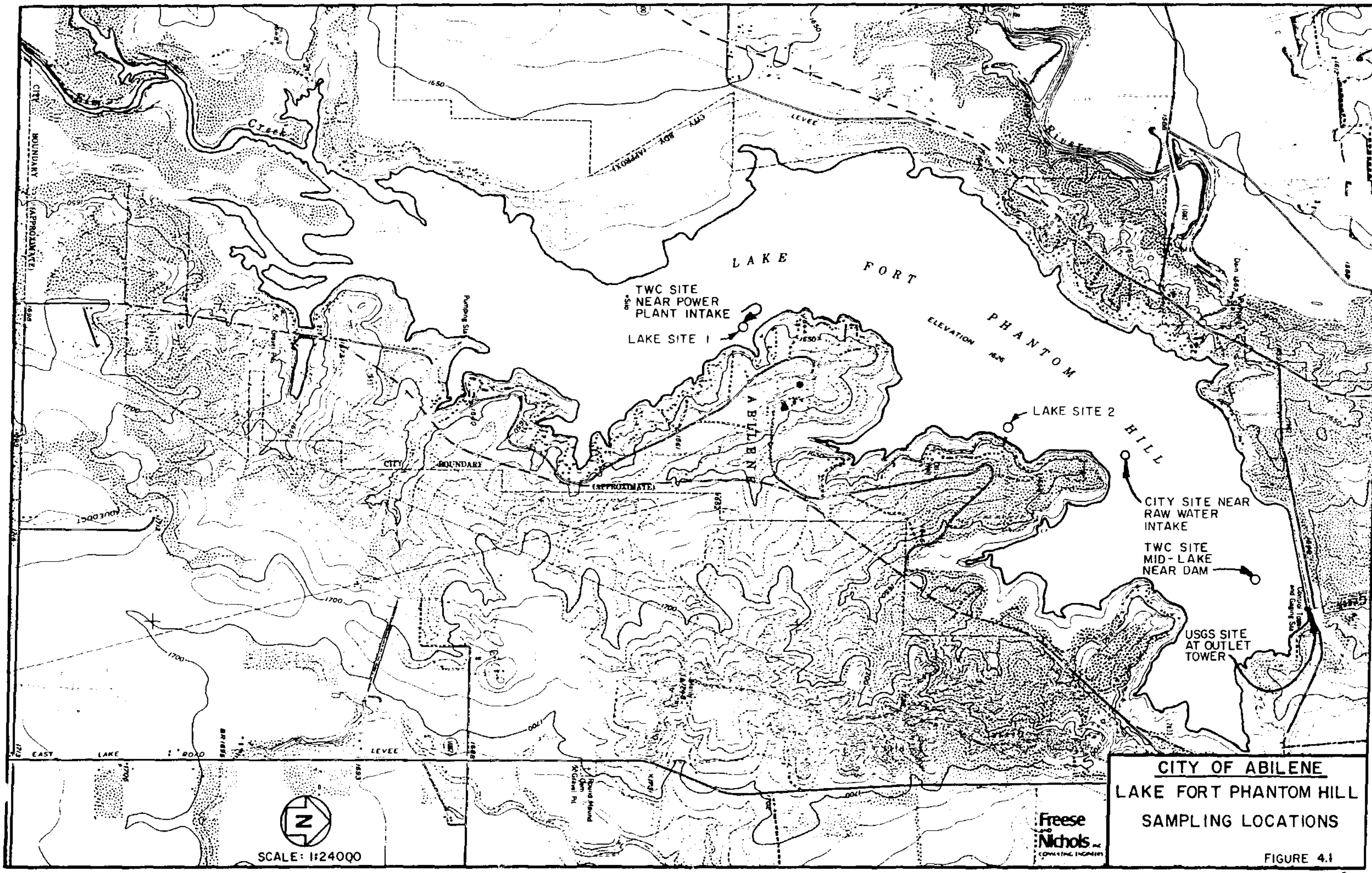
Primary Standards	Max. Allowable Level, mg/l	Lake Samples: Mean, mg/l	Lake Samples: Std. Dev.	Lake Samples: No. Samples
Arsenic	0.05	0.001	-	1*
Barium	1.0	-	-	0
Cadmium	0.01	0.001	0.002	88
Chromium	0.05	0.02	0.18	87
Lead	0.05	0.003	0.008	88
Mercury	0.002	0.0002	-	1*
Nitrate-N	10.0	0.18	0.32	112
Selenium	0.01	-	-	0
Silver	0.05	0	0	47
Turbidity (turbidity units)	1.0	37	36	89
Secondary Levels	**Recommended Limit, mg/l**			
Chloride	300	94	23	131
Fluoride	15	0.29	0.14	129
Copper	1.0	0.01	0.04	88
Iron	0.3	0.23	0.31	84
Manganese	0.05	0.01	0.04	60
pH	7.0	8.4	0.2	131
Sulfate	300	94	40	129
Total Dissolved Solids	1,000	466	105	81

Table 4-5, Continued

Secondary Standards	Recommended Limits, mg/l	Lake Samples Mean, mg/l	Std. Dev.	No. Samples
Zinc	5.0	0.05	0.19	87

NOTE: Lake samples were collected at Station 1236.012, described as north area near intake tower, unless otherwise noted.

*This sample was collected 11/20/78 at Station 1136.01, described as mid-lake near dam.



CITY OF ABILENE

LAKE FORT PHANTOM HILL

SAMPLING LOCATIONS

FIGURE 4.1

Table 4-6

Summary Statistics for Water Quality Samples Collected from Lake Fort Phantom Hill by the Texas Water Commission at Mid-Lake near the Dam (1976-1986)

Constituent	Relative Sampling Depth	Mean	Std. Dev.	Maximum	Minimum	Number
Water Depth, feet	-	41.2	5.2	50	30	21
Secchi Disk Depth, inches	-	24.6	9.2	49	15	17
Total Suspended Solids, mg/l	near surface	11.4	2.9	21	L.D.	18
Chlorophyll a, mg/l	near surface	0.010	0.009	0.042	L.D.	18
Temperature °C	near surface	17.8	7.8	29.5	4.5	28
Temperature °C	deep	17.6	7.3	27.3	4.5	21
Elec. Conductivity umhos/cm @ 25°C	composite	740	140	1000	500	27
Dissolved Oxygen, mg/l	near surface	9.4	2.4	14	4.7	24
Dissolved Oxygen, mg/l	deep	7.1	3.6	12.9	0.6	21
Total Dissolved Solids, mg/l	composite	385	68	500	255	22

L.D. indicates less than laboratory detection limits.

Table 4-7

Summary Statistics for Water Quality Samples Collected from Lake Fort Phantom Hill by the Texas Water Commission near the Power Plant Outfall (1976-1986)

Constituent	Relative Sampling Depth	Mean	Std. Dev.	Maximum	Minimum	Number
Water Depth, feet	-	23	6	35	15	20
Secchi Disk Depth, inches	-	21.3	7.0	39	14	17
Total Suspended Solids, mg/l	near surface	13.9	6.0	31	L.D.	21
Chlorophyll a, mg/l	near surface	0.014	0.016	0.033	L.D.	21
Temperature, °C	near surface	19.4	8.0	31	5.5	22
Temperature, °C	deep	17.6	7.3	28	5.5	20
Elec. Conductivity, umhos/cm @ 25°C	composite	778	131	1100	542	22
Dissolved Oxygen, mg/l	near surface	9.4	2.2	13.6	4.4	22
Dissolved Oxygen, mg/l	deep	8.4	2.9	12.8	2.0	20
Total Dissolved Solids, mg/l	composite	389	66	550	272	22

*L.D. indicates less than laboratory detection limits.

oxygen levels exhibited statistically significant differences between surface and bottom levels.

Water samples were collected from the two TWC sites at a depth of one foot, and then at ten-foot intervals downward to near the bottom. The mid-lake near dam site was the deeper of the two sampling sites, ranging from 30 feet to 50 feet deep on sampling dates. The station near the power plant outfall ranged from 15 feet to 35 feet deep on sampling dates.

An examination of the water quality profiles for both TWC stations revealed that the lake was distinctly stratified, both chemically and thermally, on only one of the sampling dates (August 9, 1978). At that time, water column temperatures at the near-dam site ranged from 29.5°C at one foot depth to 22.5°C at 42 feet in depth. The thermocline, which is defined as the zone where water temperatures decrease at the greatest rate, was between five feet and ten feet below the surface. Temperatures at those depths were 28°C and 26°C, respectively. Dissolved oxygen concentrations ranged from 14 mg/l near the surface to 0.6 mg/l at 42 feet, and total dissolved solids levels at corresponding depths ranged from 350 mg/l to 160 mg/l. Dissolved oxygen was still available on the sampling date in sufficient quantity to sustain a viable aquatic community from the lake surface to the upper portion of the hypolimnion, the layer of the lake underlying the thermocline, as evidenced by dissolved oxygen levels of 7.1 mg/l at ten feet falling to 4.3 mg/l at 15 feet.

Stratification also was evident at the TWC site near the power plant outfall on August 9, 1978, although differences in measurements throughout the profile at this site were not as great as those at the near-dam site. Water temperatures at the power plant outfall site ranged from 27.5°C near the surface to 23°C at 25 feet. The thermocline was between ten and 15 feet where temperatures decreased from 26°C to 24°C with depth. Dissolved oxygen levels were 9.4 mg/l near the surface, decreased to 6.9 mg/l at five feet, 3.2 mg/l at ten feet, and 2.0 mg/l at 25 feet. Total dissolved solids varied from 340 mg/l near the surface to 240 mg/l at 24 feet.

Temperatures at both TWC stations varied less than approximately two degrees from the surface to the bottom on all but one of the remaining sampling dates. On August 22, 1979, temperatures ranged from 29°C to 26°C at the near-dam site and from 31°C to 26°C at the power plant outfall site. However, dissolved oxygen and total dissolved solids concentrations varied little throughout the water column on this date, indicating that chemical stratification was not present even though the lake may have been weakly stratified thermally. In most of the samples, less than 50 mg/l difference was observed between total dissolved solids concentrations in the upper and lower portions of the water column.

Water column transparency, as indicated by secchi disk depth measurements, and total suspended solids and chlorophyll a concentrations are reasonably similar between the two TWC sampling stations (Tables 4-6 and 4-7). The slight differences in observed values are attributable to the different locations of the sampling sites and the different numbers of samples collected for total suspended solids and chlorophyll a levels.

The Texas Water Commission also collected and identified algae in Lake Fort Phantom Hill intermittently between 1978 and 1982. One sample was collected in 1978, two samples were collected in 1979, one sample in 1981 and two samples in 1982. The predominant species in all six samples was Cyclotella, a filter and screen-clogging diatom. Cyclotella values ranged from 35/ml in May 1979 to 350/ml in October 1978.

U.S. Geological Survey (1976-1984)

The U.S. Geological Survey (USGS) has sampled Lake Fort Phantom Hill for a number of years at the outlet gate tower near the dam (see Figure 4-1). Table 4-8 contains a statistical summary of parameters obtained from a listing of USGS records entered into EPA's water quality data base STORET and includes the sampling period from May 1976 through April 1984. Samples were collected near the surface. Comparing the

Table 4-8

Summary Statistics for Water Quality Samples Collected from Lake Fort Phantom Hill near the Outlet Tower by the U.S. Geological Survey (1976-1984)

	Mean	Std. Dev.	Maximum	Minimum	Number of Samples
Temperature, °C	22.0	5.1	30.0	15.0	14
Conductivity, umhos/cm @ 25°C	795	93	987	677	13
Chloride, mg/l	107	20	150	83	13
Sulfate, mg/l	91	19	130	76	13
Fluoride, mg/l	0.37	0.06	0.5	0.3	13
Silica, Dissolved mg/l	2.0	1.3	4.1	0.6	13
Total dissolved Solids, mg/l	440	50	540	386	13

USGS sampling data with that reported by the City of Abilene (Table 4-3) and the TWC (Tables 4-6 and 4-7) reveals no important differences.

INTENSIVE WATER QUALITY MONITORING PROGRAM (1987)

The City of Abilene has recently completed a seven-month intensive sampling program to obtain baseline water quality data for Lake Fort Phantom Hill. The fifty-nine parameters shown in Table 4.9 were analyzed on a monthly, quarterly or bi-annual basis. Four sampling sites were tested during the seven-month period (see Figure 4-1). Two sampling sites were located in Lake Fort Phantom Hill, near the City of Abilene water plant intake structure and near the West Texas Utilities intake structure. A third sampling point consisted of a composite of two samples collected from Elm Creek and Cedar Creek. The fourth sampling site consisted of the City's wastewater treatment plant effluent.

The mean values at all four sites are compared to drinking water standards in Table 4-10. This data includes results for the seven months through September. The raw sampling data, with the exception of most of the organic parameters, are included in Appendix B. A report on quality assurance procedures used during the analysis is included in Appendix C.

Table 4-10 indicates that, in general, water quality at the two lake sites is comparable to the quality of the composite creek samples. However, the creek composite samples had considerably greater mean concentrations of turbidity, bacteria, iron, odor, total Kjeldahl nitrogen (TKN), total phosphorus, chlorophyll a, and total organic halogen (TOX) than the lake samples. These results were to be expected, since the creek composite samples were collected during runoff events, which might explain the presence of greater levels of these constituents. The table also indicates that the treated effluent generally had the poorest quality, particularly from the standpoint of nutrients, salts, and odor.

Table 4-9

Water Quality Parameters Monitored
March - September 1987

Algal identification	Mercury
Alkalinity	Methylene blue active substances (MBAs)
Aluminum	Nitrate
Ammonia	Nitrite-N
Arsenic	Nitrogen, total Kjeldahl
Barium	Pesticide scan
Boron	Phosphorus
Bromide	Potassium
Cadmium	Selenium
Calcium	Silica
Chloride	Silver
Chlorophyll a	Sodium
Chromium	Standard plate count
Cobalt	Strontium
Color	Sulfate
Copper	Threshold odor
Cyanide	Total dissolved solids (TDS)
Dissolved oxygen temperature	Total hardness
Fecal coliform	Total organic carbon
Fecal streptococcus	Total organic halogens
Fluoride	Total suspended solids (TSS)
Iodide	Total trihalomethane (TTHM)
Iron	TTHMFP
Lead	Turbidity
Magnesium	Virus
Manganese	Volatile organic carbon
	Zinc

Table 4.10

Comparison of Water Quality Sampling Results (3/87-9/87)
From the Abilene Water Reuse Study
With State Drinking Water Standards
(Values are in mg/l unless otherwise noted)

Parameter	Drinking Water Standard	Mean Concentration: Lake Station No. 1	Lake Station No. 2	WWTP Effluent	Creek Composite
Primary Standard					
Arsenic	0.05	0.002	0.002	0.003	0.025
Barium	1	0.130	0.152	0.052	0.230
Cadium	0.01	0.001	0.001	LD	LD
Chromium	0.05	0.006	0.001	0.005	0.003
Fluoride	4.0				
Lead	0.05	0.012	0.002	0.003	LD
Mercury	0.002	ID	ID	ID	ID
Nitrate-N	10	LD	LD	8.600	0.200
Selenium	0.01	0.008	0.005	0.003	0.002
Silver	0.05	0.018	0.022	0.037	0.025
Endrin	0.0002	LD	LD	LD	LD
Lindane	0.004	ND	ND	ND	ND
Methoxychlor	0.1	LD	LD	LD	LD
Toxaphene	0.005	LD	LD	LD	LD
2,4-D	0.1	LD	LD	LD	LD
2,4,5-T	0.01	LD	LD	LD	LD
Turbidity (Turbidity units)	1	27	14.6	8	74
Total Coliforms	1[a]	1[b]	62.4[b]	1[b]	533[b]
Secondary Levels					
Chloride	300	81	81.4	229	102
Fluoride	2.0	0.264	0.304	1.340	0.213
Copper	1	0.008	0.012	0.010	0.017
MBAs	0.5	0.2	0.14	1.024	0.175
Iron	0.3	0.722	0.380	0.118	0.933
Manganese	0.05	0.043	0.610	0.040	0.073
Odor (threshold odor no.)	3	3.5	5	35	6.750
Sulfate	300	64	64	192	70
TDS	1,000	434	438	992	491
Zinc	5	0.009	0.067	0.322	0.021
TTHM (mg/l)	0.1	ID	0	0.013	LD
TTHMFP (mg/l)	0.1	ID	0.09	ID	ID

Table 4-10, Continued

Parameter	Drinking Water Standard	Mean Concentration Lake Station No. 1	Lake Station No. 2	WWTP Effluent	Creek Composite
Other Constituents					
Nitrite-N	NA	0.02	0.07	13.63	0.22
Ammonia-N	NA	0.39	0.21	4.93	1.84
Total Kjeldahl Nitrogen	NA	1.75	3.15	7.08	5.09
Dissolved Ortho-P	NA	LD	LD	6.63	0.04
Total Phosphorus	NA	0.07	0.08	8.1	0.16
Chlorophyll a	NA	0.002	0.001	0.001	0.04
Total Organic Carbon	NA	34.2	34.2	15.6	37.8
Volatile Organic Carbon	NA	17.4	20.6	25.8	27.1
Total Organic Halogen	NA	0.014	0.014	0.280	63.3
Total Alkalinity	NA	144	144	181	142
Calcium	NA	52	58	76	59
Magnesium	NA	22	24	59	28
Hardness	NA	224	213	314	226
Sodium	NA	52	52	157	44
Potassium	NA	13	11	16	11
Silica	NA	5	4	15	7
Bromide	NA	0.35	0.60	ND	0.22
Fecal Streptococcus (#/100 ml)	NA	23	20	ND	1.700
Standard Plate Count (#/100 ml)	NA	3,186	4,753	6,853	6,000
Aluminum	NA	1.1	0.74	0.09	1.68
Iodide	NA	0.9	0.56	1.40	0.75
Strontium	NA	0.4	0.50	0.58	0.25
Boron	NA	0.2	0.12	0.40	0.14
Cobalt	NA	0.001	LD	0.001	0.001

LD indicates less than laboratory detection limit.
ND indicates that no determinations were made for a constituent.
NA indicates that no standard has been established.
ID invalid data

[a]One coliform per 100 ml as the arithmetic mean of all samples examined per month.
[b]Fecal coliforms.

Samples were tested for a variety of organic chemicals using gas chromatographic methods. The majority of the organic compounds tested for were not detected, including the pesticides listed in Table 4-10. However, the scan for organic compounds indicated dimethyl phthalate (15 mg/l, March), acetone (98 mg/l, June), and 1,1,1-Tricharoethene (less than 5 mg/l, June) in the creek samples. Bio (2-ethylhexyl) phthalate (5 mg/l, March) was identified in only one of the wastewater treatment plant effluent samples.

Methylene chloride was also identified in samples from all sites, but the laboratory suspected that contaminated sample vials may.have introduced this compound during the analysis. The compounds detected in the creek composite and wastewater effluent samples probably were random occurrences related to runoff or an isolated disposal event, and likely will not pose a persistent water quality problem.

Lake Sediment Samples

Sediment samples were taken at both lake locations and analysis for total metal and leachate (EP Toxicity method) for each of the following elements: As, Hg, Se, Zn, Cd, Pb, Ni, B, Cr, Cu, and Ag. Analysis for barium and manganese were analyzed for total metals only; data for the leachate samples were inconclusive. Only zinc and boron were found in the leachate; zinc was identified in quantities less than the Maximum Contaminant Level Goal (MCLG) of the Safe Drinking Water Act. No MCLG has been adopted for boron; however, the levels appear reasonable. Once deposition has occurred, analysis indicates little potential of leaching from the sediments.

The bioaccumulation of heavy metals and pesticides through the food chain is always a concern for a near-static system like LFPH. The concentrating effect of the food chain may need to be monitored through bioassays of fish and benthic organisms during the next monitoring program. Metals should be expected to concentrate in the lake sediments as a natural event. The levels of metal measured in the WWTP effluent are higher, but comparable to the composite creek samples. Additional wastewater levels of treatment, especially precipitation processes (i.e., high-lime), would reduce this concentration.

In August 1987, lake sediment grab samples were also collected at both lake sampling stations. These samples were analyzed for kjehdal nitrogen (TKN), potassium, and orthophosphate. The TKN values ranged from 20 to 83 mg/l, the potassium analysis was incorrect, and the orthophosphate was 0.1 mg/l.

WATER QUALITY ASSESSMENT

The water quality data collected to date indicates that overall water quality in Lake Fort Phantom Hill is good. Only a few isolated parameters exhibited levels which are of potential interest or concern. Each of the major parameters are summarized below:

Temperature

Temperature is an important measure of water quality because it controls the rates of biological and chemical processes. It is also important in controlling physical mixing when temperature differences between surface and bottom layers become sufficient in summer to cause the lake to stratify. During stratification, the bottom layer may become anoxic and result in other adverse water quality effects.

The average water temperature of Lake Fort Phantom Hill based on 98 measurements by Abilene during the 1976-1987 sampling period was 19.1°C (Table 4-3). Monthly mean water temperatures are plotted in Figure 4-2 and range from approximately 7.0°C in January to 28°C in August. The maximum temperature recorded during the period was 34°C in August 1983, and the minimum was 2.0°C in January of 1982 and 1984. The temperature in Lake Fort Phantom Hill is probably influenced by the West Texas Utilities power plant located on the eastern side of the lake. As indicated in Figure 4-3, the intensive sampling data indicates that 1987 has been similar in temperature in the 1976-1987 average condition.

FORT PHANTOM HILL RESERVOIR QUALITY

TEMPERATURE (1976-1987)

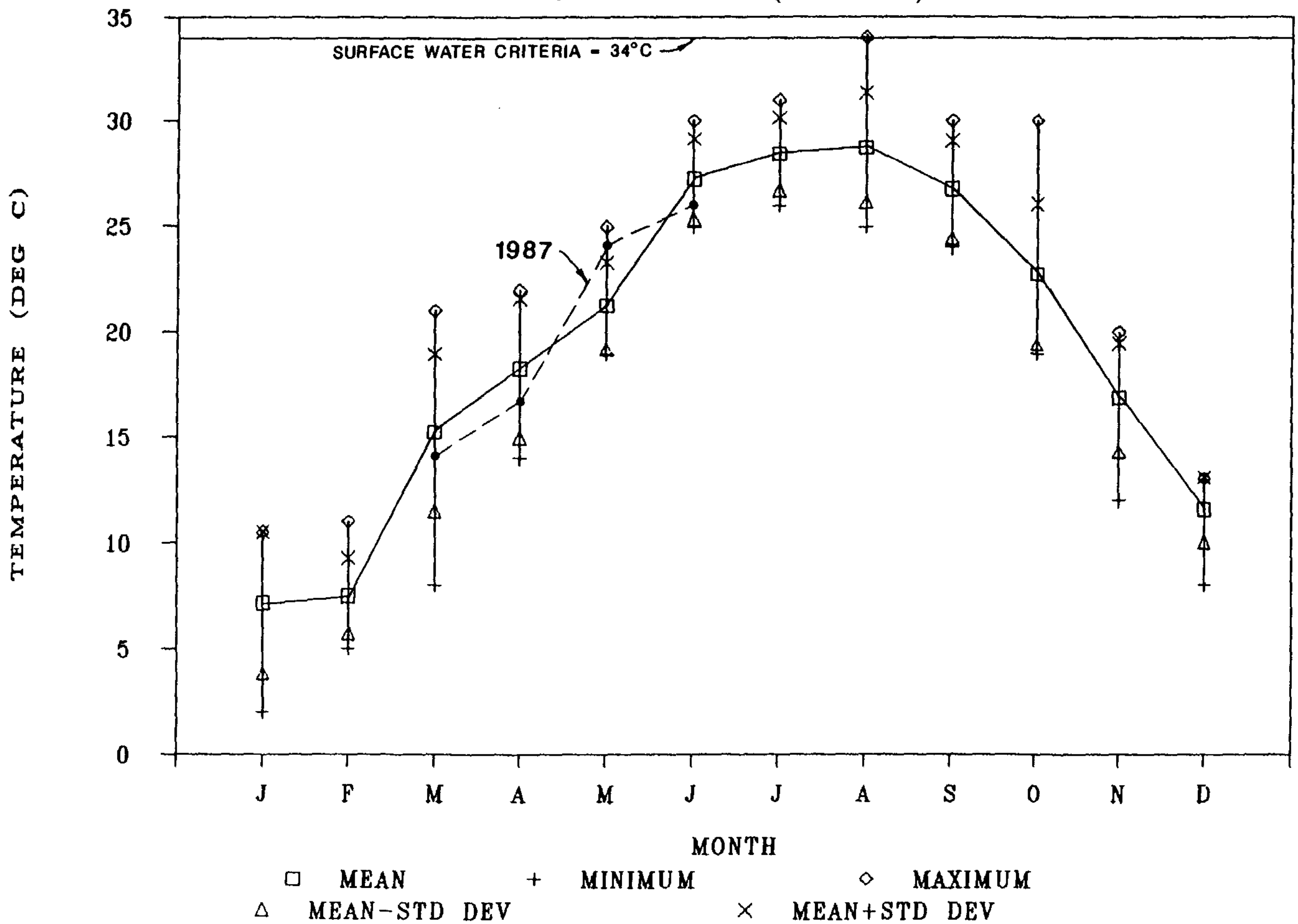


FIGURE 4-2

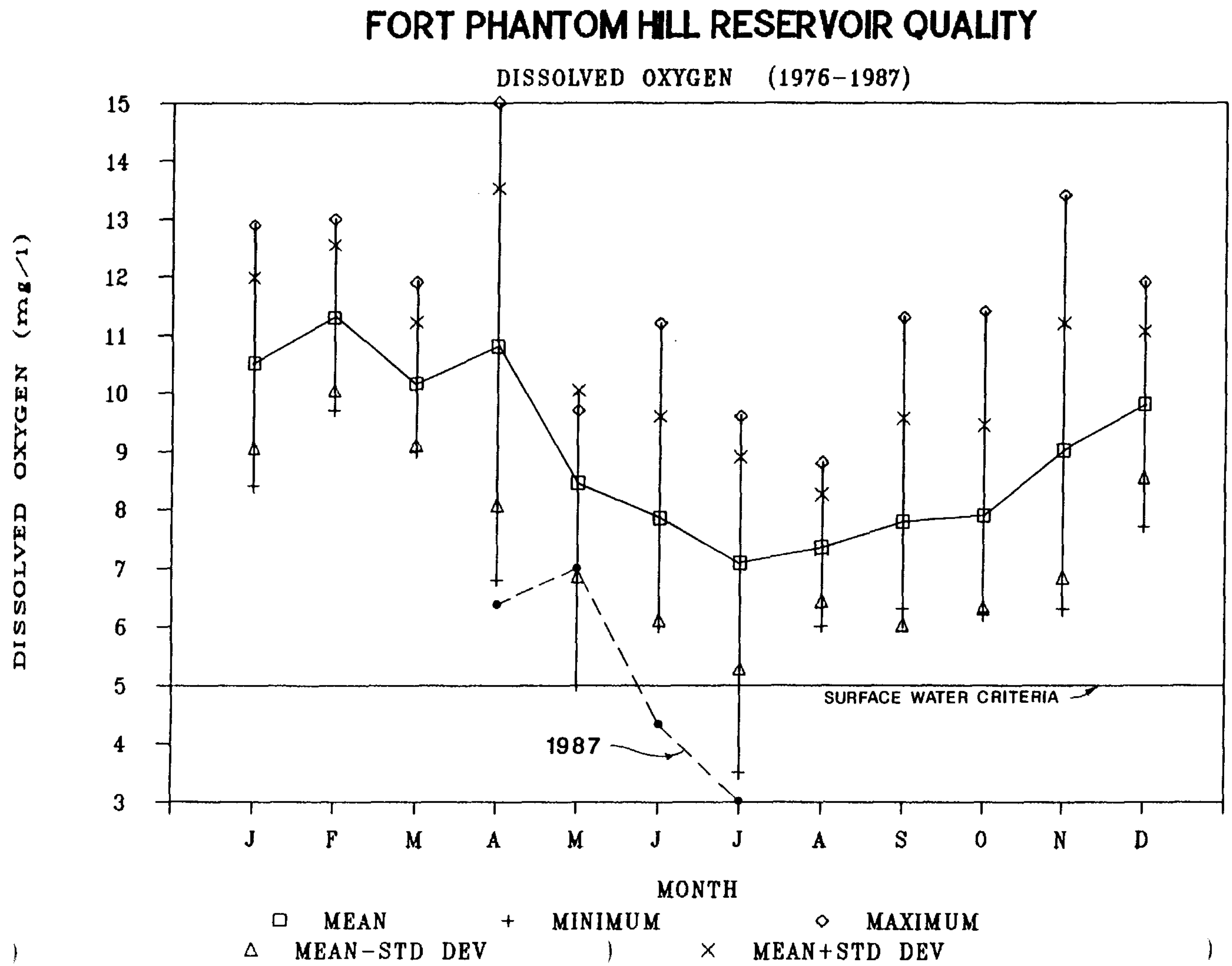

FORT PHANTOM HILL RESERVOIR QUALITY
DISSOLVED OXYGEN (1976-1987)
DISSOLVED OXYGEN (mg/l)
15
14
13
12
11
10
9
8
7
6
5
4
3
SURFACE WATER CRITERIA
1987
J F M A M J J A S O N D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-3

Lake Fort Phantom Hill was not thermally or chemically stratified according to most of the samples collected at two sites between 1976 and 1986. However, since the lake was distinctly stratified in August 1978, it is apparent that under some conditions, thermal and chemical stratification is possible. Three reasons are noted as possibilities of why the lake usually remains fairly mixed: (1) the aeration system located in the vicinity of the City's raw water intake tower keeps the lake mixed (Brazos River Authority, 1975), (2) the lake's north-south orientation along the axis of the prevailing southerly winds may keep the lake mixed during most years, and (3) circulation of cooling water from the West Texas Utilities generating plant may have at least a local mixing effect. These factors may operate in combination or independently to prevent stratification, and there may be other as yet unidentified factors acting to keep the lake mixed.

Dissolved Oxygen

Dissolved oxygen is a necessary requirement for maintenance of a healthy aquatic community. Lack of dissolved oxygen can cause stress or death to fish and other aquatic life, and also may be an indicator of other water quality problems. The Texas Water Commission has established 5.0 mg/l as the minimum level of dissolved oxygen to maintain high quality aquatic life.

Dissolved oxygen (DO) was at or above 5.0 mg/l in all but one of the 89 samples analyzed by Abilene from 1976-1987. The mean DO concentration for the period was 8.9 mg/l, and monthly averages ranged from 7.1 mg/l in July to 11.3 mg/l in February (see Figure 4-3). The minimum observed DO occurred in July 1981 when, for some unknown reason, a concentration of 3.5 mg/l was recorded. Dissolved oxygen levels during the summer months likely would be lower in the absence of mechanical aeration which the City of Abilene uses to modify and improve water quality in the lake. As expected, DO showed a significant inverse correlation (r) with temperature ($r = -0.59$; p .01).

A review of 1987 intensive sampling dissolved oxygen levels reveals somewhat lower DO levels than in the historical data. The samples taken at the lake station near the City's intake are depicted on Figure 4-3 and show DO levels falling below the 5.0 mg/l criterion during June and July. Dissolved oxygen levels at the other stations were also depressed during July.

Nitrogen

Nitrogen may be found in several forms in aquatic systems. As unionized ammonia, it may be toxic to fish in the range of 0.14 to 4.60 mg/l, depending on temperature, pH, and species of nonsalmonid fish. Nitrites react with hemoglobin and can cause serious poisoning, particularly in infants. The EPA has established a level of 1 mg/l of nitrite-nitrogen to protect human health. Nitrate is an important nutrient for algae and other plant life which form the base of the food chain. However, too much nitrate can cause an overgrowth of algae, or bloom, a process commonly referred to as eutrophication. In addition, high nitrates may be reduced to nitrites in human infants. The EPA has established a level of 10 mg/l of nitrate-nitrogen to protect human health, although many public water systems commonly exceed this limit and only one case of nitrate poisoning (mothemoglobinemia) has been reported from a public water supply.

Samples were analyzed by Abilene (1976-1987) for three forms of nitrogen; 112 samples were analyzed for nitrate nitrogen (NO_3-N), 97 samples for nitrite nitrogen (NO_2-N), and 73 samples for ammonia nitrogen (NH_3-N). The mean NO_3-N concentration for the period was 0.18 mg/l. Average monthly concentrations ranged from 0.32 mg/l in January to 0.07 mg/l in March. Figure 4-4 shows that the mean monthly concentrations are fairly constant throughout the year. Relatively high NO_3-N levels were reported in January 1976 (2.2 mg/l) and September 1977 (1.71 mg/l). Nitrate-nitrogen was below detectable limits in many of the 112 samples analyzed from 1976-1987 (see Appendix D), and continued to be undetected in the 1987 inclusive data. Only the wastewater effluent had significant levels of nitrate.

FORT PHANTOM HILL RESERVOIR QUALITY

NITRATE NITROGEN (1976-1987)

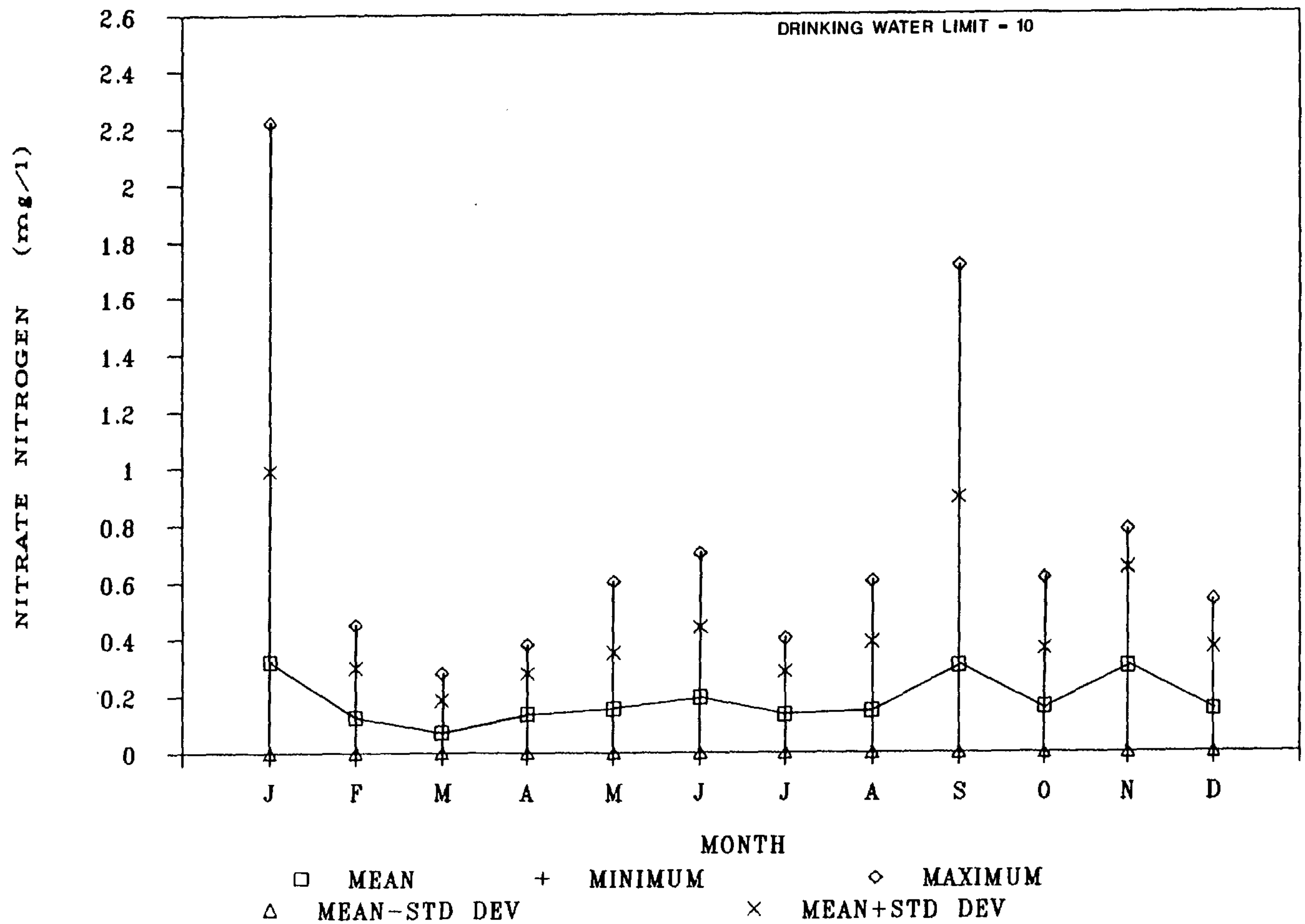


FIGURE 4-4

Nitrite-nitrogen was absent or not detected in most of the 97 samples analyzed by Abilene from 1976-1987. During the 1987 intensive sampling effort, the reported nitrite levels from the wastewater plant were unusually high during the first several months of sampling. The elevated levels were due to modifications in the daily operation of the wastewater treatment plant during the first several months of sampling. Once the plant operation was modified, nitrite-nitrogen levels from the plant were in the expected range.

Ammonia nitrogen concentrations averaged 0.30 mg/l in 73 samples collected during the 1976-1987 period. Mean monthly NH_3-N concentrations showed slightly more fluctuation than NO_3-N means and varied from 0.04 mg/l in September to 0.68 mg/l in July (see Figure 4-5). The maximum reported level was 3.50 mg/l in July 1985. Many samples had no detectable NH_3-N. Ammonia was significantly correlated with conductivity (r=0.50;p 0.01) and sulfate (r=0.63;p 0.01), but the reason for this correlation is not known. The 1987 intensive sampling data fall within the same range as the 1976-1987 tests.

As a general guide to evaluating the probability of potential water quality problems from high nitrogen levels, the TWC (1986) considers a combined NH_3-N and NO_3-N concentration of greater than 1.0 mg/l as "elevated". Based on this general guide, mean nitrogen levels in Lake Fort Phantom Hill would not be considered elevated, although occasional samples did exceed the combined 1.0 mg/l ammonia plus nitrate-nitrogen level.

Phosphorus

Phosphorus, in the form of phosphate, is of interest primarily because of its role as an algal nutrient and its effect on eutrophication. Dissolved orthophosphate phosphorus (PO_4-P) was analyzed in 105 samples during the period and averaged 0.05 mg/l. Average monthly concentrations ranged from less than detectable limits in September to 0.11 mg/l in June and 0.12 mg/l in November (see Figure 4-6). Peak concentrations occurred in June 1983 (0.90 mg/l) and November 1983 (0.65 mg/l), while less than detection limits were reported as minimum values

FORT PHANTOM HILL RESERVOIR QUALITY

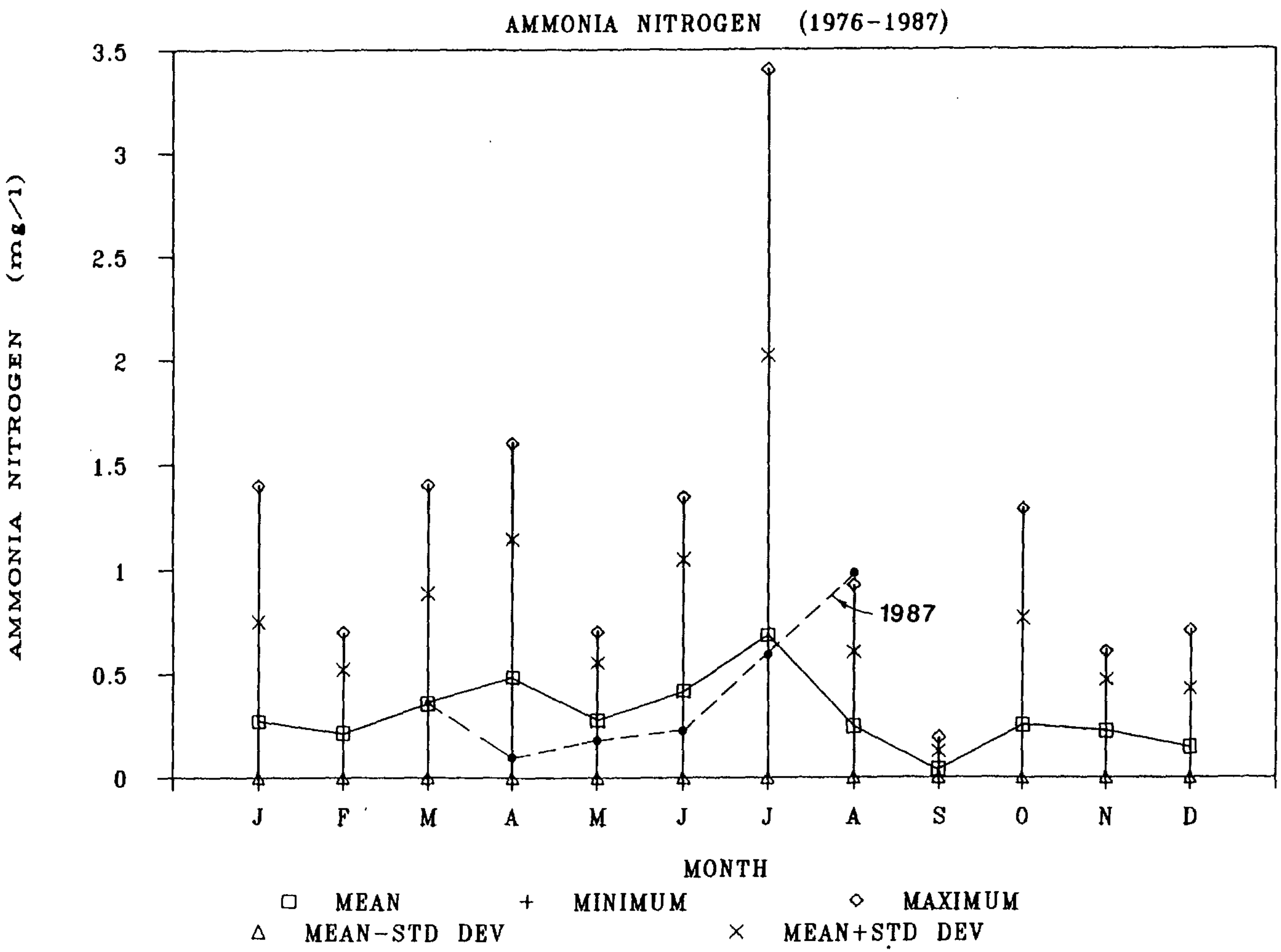


FIGURE 4-5

FORT PHANTOM HILL RESERVOIR QUALITY

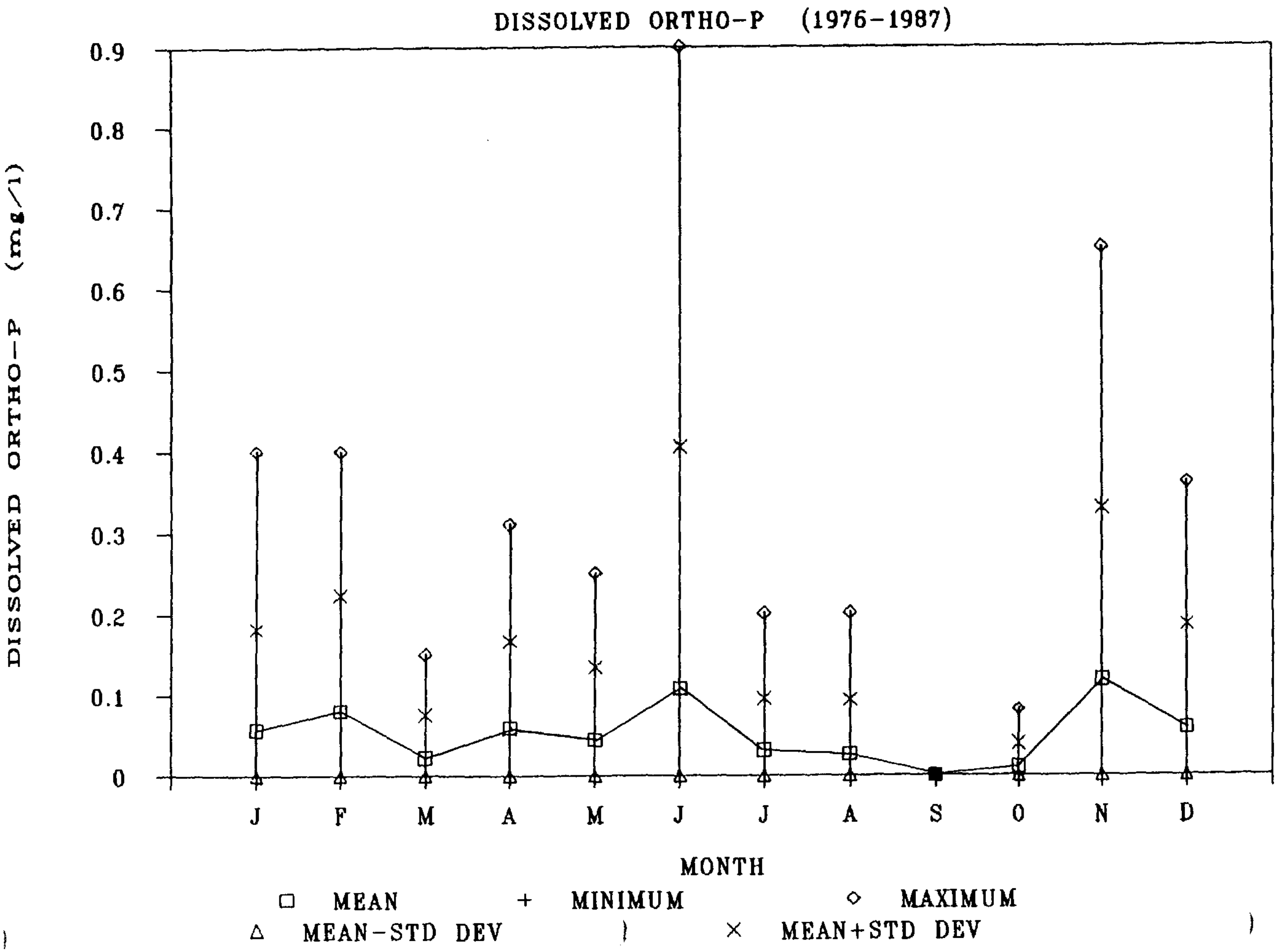


FIGURE 4-

in all months. The 1987 intensive data also fall below detection limits for all months at Lake Station Number 1. The TWC (1986) employs a guideline of 0.07 mg/l dissolved phosphorus as the level above which the nutrient is considered elevated. Based on the TWC guideline concentration, the overall mean PO_4-P level is not elevated, but mean monthly phosphate levels have been elevated in February, June, and November. Dissolved orthophosphate showed a significant relationship only with nickel (r=0.59;p 0.01), but the importance of the relationship is not apparent.

Eutrophication

Eutrophication is the nutrient enrichment of a water body and the resulting aquatic plant production. The productivity level is directly related to the conditions necessary for aquatic plant growth, primarily nutrient input, sunlight, hydraulic residence time, and temperature. Therefore, the level of eutrophication or trophic status will depend on the extent to which one or more of the factors required for aquatic plant growth may be limiting.

Most reservoirs in Texas are considered to be eutrophic, meaning that they are well supplied with nutrients and are highly productive. The TWC (1986) ranked Lake Fort Phantom Hill 71st out of 96 Texas reservoirs evaluated using Carlson's (1977) trophic state index method based on Secchi disk transparency, chlorophyll a and total phosphorus concentrations. A rank of one was the least productive while a 96 indicated the most productive reservoir. The mean chlorophyll a levels presented in Tables 4-6 and 4-7 indicate that Lake Fort Phantom Hill is borderline eutrophic, or meso-eutrophic, based on the EPA (1973) suggested criteria that concentrations between 0.01 mg/l and 0.1 mg/l correspond to eutrophic conditions. However, the recent sampling results indicate the lake may be less productive (see Table 4-10).

The mean inorganic nitrogen to orthophosphorus ratio, computed from the values reported in Table 4-3, was 10:1. Although this indicates that productivity is nitrogen-limited, other monitoring data indicate that phosphorus may be the limiting nutrient at times. For example, comparison of nitrate-nitrogen (Figure 4-4) and dissolved orthophosphate phosphorus concentrations (Figure 4-6) for the month of September show that some nitrate was available, but orthophosphate was always below detectable limits. The recent sampling data (Table 4-10) indicate that dissolved orthophosphate was below detection limits from March through August 1987 in the lake. However, light may be the most significant factor limiting productivity as evidenced by the low Secchi disk transparencies (Tables 4-6 and 4-7) and high turbidities (Tables 4-3 and 4-10).

In the Environmental Protection Agency's eutrophication study on Lake Fort Phantom Hill (EPA, 1977), the EPA classified the lake as eutrophic and identified nitrogen as the limiting nutrient. The EPA also noted that the low mean secchi disk transparency (24 inches) suggests that "primary productivity may be light-limited at times rather than nutrient-limited."

The differences between nitrate-nitrogen and dissolved orthophosphate-phosphorus levels during wet and dry years were examined to evaluate the effects of drought periods on these nutrients. A review of annual precipitation data at Abilene, Texas for the period 1976 through 1986 showed that 1986 was the wettest year with 31.98 inches, and 1977 was the dryest with 16.27 inches. Figures 4-7 and 4-8 show that nitrogen and phosphorus levels were below laboratory detection limits during the wet year (1986), but measureable concentrations were present during dry year sampling (1977). This may be attributable to the dilution effect of higher rainfall in 1986. Note that the 1987 intensive sampling data for nitrate and phosphate also fall below detection limits, reflecting the continued high rainfall in Abilene during 1987.

pH and Alkalinity

The pH of Lake Fort Phantom Hill averaged 8.4 standard units based on the 131 samples collected between 1976 and 1987. Figure 4-9 shows that the mean monthly pH level is fairly constant during the year,

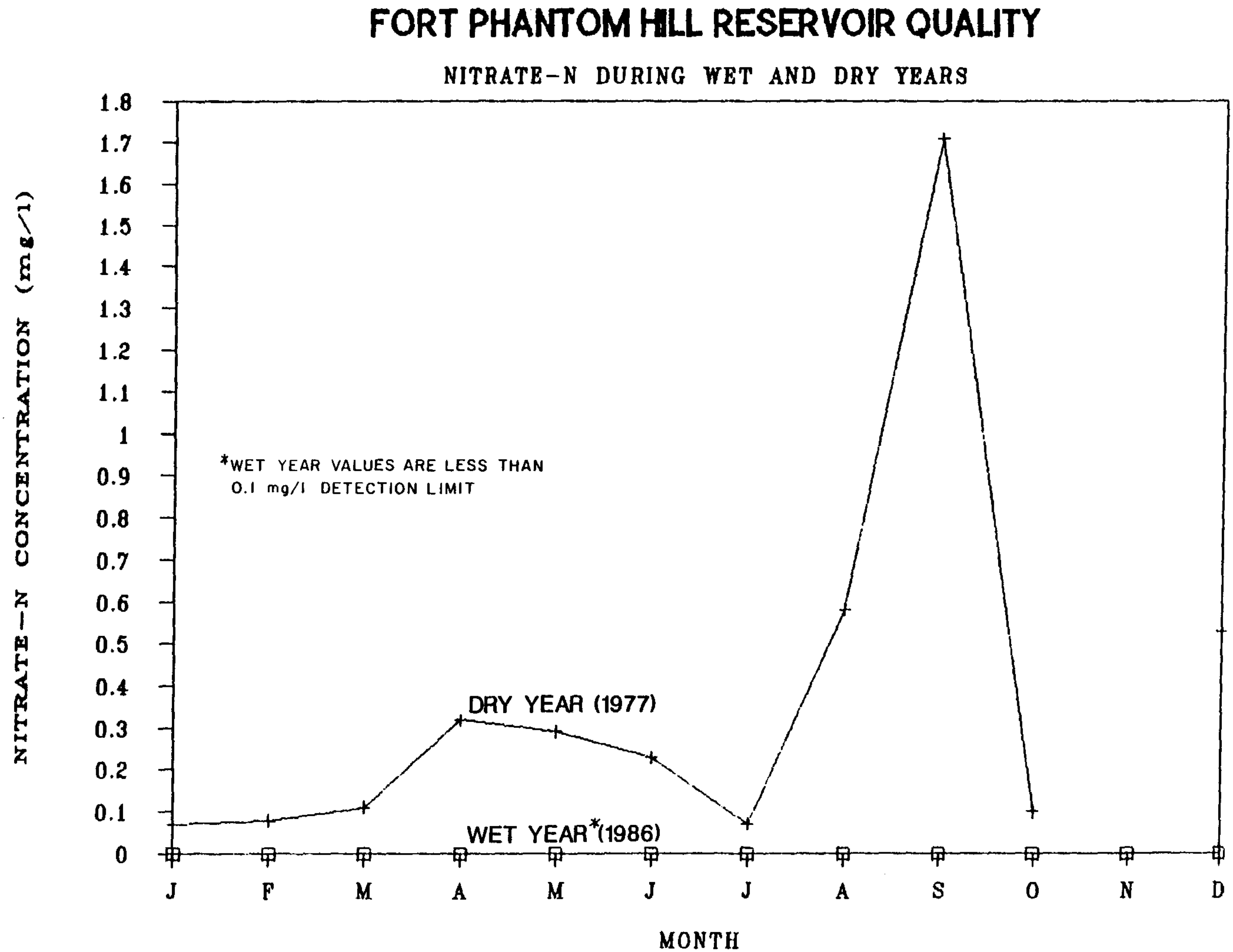

FORT PHANTOM HILL RESERVOIR QUALITY
NITRATE-N DURING WET AND DRY YEARS
NITRATE-N CONCENTRATION (mg/l)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
*WET YEAR VALUES ARE LESS THAN
0.1 mg/l DETECTION LIMIT
DRY YEAR (1977)
WET YEAR*(1986)
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

FIGURE 4-7

FORT PHANTOM HILL RESERVOIR QUALITY

DISS. ORTHO-P DURING WET AND DRY YEARS

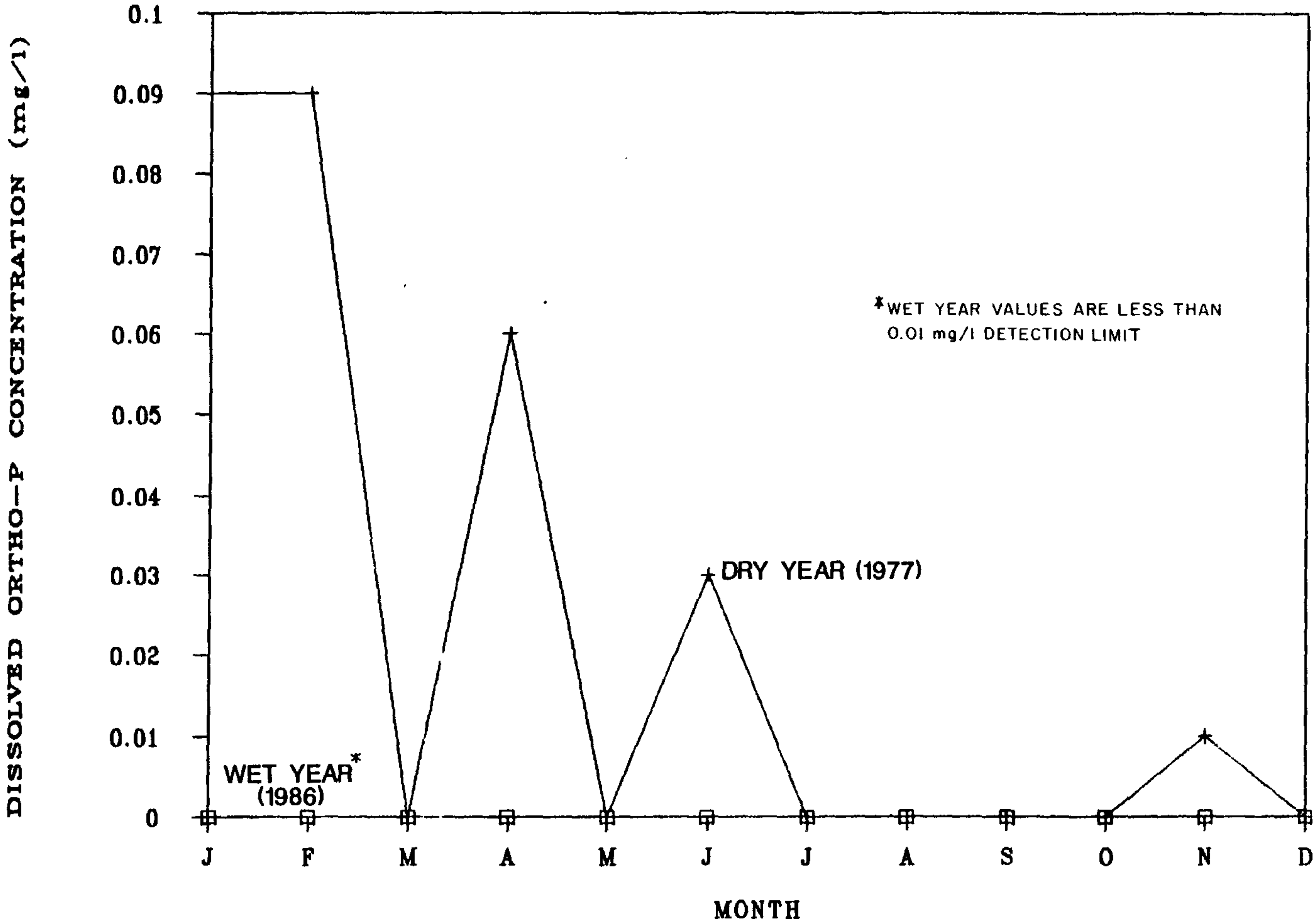


FIGURE 4-8

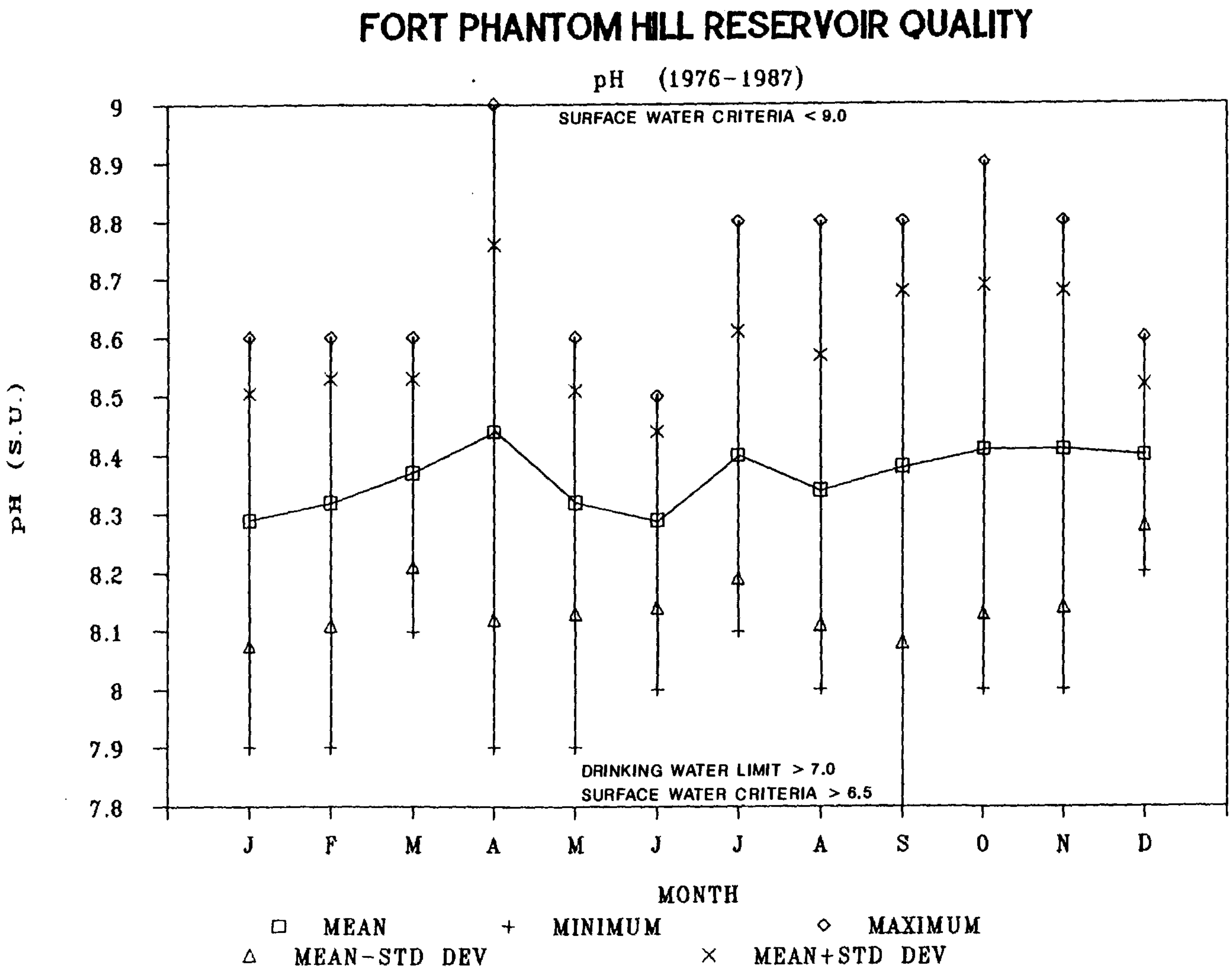

FORT PHANTOM HILL RESERVOIR QUALITY
pH (1976-1987)
SURFACE WATER CRITERIA < 9.0
DRINKING WATER LIMIT > 7.0
SURFACE WATER CRITERIA > 6.5
pH (S.U.)
9
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8
7.9
7.8
J F M A M J J A S O N D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-9

ranging from 8.3 in January and June to 8.4 in April. The lowest observed pH was 7.8 in September 1977, and the maximum pH was 9.0 in April 1985.

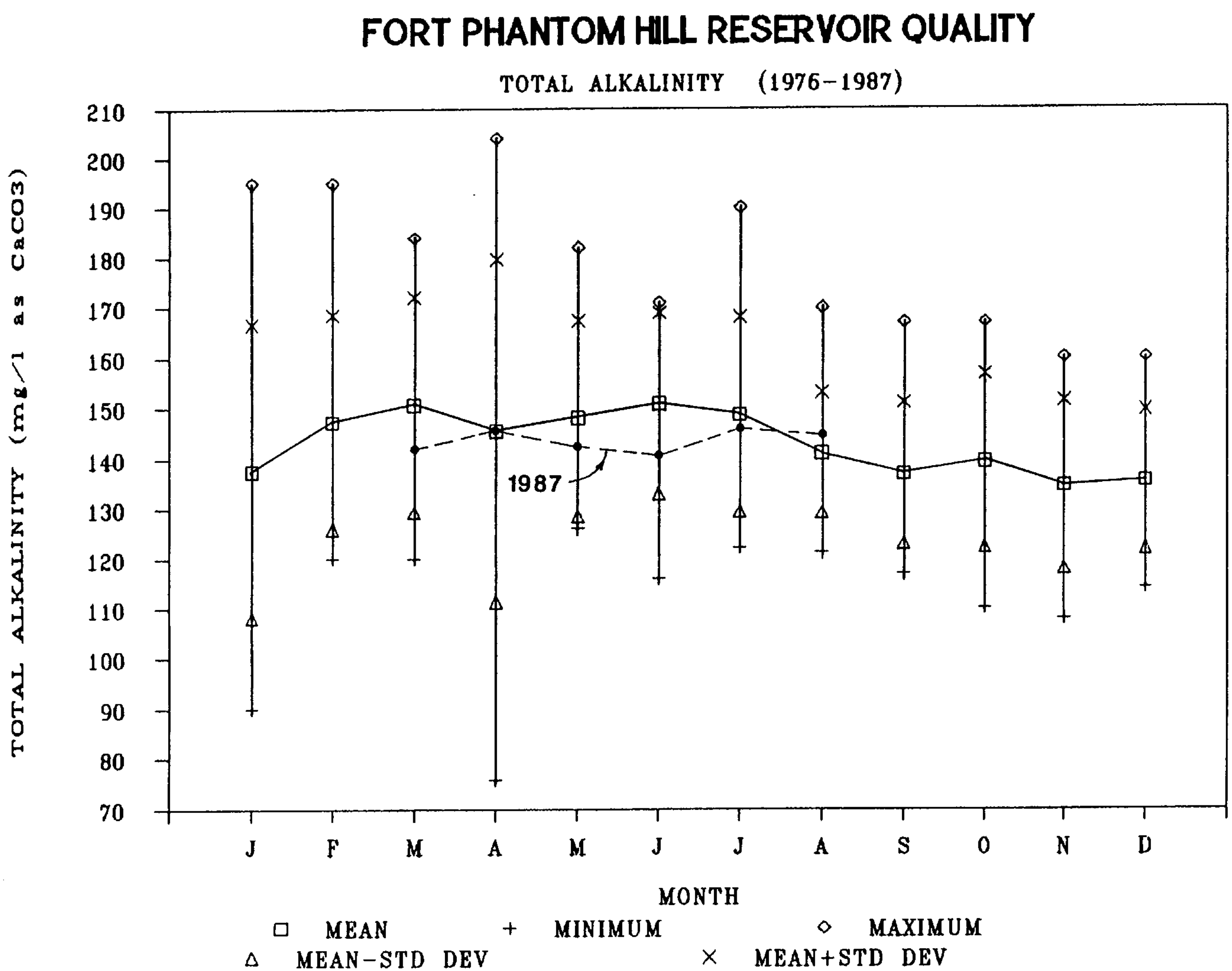
The relatively stable, alkaline pH reflects the high buffering capacity of the lake water. Total alkalinity was measured in 131 samples from 1976-1987 and averaged 143 mg/l as $CaCO_3$. The observed range of total alkalinity was from 76 mg/l in April 1981 to 204 mg/l in April 1980. The alkalinity means and ranges are plotted in Figure 4-10. Neither pH nor alkalinity were strongly correlated with other parameters. The 1987 alkalinity values were similar to the historical mean values (see Figure 4-10).

Total Dissolved Solids

High levels of dissolved solids, including chlorides and sulfates, is a common problem in both surface and ground water in west central Texas. These emanate from both naturally occurring mineral deposits and from past oil and gas production practices. The presence of dissolved minerals in excess of the drinking water standards can be of concern because of their objectionable taste, limitations for use in industrial boilers, and potential laxative effects.

The total dissolved solids (TDS) concentration in Lake Fort Phantom Hill averaged 466 mg/l based on 81 samples collected during the 1976-1987 period. Figure 4-11 indicates that mean monthly TDS varied from 401 mg/l in November and December to 535 mg/l in May. The minimum observed TDS levels occurred in 1982 with 200 mg/l in November and 203 mg/l in December. The peak concentration was 920 mg/l in May 1986.

Not surprisingly, total dissolved solids were positively correlated (p .01) with hardness (r=.75), chlorides (r=.67), sulfates (r=.58), and specific conductivity (r=.73). Mean monthly specific conductivity and ranges are plotted in Figure 4-12. An inverse relationship was noted between TDS concentration and water surface elevation (r=-.52; p .01), reflecting the influence of lake evaporation and freshwater inflows on



FORT PHANTOM HILL RESERVOIR QUALITY
TOTAL ALKALINITY (1976-1987)
TOTAL ALKALINITY (mg/l as CaCO3)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
1987
J F M A M J J A S O N D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-

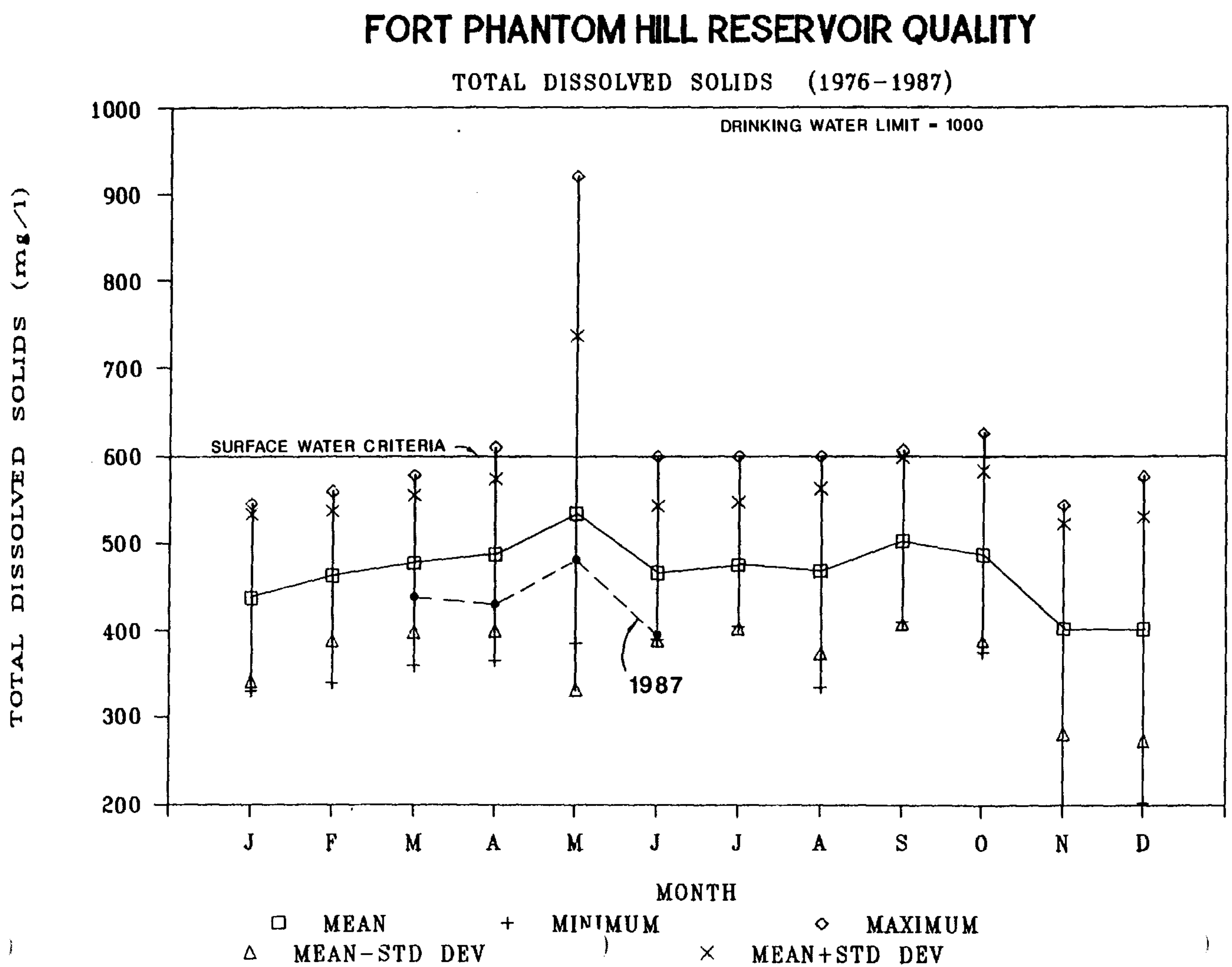
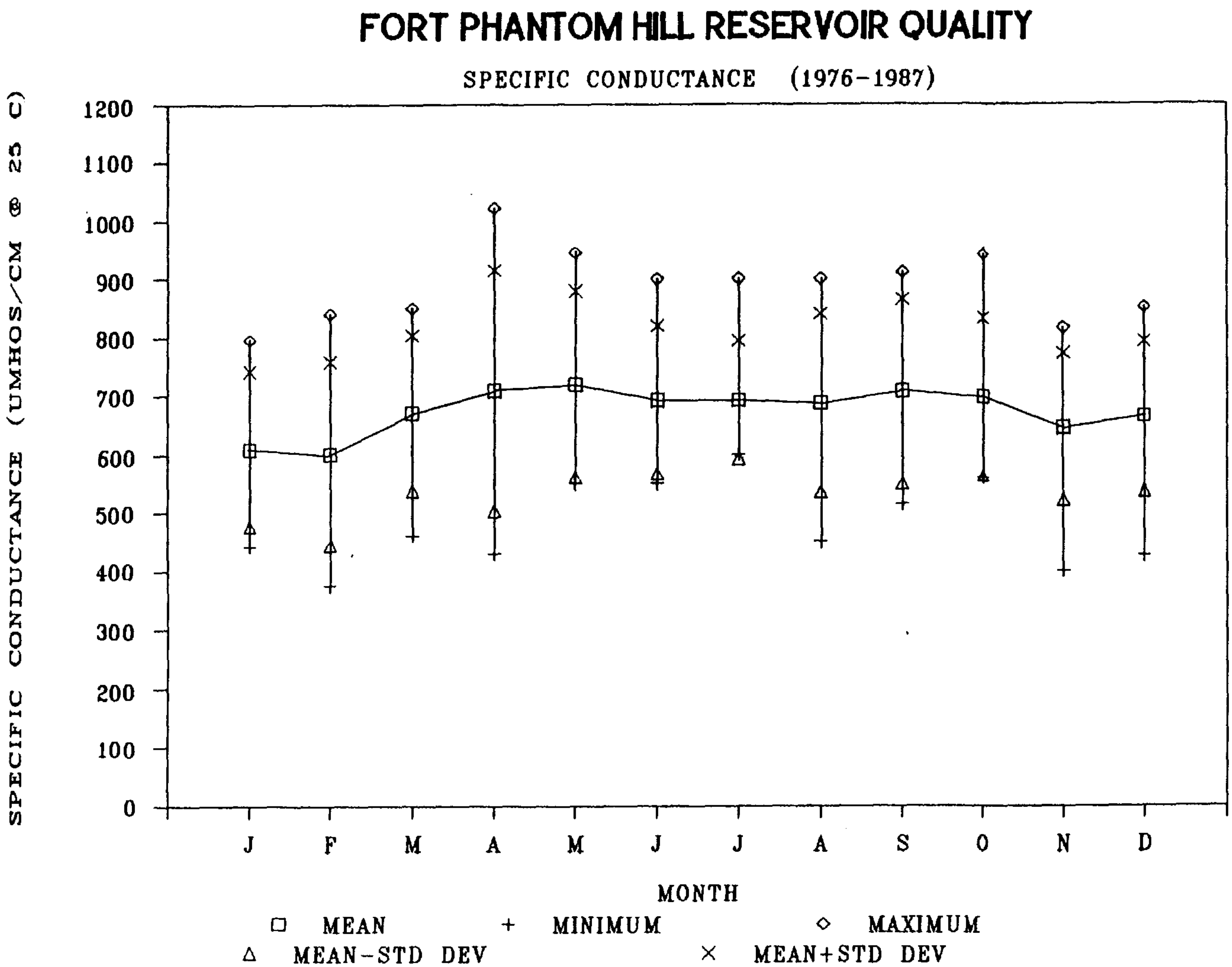

FORT PHANTOM HILL RESERVOIR QUALITY
TOTAL DISSOLVED SOLIDS (1976-1987)
DRINKING WATER LIMIT = 1000
SURFACE WATER CRITERIA
1987
TOTAL DISSOLVED SOLIDS (mg/l)
1000
900
800
700
600
500
400
300
200
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-



FORT PHANTOM HILL RESERVOIR QUALITY
SPECIFIC CONDUCTANCE (1976-1987)
SPECIFIC CONDUCTANCE (UMHOS/CM @ 25 C)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-12

mineral levels. The intensive sampling data for 1987 indicates slightly lower levels of dissolved solids.

The average chloride concentration of 131 samples collected between 1976 and 1987 was 94 mg/l. Mean monthly chlorides during the period are plotted in Figure 4-13 and varied from 88 mg/l in January to 104 mg/l in June. Observed concentrations ranged from 51 mg/l in March 1982 to 152 mg/l in April 1980. Chlorides showed significant positive correlations (p .01), with conductivity (r=.70), TDS (r=.67), and hardness (r=.55). Chlorides observed in the 1987 intensive sampling effort were lower than the 1976-1987 mean values.

Sulfates averaged 94 mg/l in 129 samples collected during the period. The average monthly concentrations for the period were between 80 mg/l and 100 mg/l in all months except March, June and July, when mean levels ranged above the 100 mg/l surface water quality criteria (TWC, 1985) up to 108 mg/l (see Figure 4-14). The observed extremes included a minimum sulfate concentration of 31 mg/l in January 1983, and a maximum of 270 mg/l in November 1983. Sulfate was significantly, positively correlated (p .01) with TDS (r=.58), NH_3-N (r=.63), and conductivity (r=.48). The 1987 intensive sampling indicates lower levels of sulfates.

The mean concentrations of total dissolved solids, chlorides, and sulfates in Lake Fort Phantom Hill are within state limits for drinking water quality. These constituents would be expected to become more concentrated during hot, dry periods when evaporation removes water and leaves the salts behind. However, comparison of wet year and dry year concentrations indicates that the opposite effect occurred in the lake for two of these constituents. Total dissolved solids levels were greater during the wet year (1986 rainfall = 31.98 inches) than the dry year (1983 rainfall = 19.50 inches) in nine out of 12 months (see Figure 4-15). Chloride concentrations during the wet year (1986) were greater than during the dry year (1977 rainfall = 16.27 inches) only in May (see Figure 4-16). Sulfate concentrations during the wet year (1986) exceeded the dry year (1977) levels in every month (see Figure 4-17).

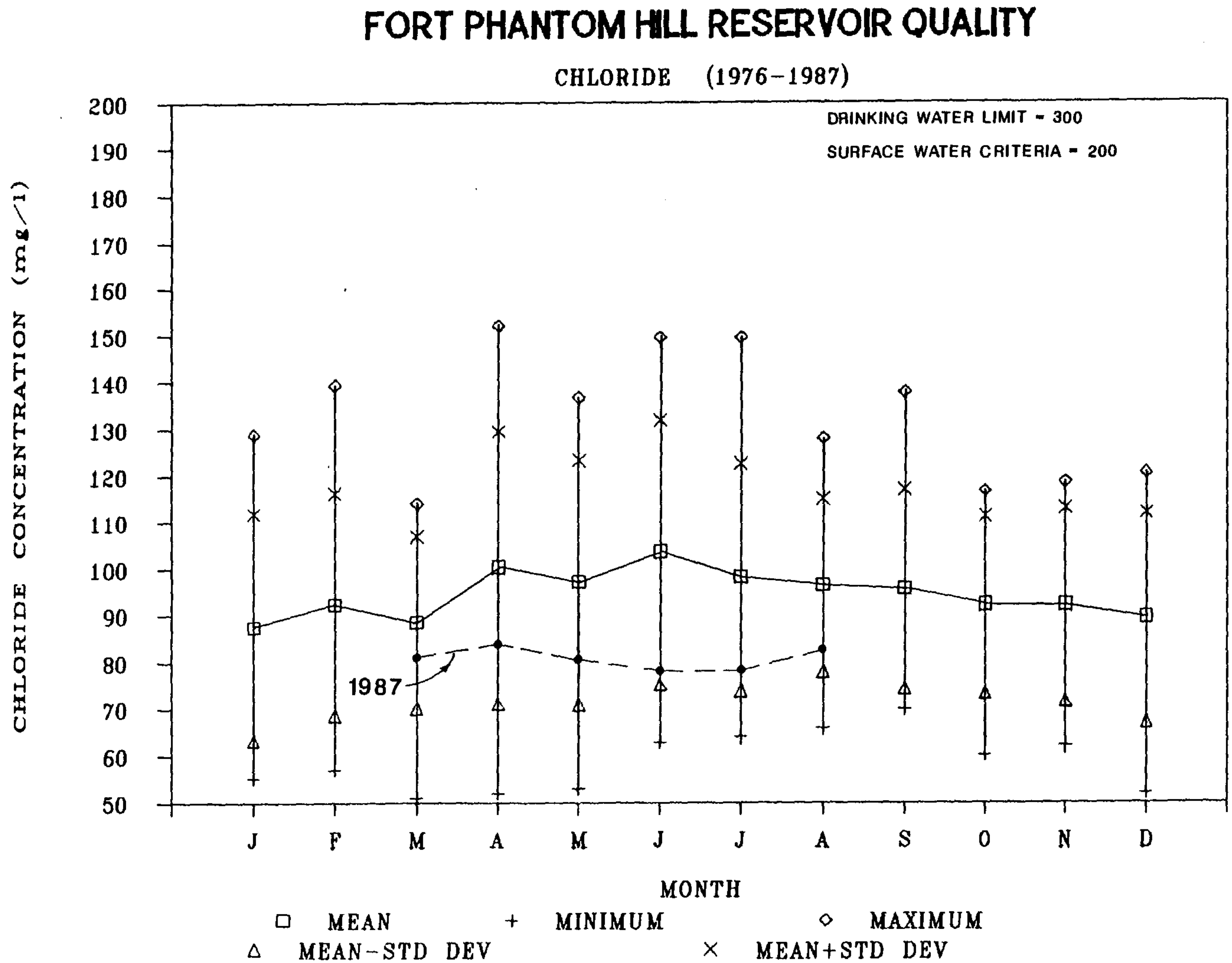

FORT PHANTOM HILL RESERVOIR QUALITY
CHLORIDE (1976-1987)
DRINKING WATER LIMIT = 300
SURFACE WATER CRITERIA = 200
CHLORIDE CONCENTRATION (mg/l)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
1987
J F M A M J J A S O N D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-13

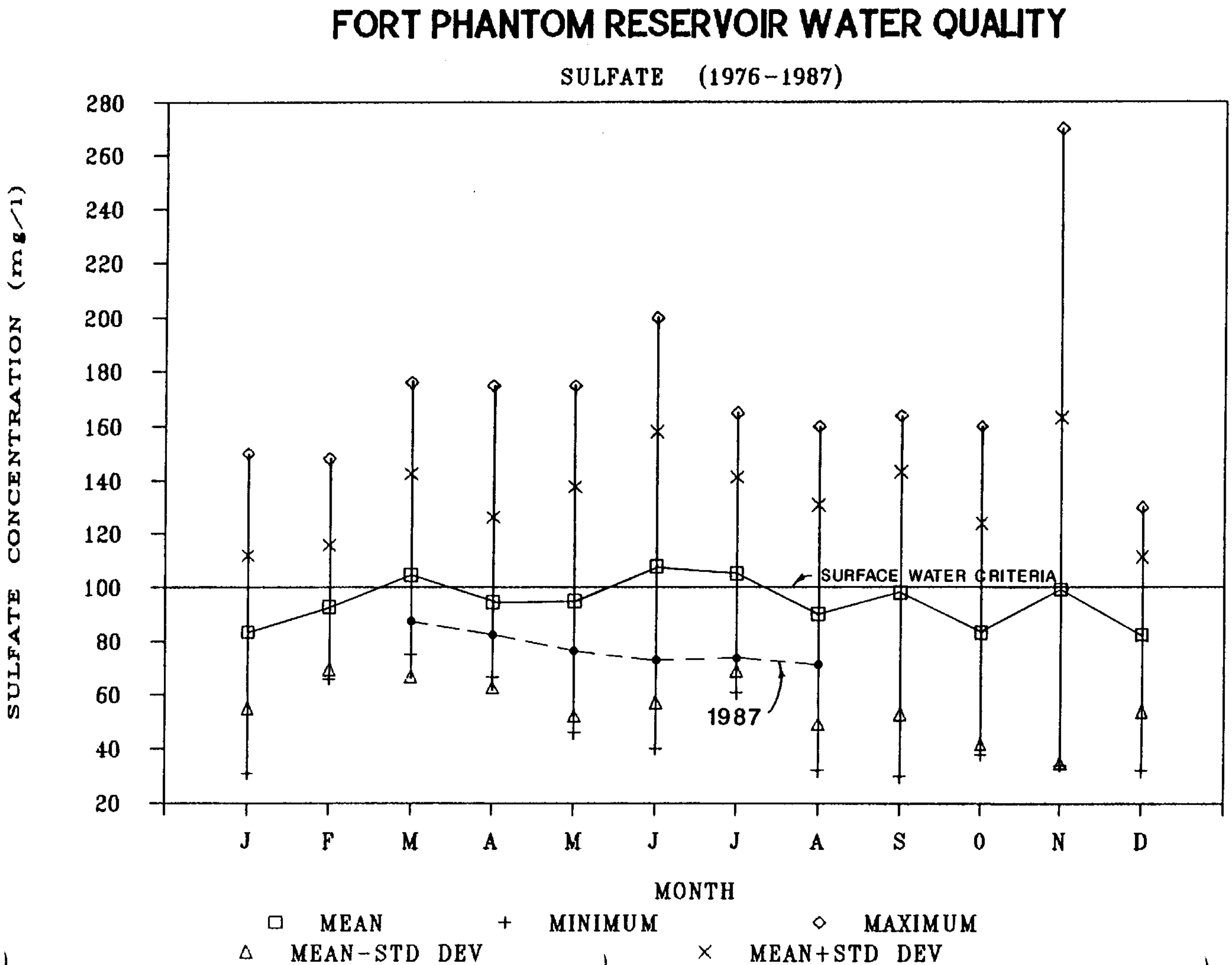

FORT PHANTOM RESERVOIR WATER QUALITY
SULFATE (1976-1987)
SULFATE CONCENTRATION (mg/l)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
SURFACE WATER CRITERIA
1987
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-14

FORT PHANTOM HILL RESERVOIR QUALITY

TDS DURING WET AND DRY YEARS

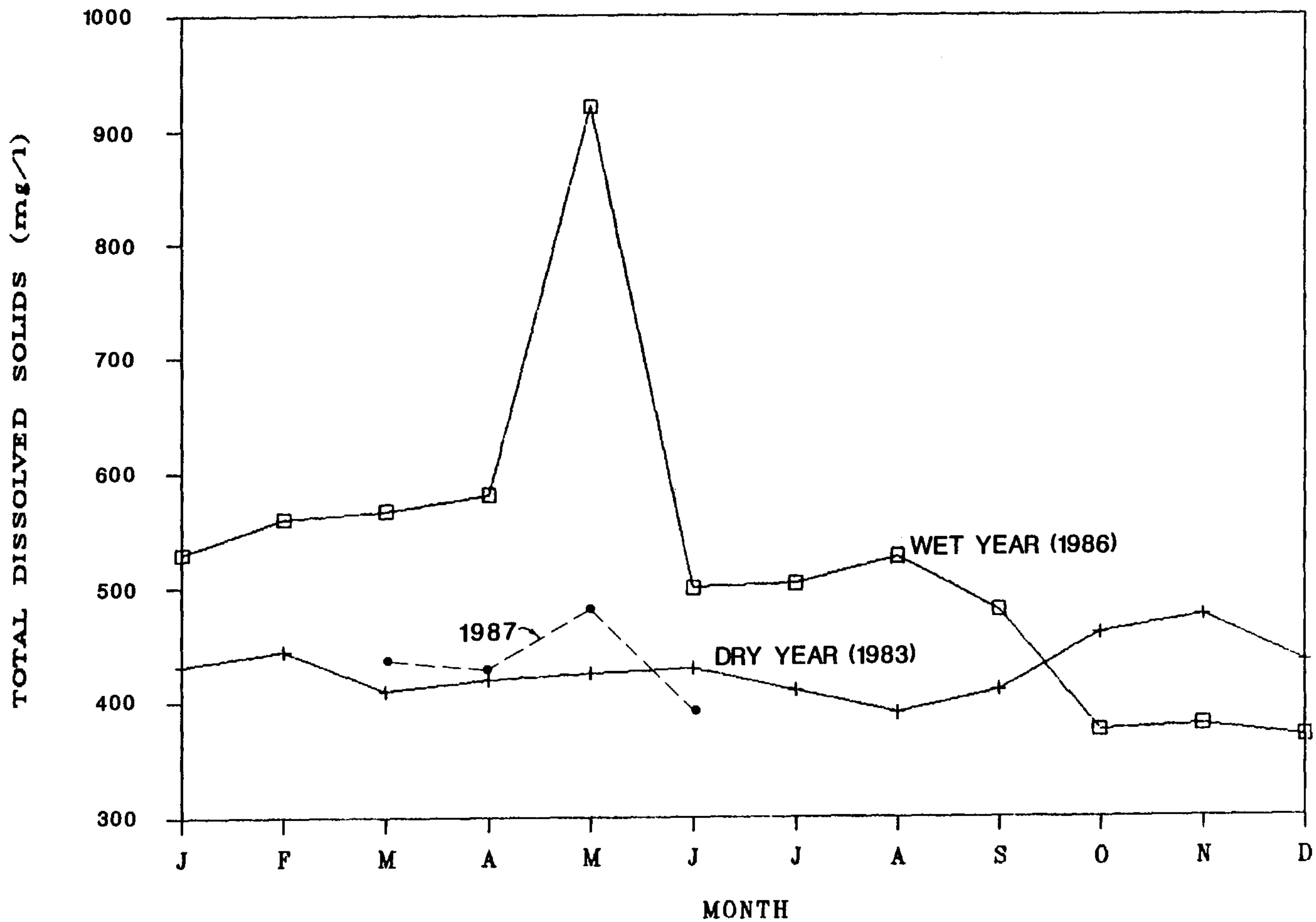


FIGURE 4-15

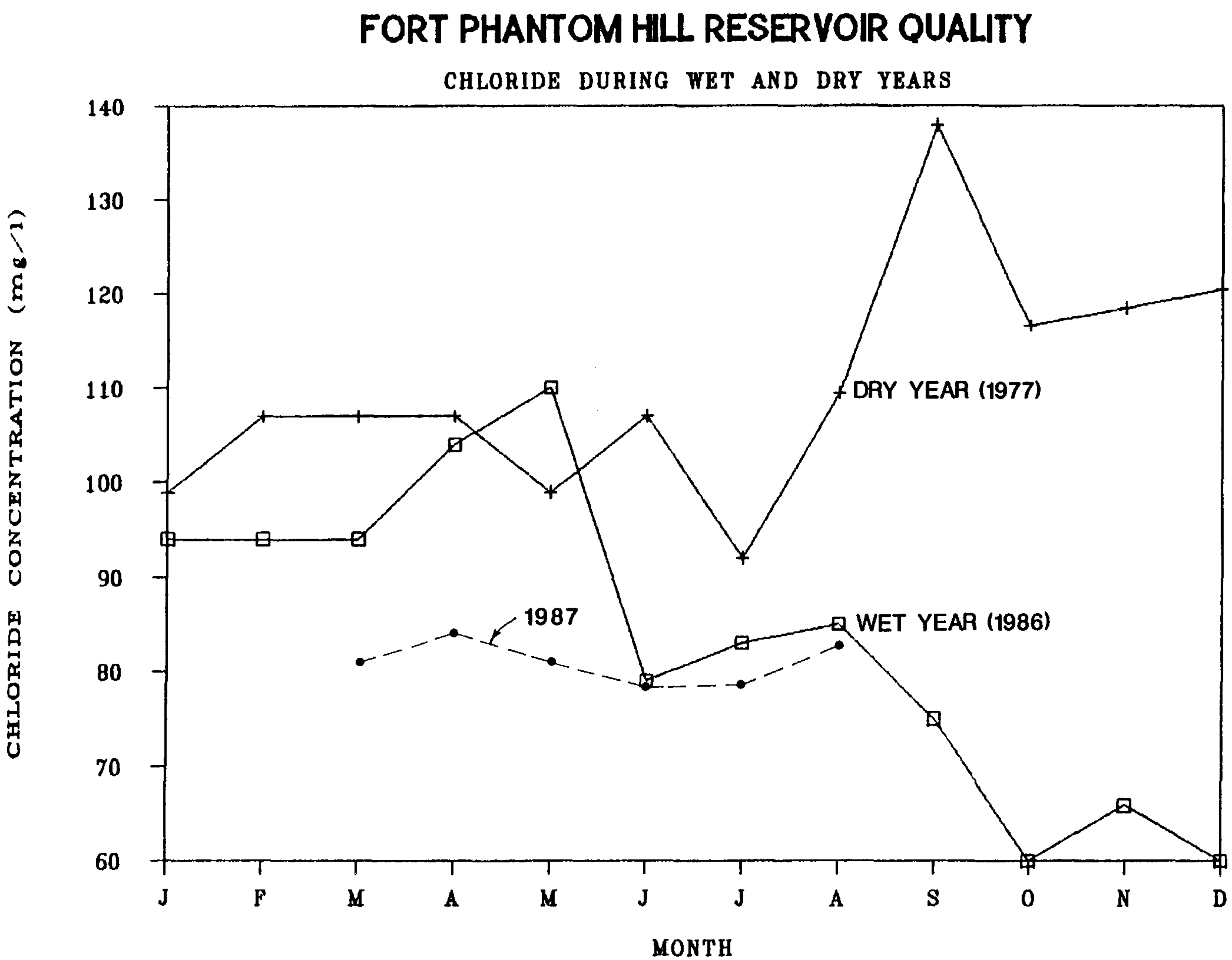

FORT PHANTOM HILL RESERVOIR QUALITY
CHLORIDE DURING WET AND DRY YEARS
CHLORIDE CONCENTRATION (mg/l)
140
130
120
110
100
90
80
70
60
DRY YEAR (1977)
WET YEAR (1986)
1987
J F M A M J J A S O N D
MONTH

FIGURE 4-16

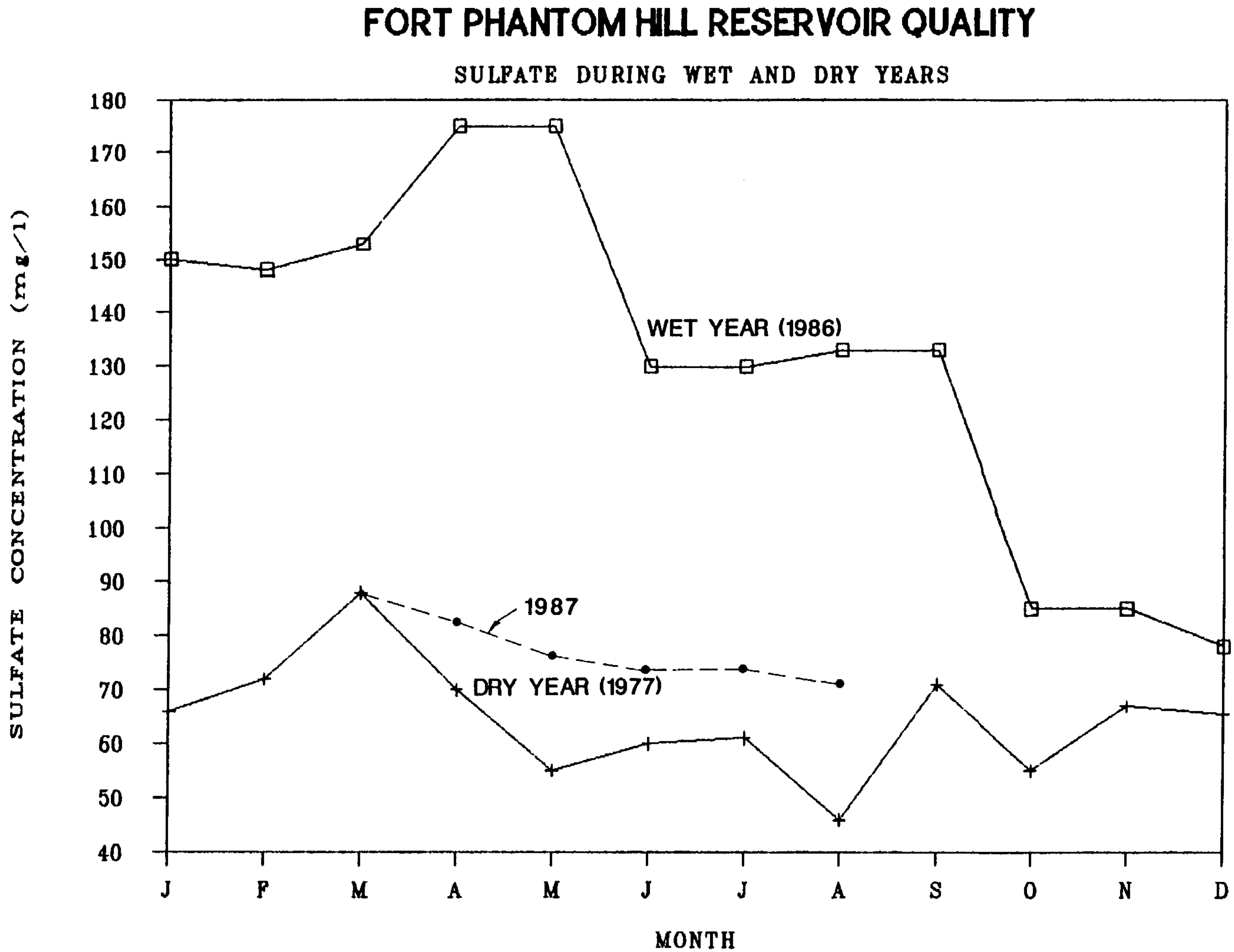

FORT PHANTOM HILL RESERVOIR QUALITY
SULFATE DURING WET AND DRY YEARS
SULFATE CONCENTRATION (mg/l)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
WET YEAR (1986)
1987
DRY YEAR (1977)
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

FIGURE 4-17

Further investigation may be necessary to determine the reason for these unexpected results, particularly since the 1987 intensive sampling data, which also represent a wet year, do not always conform to the levels observed in 1986. Some factors which potentially may influence the dissolved mineral levels include the amount of lake inflow derived from the Clear Fork Brazos River, Deadman Creek, and the lake's natural watershed; the quality of water from each of these sources; monthly rainfall; and water surface elevation on the day of sample collections.

Iron

Of all the inorganic substances which have been evaluated, only iron exhibits consistently high levels. Iron is naturally abundant in soils and rock and commonly found in waters in various forms and concentrations. Although it is not a concern from a health standpoint, iron can stain laundry and porcelain and can cause an unpleasant taste at levels exceeding 0.31 mg/l (Manahan, 1975).

The average concentration of iron analyzed in 84 samples during the 1976-1987 period was 0.23 mg/l. Mean monthly concentrations exceeded the 0.30 mg/l recommended limit for drinking water (TDH, 1986) in March, July, November and December and varied from 0.12 mg/l to 0.25 mg/l during the remaining months (see Figure 4.18). The observed extremes ranged from less than detectable limits to 1.31 mg/l in August 1980. No important correlations were observed between iron and other sampling parameters. The 1987 intensive sampling data exhibits continued high levels of iron in all but the wastewater effluent (see Table 4-10).

The 1987 intensive sampling data also contained some elevated levels of manganese, particularly in the creek samples. Manganese exhibits the same objectionable characteristics as iron, but at much lower concentrations.

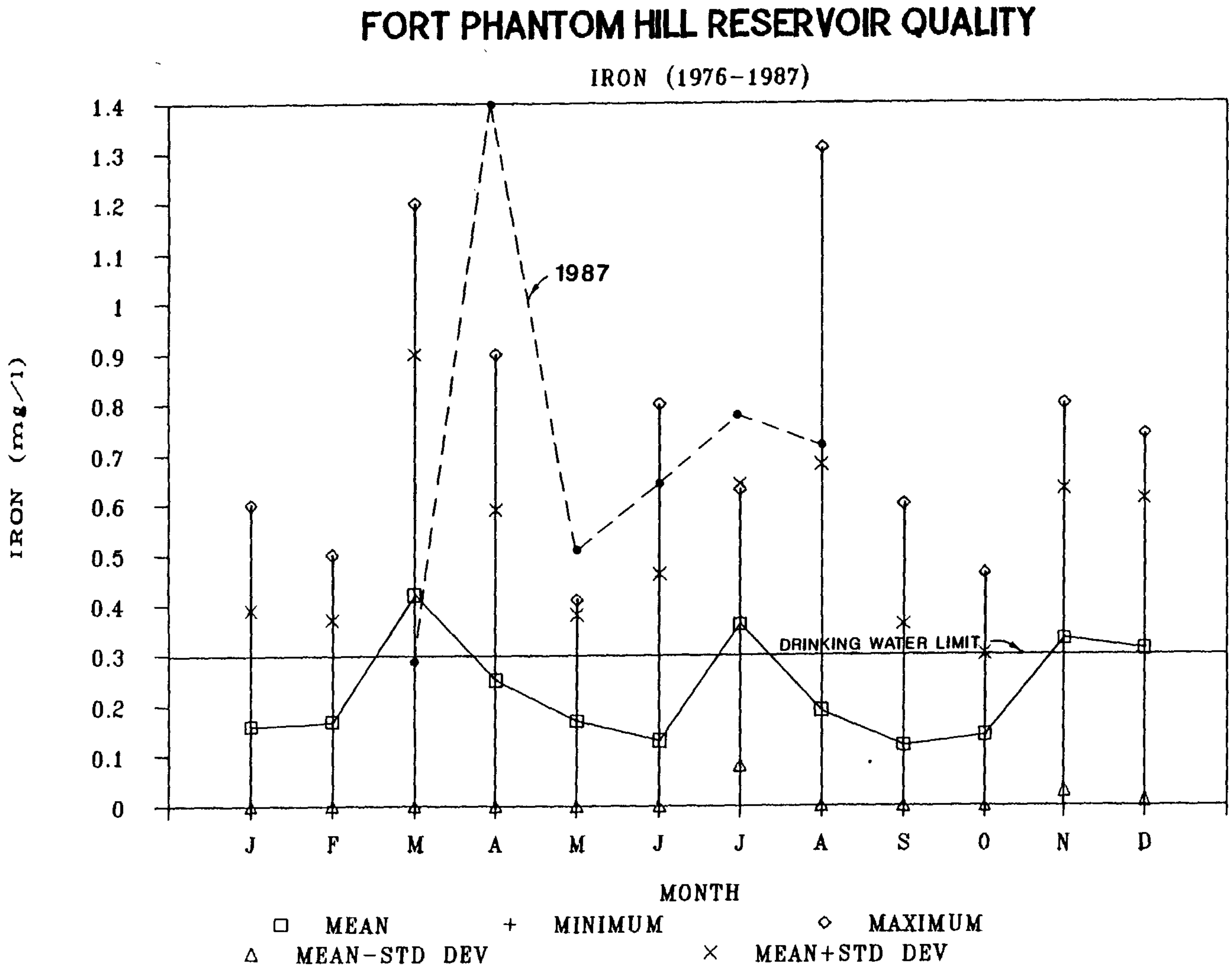

FORT PHANTOM HILL RESERVOIR QUALITY
IRON (1976-1987)
IRON (mg/l)
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1987
DRINKING WATER LIMIT
J F M A M J J A S O N D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-18

Fecal Coliform

The presence of fecal coliforms in water is used to measure the potential risk of contamination by various pathogenic bacteria from intestinal wastes of warm-blooded animals. Escherichia coli is normally the dominant organism measured as fecal coliform, but other genera may also include Streptococcus, Pseudomonas, and other pathogenic organisms. A level of 200 colonies per 100 milliliters has been established for protection of public health during contact recreation such as swimming.

Fecal coliform bacteria averaged 38 colonies per 100 ml in 81 samples collected from Lake Fort Phantom Hill between 1976 and 1987. Figure 4-19 shows that the mean monthly concentrations varied somewhat during the year with higher counts observed during May and October. The average May and October fecal coliform levels were 147 colonies per 100 ml and 83 colonies per 100 ml, respectively. The mean counts during other months varied between 13 colonies and 49 colonies per 100 ml. Zero counts were observed in each month at least one year, and the maximum observed counts were 300 colonies per 100 ml in May 1981, and 232 colonies per 100 ml in October 1979. It should be noted that the 200 colonies per 100 ml surface water quality criterion for fecal coliforms adopted by the TWC (1985) is based on a geometric mean of at least five samples collected over a 30-day period. Thus, the individual samples reported as greater than 200 colonies per 100 ml do not constitute a water quality standards violation. No important correlations were observed between fecal coliforms and the other parameters.

Turbidity

The average sampling value was 37 Formazin turbidity units (FTU). Mean monthly values varied from 20 FTU in February to 53 FTU in June. The observed extremes ranged from 4 FTU in January 1984 to 170 FTU in July 1979. The turbidity sampling statistics are plotted in Figure 4-20. The 1987 intensive sampling data fell within the same range. No important correlations were detected between turbidity and the other sampling parameters.

FORT PHANTOM HILL RESERVOIR QUALITY

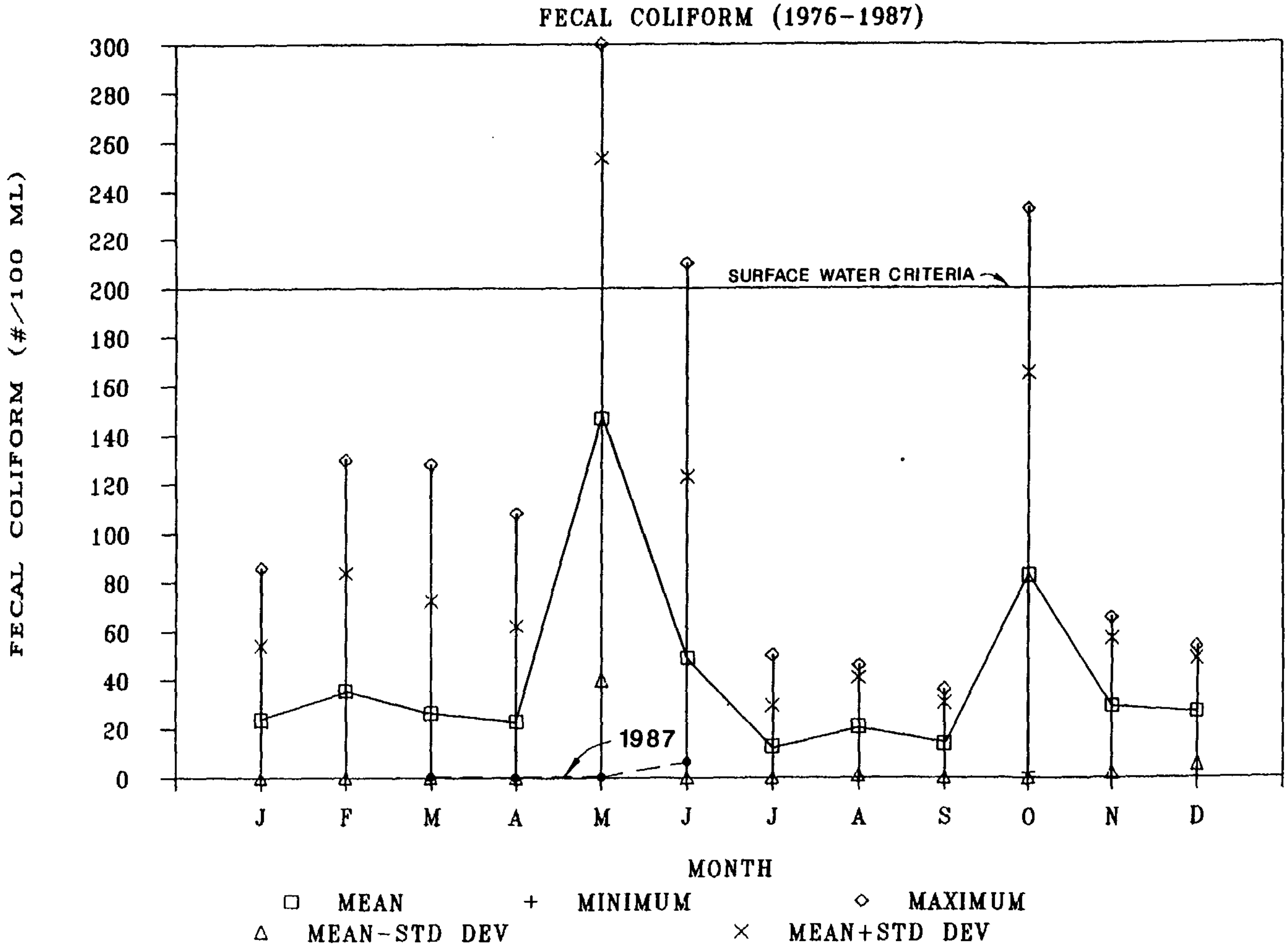
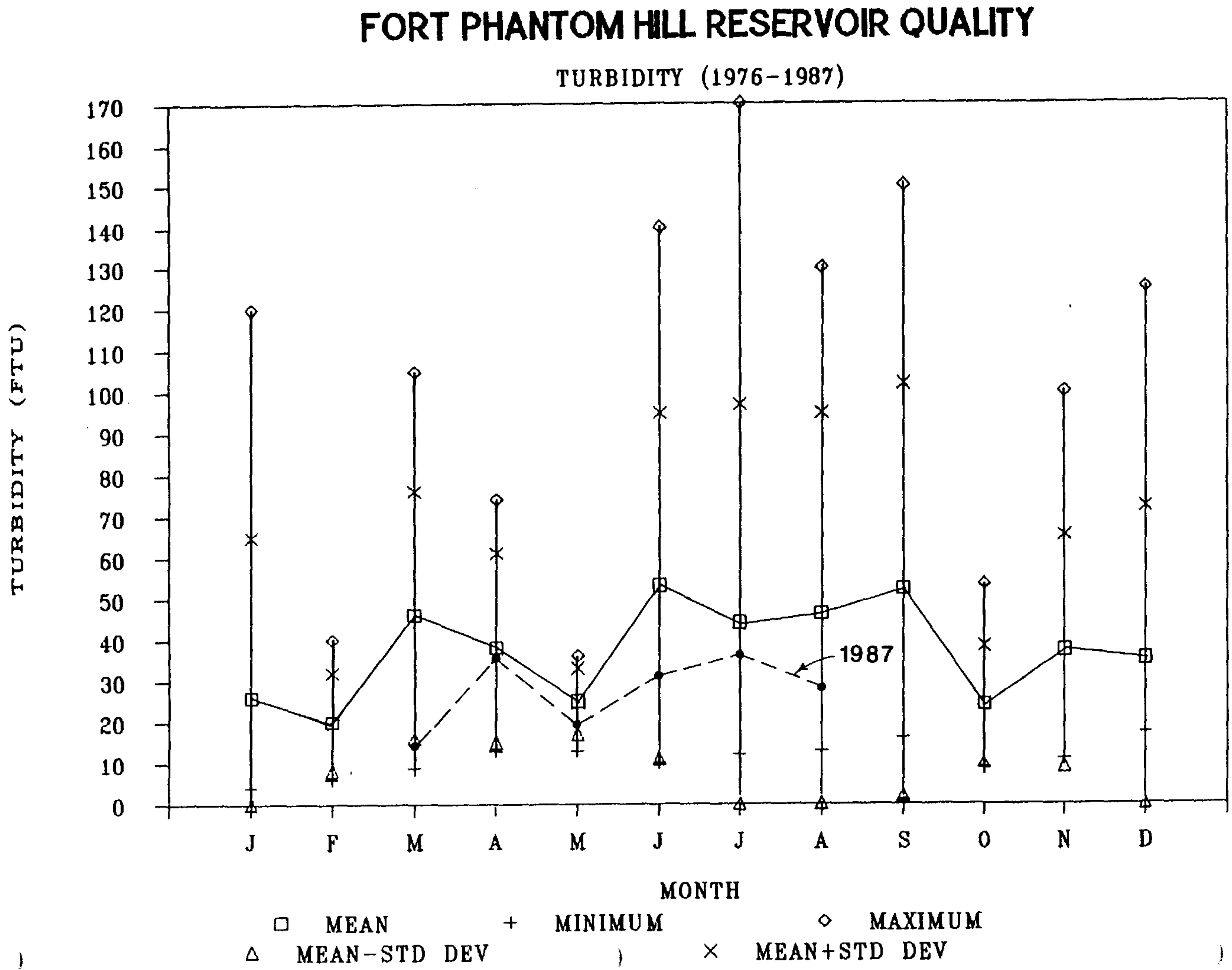


FIGURE 4-19



FORT PHANTOM HILL RESERVOIR QUALITY
TURBIDITY (1976-1987)
TURBIDITY (FTU)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1987
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
MEAN
MINIMUM
MAXIMUM
MEAN-STD DEV
MEAN+STD DEV

FIGURE 4-20

Algae

Little information on algae is available for Lake Fort Phantom Hill. The City of Abilene has records of algae identification intermittently from 1963 to 1974. During this time, algae were identified, but not quantified. Data from 1970 to 1974 indicate that Cyclotella were present throughout the spring, fall and winter months, but that Anabaena was the predominant algae during the summer months. Oscillatoria was also present during the summer months.

Organic Chemicals

With the exception of the isolated samples containing phthalato, acetone, and trichloroethene, none of the other organic chemicals (including pesticides) analyzed during the intensive sampling of 1987 have exhibited detectable levels. Total organic carbon, total trihalomethane forming potential, and odor were elevated in the lake which probably reflects the presence of naturally occurring humic substances.

Viruses

Water samples were collected in April and August to determine the presence of any viruses in the reservoir, creek or wastewater effluent. Hepatitis A virus (HAV) was not detected in any of the samples. Human rotavirus (RV) was only found in the April wastewater samples, consistent with the recognized occurrence of rotavirus in winter and spring. A number of enteroviruses were present in wastewater with significantly greater numbers detected in summer than in the spring.

The only viruses detected in samples other than the raw and treated wastewater were reovirus type 2. This virus was found in both creeks; one reservoir site, and the wastewater. The virology technical report is found in Appendix E.

Parasitics

Water samples were collected in September 1987 and January 1988 to determine the presence of any parasitic organisms in water system and wastewater system. Samples were collected from the Northeast WTP influent and effluent waters and the Hamby WWTP influent and effluent wastewaters. No parasitics were found in the potable water system on either occasion.

A pathogenic organism Acanthamoeba was encountered in the cold weather sampling of the raw water supply in a dilute concentration of 4 per liter. A nonpathogenic amoeba, Entamoeba hartmanni, was identified in higher, although normal concentrations of 241 per liter. Three organisms, Entamoeba hartmanni, Entamoeba coli, and Endolimax nana were identified in the wastewater effluent in concentrations of 2377-130 per liter, 679-66 per liter, and 340 per liter, respectively. Where two values are given, the second were the warm weather values.

As would be expected, large quantities were found in the raw wastewater. The same organisms identified in the effluent plus Acanthamoeba sp. were quantified as 60,000-860 per liter, 25,000-286 per liter, 5,000-143 per liter and 3,200-3 per liter. The higher values are the cold weather counts.

During the cold weather monitoring, special testing was conducted for cryptospiridium sp. No cryptospiridium sp. were identified in either the waters or wastewaters tested.

The parasitic organism technical report is found in Appendix E.

OVERALL EVALUATION

The water quality data indicate that Lake Fort Phantom Hill is good to excellent, with few parameters at levels which would limit its use for domestic use or aquatic life. The lake supports an excellent fishery, which is indicative of its quality.

References

Brazos River Authority. 1975. Water quality management plan for the Brazos Basin.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22(2):361-369.

Manahan, S.E. 1975. Environmental Chemistry. Willard Grant Press, Boston, Massachusetts. 532 pp.

Texas Department of Health. 1987. Drinking water standards governing drinking water quality and reporting requirements for public water supply systems. Revised standards effective January 6, 1987.

Texas Water Commission. 1985. Draft Texas surface water quality standards. 95 pp.

Texas Water Commission. 1986. The State of Texas water quality inventory. 8th Edition. LP 86-07.

U.S. Environmental Protection Agency. 1973. Water Quality Criteria 1972. EPA/R3-73-033.

U.S. Environmental Protection Agency. 1977. National eutrophication survey report on Lake Fort Phantom Hill, Jones County, Texas. EPA Region VI Working Paper No. 644. 16 pp.

U.S. EPA 1977. Algae and Water Pollution. Municipal Environmental Research Laboratory. Office of Research and Development. U.S. Environmental Protection Agency. Cincinnati, OH. EPA-600 19-77-036. 124 pp.

APPENDICES

Table of Contents
Technical Memorandum No. 4
Water Quality Assessment

APPENDICES

APPENDIX A

```
TITLE FORT PHANTOM HILL RESERVOIR QUALITY.
DATA LIST FILE='B:PHANTWQ.DAT' / YEAR 1-2 MONTH 3-4 DAY 5-6 TEMP 7-10
           DO 11-15 PH 16-20 TURB 21-25
           COND 26-30 TDS 31-35 TALK 36-40 HARD 41-45 CA 46-50 MG 51-55
           CL 56-60 FL 61-65 PO4 66-70 SI 71-75 FCOLI 76-80 / CR 7-10 CU 11-15
           NI 16-20 PB 21-25 ZN 26-30 FE 31-35 AG 36-40 NA 41-45 BA 46-50
           NH3 51-55 NO3 56-60 NO2 61-65 MN 66-70 ELEV 71-75 K 76-80 /
           SO4 7-10 CD 11-15 BR 16-20.
VALUE LABELS MONTH 01 'JANUARY'
                   02 'FEBRUARY'
                   03 'MARCH'
                   04 'APRIL'
                   05 'MAY'
                   06 'JUNE'
                   07 'JULY'
                   08 'AUGUST'
                   09 'SEPTEMBER'
                   10 'OCTOBER'
                   11 'NOVEMBER'
                   12 'DECEMBER'.
MISSING VALUE ALL (-1).
CORRELATION VARIABLES=ALL
The raw data or transformation pass is proceeding
    133 cases are written to the uncompressed active file.
            /OPTIONS=2 5
            /STATISTICS=1.
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Variable	Cases	Mean	Std Dev
YEAR	133	81.0451	3.2048
MONTH	133	6.4586	3.4848
DAY	123	11.8780	9.4683
TEMP	98	19.1031	7.9981
DO	89	8.9247	2.0914
PH	131	8.3622	.2251
TURB	89	37.4652	35.6806
COND	101	674.2376	141.9099
TDS	81	466.4938	104.8803
TALK	131	142.9473	20.7422
HARD	131	231.9031	29.3995
CA	124	60.5944	19.3952
MG	123	22.4106	10.2599
CL	131	94.4786	22.8382
FL	129	.2946	.1452
PO4	105	.0522	.1338
SI	90	4.3248	2.8016
FCOLI	81	38.3951	57.1736
CR	87	.0215	.1822
CU	88	.0108	.0447
NI	88	.0019	.0109
PB	88	.0034	.0084
ZN	87	.0524	.1871
FE	84	.2306	.3076
AG	47	0.0	0.0
NA	100	64.5070	21.7961
BA	0	.	.
NH3	73	.2977	.5412
NO3	112	.1813	.3182
NO2	97	.0138	.0263
MN	60	.0120	.0428
ELEV	114	1627.4825	5.1167
K	74	8.6238	3.7855
SO4	129	94.4721	39.5731
CD	88	.0002	.0021
BR	67	.4604	.8570

Correlations:	YEAR	MONTH	DAY	TEMP	DO	PH	TURB	COND	TDS	TALK	HARD
YEAR	1.0000 (133) P= .	-.0222 (133) P= .400	-.1056 (123) P= .123	-.0255 (98) P= .402	.2345 (89) P= .013	.2149 (131) P= .007	-.4234 (89) P= .000	.2892 (101) P= .002	.2889 (81) P= .004	-.3252 (131) P= .000	.1112 (131) P= .103
MONTH	-.0222 (133) P= .400	1.0000 (133) P= .	.0167 (123) P= .427	.3699 (98) P= .000	-.3393 (89) P= .001	.1218 (131) P= .083	.0750 (89) P= .243	.0887 (101) P= .189	-.1049 (81) P= .176	-.1566 (131) P= .037	-.0182 (131) P= .418
DAY	-.1056 (123) P= .123	.0167 (123) P= .427	1.0000 (123) P= .	.1586 (94) P= .063	-.1844 (85) P= .046	-.0913 (123) P= .158	-.2478 (85) P= .011	.0542 (96) P= .300	-.0762 (76) P= .257	.0587 (123) P= .260	.0420 (123) P= .322
TEMP	-.0255 (98) P= .402	.3699 (98) P= .000	.1586 (94) P= .063	1.0000 (98) P= .	-.5926 (89) P= .000	.1011 (98) P= .161	.2068 (89) P= .026	.2626 (98) P= .004	.2583 (78) P= .011	.1002 (98) P= .163	.3178 (98) P= .001
DO	.2345 (89) P= .013	-.3393 (89) P= .001	-.1844 (85) P= .046	-.5926 (89) P= .000	1.0000 (89) P= .	.2129 (89) P= .023	-.3156 (87) P= .001	-.0008 (89) P= .497	-.0220 (71) P= .428	-.1940 (89) P= .034	-.0736 (89) P= .247
PH	.2149 (131) P= .007	.1218 (131) P= .083	-.0913 (123) P= .158	.1011 (98) P= .161	.2129 (89) P= .023	1.0000 (131) P= .	-.0753 (89) P= .241	.1321 (101) P= .094	.1108 (81) P= .162	.0497 (131) P= .286	.1186 (131) P= .089
TURB	-.4234 (89) P= .000	.0750 (89) P= .243	-.2478 (85) P= .011	.2068 (89) P= .026	-.3156 (87) P= .001	-.0753 (89) P= .241	1.0000 (89) P= .	-.0536 (89) P= .309	.0202 (72) P= .433	.2176 (89) P= .020	-.0287 (89) P= .395
COND	.2892 (101) P= .002	.0887 (101) P= .189	.0542 (96) P= .300	.2626 (98) P= .004	-.0008 (89) P= .497	.1321 (101) P= .094	-.0536 (89) P= .309	1.0000 (101) P= .	.7347 (81) P= .000	.1184 (101) P= .119	.6292 (101) P= .000
TDS	.2889 (81) P= .004	-.1049 (81) P= .176	-.0762 (76) P= .257	.2583 (78) P= .011	-.0220 (71) P= .428	.1108 (81) P= .162	.0202 (72) P= .433	.7347 (81) P= .000	1.0000 (81) P= .	.0043 (81) P= .485	.7529 (81) P= .000
TALK	-.3252 (131) P= .000	-.1566 (131) P= .037	.0587 (123) P= .260	.1002 (98) P= .163	-.1940 (89) P= .034	.0497 (131) P= .286	.2176 (89) P= .020	.1184 (101) P= .119	.0043 (81) P= .485	1.0000 (131) P= .	.2476 (131) P= .002
HARD	.1112 (131) P= .103	-.0182 (131) P= .418	.0420 (123) P= .322	.3178 (98) P= .001	-.0736 (89) P= .247	.1186 (131) P= .089	-.0287 (89) P= .395	.6292 (101) P= .000	.7529 (81) P= .000	.2476 (131) P= .002	1.0000 (131) P= .
CA	.4665 (124) P= .000	-.0061 (124) P= .473	.0110 (116) P= .453	.1387 (91) P= .095	.0642 (82) P= .283	.2913 (124) P= .001	.0553 (82) P= .311	.2085 (94) P= .022	.1079 (74) P= .180	.0443 (124) P= .312	.2974 (124) P= .000
MG	-.1559 (123) P= .043	.0248 (123) P= .393	.0130 (115) P= .445	.0489 (90) P= .324	.2321 (81) P= .019	.1134 (123) P= .106	.0783 (81) P= .243	.2543 (93) P= .007	.0474 (73) P= .345	.0519 (123) P= .284	.2669 (123) P= .001

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

Correlations:	YEAR	MONTH	DAY	TEMP	DO	PH	TURB	COND	TDS	TALK	HARD
CL	-.4720 (131) P= .000	.0079 (131) P= .464	.1141 (123) P= .104	.2817 (98) P= .002	-.1223 (89) P= .127	-.0457 (131) P= .302	.1109 (89) P= .150	.6972 (101) P= .000	.6748 (81) P= .000	.3331 (131) P= .000	.5503 (131) P= .000
FL	.0635 (129) P= .237	.1023 (129) P= .124	.0154 (122) P= .433	.2313 (98) P= .011	-.1713 (89) P= .054	.0479 (129) P= .295	.0247 (89) P= .409	.0607 (100) P= .274	.1233 (80) P= .138	.1350 (129) P= .064	.2469 (129) P= .002
PO4	.1401 (105) P= .077	-.0102 (105) P= .459	-.1974 (97) P= .026	-.1213 (73) P= .153	.1135 (65) P= .184	.0969 (105) P= .163	.1905 (64) P= .066	-.0897 (76) P= .220	-.1963 (57) P= .072	-.0315 (105) P= .375	-.1049 (105) P= .143
SI	.4077 (90) P= .000	.1675 (90) P= .057	-.1817 (86) P= .047	-.1092 (90) P= .153	.0654 (88) P= .272	-.0202 (90) P= .425	-.0759 (88) P= .241	.0112 (90) P= .458	.0244 (73) P= .419	-.2633 (90) P= .006	-.0283 (90) P= .396
FCOLI	-.3523 (81) P= .001	.0083 (81) P= .471	-.0534 (79) P= .320	.1004 (80) P= .188	-.1077 (74) P= .180	-.1685 (81) P= .066	-.1127 (73) P= .171	-.0717 (81) P= .262	-.0695 (62) P= .296	.0203 (81) P= .429	.0471 (81) P= .338
CR	.1122 (87) P= .150	-.1036 (87) P= .170	-.1521 (83) P= .085	-.0391 (55) P= .389	.2294 (46) P= .063	-.0707 (87) P= .258	-.1178 (46) P= .218	-.0520 (57) P= .350	-.1240 (40) P= .223	.1890 (87) P= .040	-.0560 (87) P= .303
CU	-.0283 (88) P= .397	.1056 (88) P= .164	-.1171 (84) P= .144	-.1397 (56) P= .152	.3402 (47) P= .010	-.0260 (88) P= .405	-.1716 (47) P= .124	-.0298 (58) P= .412	-.0584 (40) P= .360	-.0099 (88) P= .463	-.0460 (88) P= .335
NI	.1104 (88) P= .153	-.0085 (88) P= .469	.0265 (84) P= .405	.1009 (56) P= .230	-.0765 (47) P= .305	.0546 (88) P= .307	.3440 (47) P= .009	-.0741 (58) P= .290	-.0777 (40) P= .317	.0711 (88) P= .255	.0582 (88) P= .295
PB	.0700 (88) P= .259	-.0802 (88) P= .229	-.0726 (84) P= .256	-.1545 (56) P= .128	-.0886 (47) P= .277	.0702 (88) P= .258	.0775 (47) P= .302	-.1689 (58) P= .102	.0822 (40) P= .307	.1954 (88) P= .034	-.1022 (88) P= .172
ZN	-.0713 (87) P= .256	.0799 (87) P= .231	.1935 (83) P= .040	.1414 (55) P= .152	-.0076 (46) P= .480	-.0527 (87) P= .314	-.0835 (46) P= .291	-.0396 (57) P= .385	-.1015 (40) P= .267	.0396 (87) P= .358	.0155 (87) P= .441
FE	.3165 (84) P= .002	.0408 (84) P= .356	-.1466 (79) P= .099	-.1056 (51) P= .230	.1090 (43) P= .243	-.0028 (84) P= .490	.0433 (42) P= .393	-.0417 (54) P= .382	.0119 (37) P= .472	-.1596 (84) P= .074	.2053 (84) P= .030
AG	. (47) P= .	. (47) P= .	. (46) P= .	. (46) P= .	. (40) P= .	. (47) P= .	. (39) P= .	. (47) P= .	. (30) P= .	. (47) P= .	. (47) P= .
NA	-.0609 (100) P= .274	-.0539 (100) P= .297	-.1380 (95) P= .091	-.0683 (67) P= .291	.1946 (58) P= .072	-.1106 (100) P= .137	.2087 (58) P= .058	.2828 (70) P= .009	.3170 (52) P= .011	.2112 (100) P= .017	.3185 (100) P= .001

(Coefficient / (Cases) / 1-tailed Significance)

Correlations:	YEAR	MONTH	DAY	TEMP	DO	PH	TURB	COND	TDS	TALK	HARD
BA	.	.	.	.	.	.	.	.	.	.	.
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .
NH3	.3755	-.0777	-.0072	.1906	.0306	.1313	-.2474	.5025	.4059	-.2713	.4056
	(73)	(73)	(70)	(44)	(37)	(73)	(35)	(46)	(31)	(73)	(73)
	P= .001	P= .257	P= .476	P= .108	P= .429	P= .134	P= .076	P= .000	P= .012	P= .010	P= .000
NO3	-.2818	.0238	.0688	-.0363	-.0405	-.1216	-.0654	-.4431	-.3166	.0050	-.0979
	(112)	(112)	(104)	(82)	(73)	(112)	(73)	(85)	(66)	(112)	(112)
	P= .001	P= .402	P= .244	P= .373	P= .367	P= .101	P= .291	P= .000	P= .005	P= .479	P= .152
NO2	.0552	.0139	.1569	-.0562	.2201	-.0697	-.1977	.0577	-.0477	-.1655	.0343
	(97)	(97)	(90)	(66)	(57)	(97)	(57)	(68)	(49)	(97)	(97)
	P= .296	P= .446	P= .070	P= .327	P= .050	P= .249	P= .070	P= .320	P= .372	P= .053	P= .369
MN	.1478	.2037	-.2171	-.0646	-.0476	.1979	.2837	-.0749	-.1777	.0162	-.0738
	(60)	(60)	(57)	(30)	(23)	(60)	(21)	(32)	(14)	(60)	(60)
	P= .130	P= .059	P= .052	P= .367	P= .415	P= .065	P= .106	P= .342	P= .272	P= .451	P= .287
ELEV	-.2527	-.0686	.2010	-.1051	-.0206	-.2318	-.0797	-.5571	-.5258	-.2229	-.3942
	(114)	(114)	(107)	(82)	(73)	(114)	(73)	(84)	(64)	(114)	(114)
	P= .003	P= .234	P= .019	P= .174	P= .431	P= .007	P= .251	P= .000	P= .000	P= .009	P= .000
K	-.3041	-.0359	.2361	-.2012	-.0132	.0084	.0421	.2433	.4102	.1319	.2544
	(74)	(74)	(70)	(42)	(35)	(74)	(33)	(44)	(26)	(74)	(74)
	P= .004	P= .381	P= .025	P= .101	P= .470	P= .472	P= .408	P= .056	P= .019	P= .131	P= .014
SO4	.5359	-.0236	-.2092	.1981	.0010	.2026	-.0168	.4764	.5847	-.0803	.4919
	(129)	(129)	(121)	(97)	(88)	(129)	(88)	(100)	(81)	(129)	(129)
	P= .000	P= .395	P= .011	P= .026	P= .496	P= .011	P= .438	P= .000	P= .000	P= .183	P= .000
CD	.1206	-.1287	-.1023	-.1755	.	-.0205	-.1373	-.2186	-.0368	.2363	.0000
	(88)	(88)	(84)	(56)	(47)	(88)	(47)	(58)	(40)	(88)	(88)
	P= .132	P= .116	P= .177	P= .098	P= .	P= .425	P= .179	P= .050	P= .411	P= .013	P= .500
BR	.1729	.0059	-.0903	.3023	-.2006	.0859	.1642	.2795	-.1356	.1554	.1420
	(67)	(67)	(63)	(66)	(64)	(67)	(65)	(66)	(50)	(67)	(67)
	P= .081	P= .481	P= .241	P= .007	P= .056	P= .245	P= .096	P= .012	P= .174	P= .105	P= .126

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

Correlations:	CA	MG	CL	FL	PO4	SI	FCOLI	CR	CU	NI	PB
YEAR	.4665	-.1559	-.4720	.0635	.1401	.4077	-.3523	.1122	-.0283	.1104	.0700
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .000	P= .043	P= .000	P= .237	P= .077	P= .000	P= .001	P= .150	P= .397	P= .153	P= .259
MONTH	-.0061	.0248	.0079	.1023	-.0102	.1675	.0083	-.1036	.1056	-.0085	-.0802
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .473	P= .393	P= .464	P= .124	P= .459	P= .057	P= .471	P= .170	P= .164	P= .469	P= .229
DAY	.0110	.0130	.1141	.0154	-.1974	-.1817	-.0534	-.1521	-.1171	.0265	-.0726
	(116)	(115)	(123)	(122)	(97)	(86)	(79)	(83)	(84)	(84)	(84)
	P= .453	P= .445	P= .104	P= .433	P= .026	P= .047	P= .320	P= .085	P= .144	P= .405	P= .256
TEMP	.1387	.0489	.2817	.2313	-.1213	-.1092	.1004	-.0391	-.1397	.1009	-.1545
	(91)	(90)	(98)	(98)	(73)	(90)	(80)	(55)	(56)	(56)	(56)
	P= .095	P= .324	P= .002	P= .011	P= .153	P= .153	P= .188	P= .389	P= .152	P= .230	P= .128
DO	.0642	.2321	-.1223	-.1713	.1135	.0654	-.1077	.2294	.3402	-.0765	-.0886
	(82)	(81)	(89)	(89)	(65)	(88)	(74)	(46)	(47)	(47)	(47)
	P= .283	P= .019	P= .127	P= .054	P= .184	P= .272	P= .180	P= .063	P= .010	P= .305	P= .277
PH	.2913	.1134	-.0457	.0479	.0969	-.0202	-.1685	-.0707	-.0260	.0546	.0702
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .001	P= .106	P= .302	P= .295	P= .163	P= .425	P= .066	P= .258	P= .405	P= .307	P= .258
TURB	.0553	.0783	.1109	.0247	.1905	-.0759	-.1127	-.1178	-.1716	.3440	.0775
	(82)	(81)	(89)	(89)	(64)	(88)	(73)	(46)	(47)	(47)	(47)
	P= .311	P= .243	P= .150	P= .409	P= .066	P= .241	P= .171	P= .218	P= .124	P= .009	P= .302
COND	.2085	.2543	.6972	.0607	-.0897	.0112	-.0717	-.0520	-.0298	-.0741	-.1689
	(94)	(93)	(101)	(100)	(76)	(90)	(81)	(57)	(58)	(58)	(58)
	P= .022	P= .007	P= .000	P= .274	P= .220	P= .458	P= .262	P= .350	P= .412	P= .290	P= .102
TDS	.1079	.0474	.6748	.1233	-.1963	.0244	-.0695	-.1240	-.0584	-.0777	.0822
	(74)	(73)	(81)	(80)	(57)	(73)	(62)	(40)	(40)	(40)	(40)
	P= .180	P= .345	P= .000	P= .138	P= .072	P= .419	P= .296	P= .223	P= .360	P= .317	P= .307
TALK	.0443	.0519	.3331	.1350	-.0315	-.2633	.0203	.1890	-.0099	.0711	.1954
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .312	P= .284	P= .000	P= .064	P= .375	P= .006	P= .429	P= .040	P= .463	P= .255	P= .034
HARD	.2974	.2669	.5503	.2469	-.1049	-.0283	.0471	-.0560	-.0460	.0582	-.1022
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .000	P= .001	P= .000	P= .002	P= .143	P= .396	P= .338	P= .303	P= .335	P= .295	P= .172
CA	1.0000	.4192	-.1315	.1445	.3320	-.1669	-.0272	-.0356	-.1273	.7390	-.0043
	(124)	(123)	(124)	(122)	(98)	(83)	(77)	(85)	(86)	(86)	(86)
	P= .	P= .000	P= .073	P= .056	P= .000	P= .066	P= .407	P= .373	P= .121	P= .000	P= .484
MG	.4192	1.0000	.3069	.0730	.2086	-.2093	-.1248	-.0114	.0296	.5356	-.1942
	(123)	(123)	(123)	(121)	(97)	(82)	(77)	(85)	(86)	(86)	(86)
	P= .000	P= .	P= .000	P= .213	P= .020	P= .030	P= .140	P= .459	P= .394	P= .000	P= .037

(Coefficient / (Cases) / 1-tailed Significance)

Correlations:	CA	MG	CL	FL	PO4	SI	FCOLI	CR	CU	NI	PB
CL	-.1315	.3069	1.0000	.0696	-.2034	-.1163	.0548	-.1263	-.0385	-.1665	-.0986
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .073	P= .000	P= .	P= .216	P= .019	P= .138	P= .313	P= .122	P= .361	P= .061	P= .180
FL	.1445	.0730	.0696	1.0000	-.0338	.0441	-.0226	-.2117	-.1790	.1525	.0794
	(122)	(121)	(129)	(129)	(103)	(90)	(81)	(86)	(87)	(87)	(87)
	P= .056	P= .213	P= .216	P= .	P= .367	P= .340	P= .421	P= .025	P= .049	P= .079	P= .232
PO4	.3320	.2086	-.2034	-.0338	1.0000	.2447	-.2656	.1136	.0804	.5933	-.1771
	(98)	(97)	(105)	(103)	(105)	(66)	(59)	(78)	(79)	(79)	(79)
	P= .000	P= .020	P= .019	P= .367	P= .	P= .024	P= .021	P= .161	P= .241	P= .000	P= .059
SI	-.1669	-.2093	-.1163	.0441	.2447	1.0000	-.2019	.0076	.0451	-.1813	-.4325
	(83)	(82)	(90)	(90)	(66)	(90)	(74)	(47)	(48)	(48)	(48)
	P= .066	P= .030	P= .138	P= .340	P= .024	P= .	P= .042	P= .480	P= .380	P= .109	P= .001
FCOLI	-.0272	-.1248	.0548	-.0226	-.2656	-.2019	1.0000	-.0601	-.1184	-.0526	-.0321
	(77)	(77)	(81)	(81)	(59)	(74)	(81)	(51)	(52)	(52)	(52)
	P= .407	P= .140	P= .313	P= .421	P= .021	P= .042	P= .	P= .338	P= .202	P= .356	P= .411
CR	-.0356	-.0114	-.1263	-.2117	.1136	.0076	-.0601	1.0000	.4574	-.0189	-.0418
	(85)	(85)	(87)	(86)	(78)	(47)	(51)	(87)	(87)	(87)	(87)
	P= .373	P= .459	P= .122	P= .025	P= .161	P= .480	P= .338	P= .	P= .000	P= .431	P= .350
CU	-.1273	.0296	-.0385	-.1790	.0804	.0451	-.1184	.4574	1.0000	-.0385	-.0439
	(86)	(86)	(88)	(87)	(79)	(48)	(52)	(87)	(88)	(88)	(88)
	P= .121	P= .394	P= .361	P= .049	P= .241	P= .380	P= .202	P= .000	P= .	P= .361	P= .342
NI	.7390	.5356	-.1665	.1525	.5933	-.1813	-.0526	-.0189	-.0385	1.0000	.0026
	(86)	(86)	(88)	(87)	(79)	(48)	(52)	(87)	(88)	(88)	(88)
	P= .000	P= .000	P= .061	P= .079	P= .000	P= .109	P= .356	P= .431	P= .361	P= .	P= .491
PB	-.0043	-.1942	-.0986	.0794	-.1771	-.4325	-.0321	-.0418	-.0439	.0026	1.0000
	(86)	(86)	(88)	(87)	(79)	(48)	(52)	(87)	(88)	(88)	(88)
	P= .484	P= .037	P= .180	P= .232	P= .059	P= .001	P= .411	P= .350	P= .342	P= .491	P= .
ZN	-.1393	.0831	.0469	.4001	-.0104	.1319	-.1497	-.0331	-.0660	-.0441	-.0634
	(85)	(85)	(87)	(86)	(78)	(47)	(51)	(86)	(87)	(87)	(87)
	P= .102	P= .225	P= .333	P= .000	P= .464	P= .188	P= .147	P= .381	P= .272	P= .343	P= .280
FE	.0621	-.0467	-.1378	.1741	.1192	.2758	-.1132	-.0747	.0240	-.0015	.0639
	(82)	(82)	(84)	(82)	(77)	(43)	(49)	(82)	(83)	(83)	(83)
	P= .290	P= .339	P= .106	P= .059	P= .151	P= .037	P= .219	P= .252	P= .415	P= .495	P= .283
AG	.	.	.	.	.	.	.	.	.	.	.
	(45)	(45)	(47)	(47)	(43)	(40)	(47)	(46)	(47)	(47)	(47)
	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .
NA	.1391	.3503	.3499	.0902	.1807	-.0338	-.1643	.1737	.0405	.4048	-.2057
	(98)	(98)	(100)	(98)	(80)	(59)	(61)	(87)	(88)	(88)	(88)
	P= .086	P= .000	P= .000	P= .189	P= .054	P= .400	P= .103	P= .054	P= .354	P= .000	P= .027

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

Correlations:	CA	MG	CL	FL	PO4	SI	FCOLI	CR	CU	NI	PB
BA	.	.	.	.	.	.	.	.	.	.	.
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .
NH3	.2654	-.0446	.1171	-.0979	-.0033	.2098	-.2763	.0121	.0330	-.0435	-.1462
	(68)	(67)	(73)	(72)	(73)	(37)	(35)	(55)	(56)	(56)	(56)
	P= .014	P= .360	P= .162	P= .207	P= .489	P= .106	P= .054	P= .465	P= .405	P= .375	P= .141
NO3	-.2292	-.1150	.0356	.0771	-.0383	-.1192	.0129	-.0661	-.0033	-.0916	-.0373
	(107)	(106)	(112)	(110)	(91)	(75)	(65)	(68)	(69)	(69)	(69)
	P= .009	P= .120	P= .355	P= .212	P= .359	P= .154	P= .460	P= .296	P= .489	P= .227	P= .380
NO2	.0221	.1563	-.0326	.2024	.0584	.0468	-.0755	-.0169	.1522	.0299	-.1965
	(97)	(97)	(97)	(96)	(76)	(59)	(57)	(70)	(71)	(71)	(71)
	P= .415	P= .063	P= .376	P= .024	P= .308	P= .362	P= .288	P= .445	P= .103	P= .402	P= .050
MN	.0875	-.1391	-.0835	.0816	-.1109	.3131	-.0348	.0341	-.0583	.2331	.0430
	(60)	(60)	(60)	(59)	(58)	(22)	(29)	(59)	(60)	(60)	(60)
	P= .253	P= .145	P= .263	P= .269	P= .204	P= .078	P= .429	P= .399	P= .329	P= .037	P= .372
ELEV	-.1262	-.0713	-.3902	-.2429	.0401	-.0359	-.0510	.1085	.1668	.0706	-.1338
	(112)	(112)	(114)	(113)	(88)	(74)	(73)	(87)	(88)	(88)	(88)
	P= .092	P= .228	P= .000	P= .005	P= .355	P= .381	P= .334	P= .159	P= .060	P= .257	P= .107
K	-.1268	.1916	.3607	-.0299	-.3333	-.0605	.1577	.0435	-.0412	-.1352	.0657
	(72)	(72)	(74)	(73)	(72)	(34)	(39)	(73)	(74)	(74)	(74)
	P= .144	P= .053	P= .001	P= .401	P= .002	P= .367	P= .169	P= .357	P= .364	P= .125	P= .289
SO4	.3070	.0236	.1734	.0675	.2058	.3275	-.2309	.2747	.0550	.0802	-.1825
	(122)	(121)	(129)	(127)	(105)	(90)	(80)	(85)	(86)	(86)	(86)
	P= .000	P= .399	P= .025	P= .225	P= .018	P= .001	P= .020	P= .005	P= .307	P= .232	P= .046
CD	.0519	-.0858	-.2033	.2143	.	.0919	.	-.0128	-.0019	.0797	.2123
	(86)	(86)	(88)	(87)	(79)	(48)	(52)	(87)	(88)	(88)	(88)
	P= .318	P= .216	P= .029	P= .023	P= .	P= .267	P= .	P= .453	P= .493	P= .230	P= .024
BR	.2389	-.0189	-.0082	-.2374	.0433	-.3406	-.0277	.0548	.0546	.0659	.1552
	(62)	(61)	(67)	(67)	(46)	(66)	(50)	(25)	(26)	(26)	(26)
	P= .031	P= .443	P= .474	P= .027	P= .388	P= .003	P= .424	P= .397	P= .396	P= .375	P= .225

(Coefficient / (Cases) / 1-tailed Significance)

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Correlations:	ZN	FE	AG	NA	BA	NH3	NO3	NO2	MN	ELEV	K
YEAR	-.0713	.3165	.	-.0609	.	.3755	-.2818	.0552	.1478	-.2527	-.3041
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .256	P= .002	P= .	P= .274	P= .	P= .001	P= .001	P= .296	P= .130	P= .003	P= .004
MONTH	.0799	.0408	.	-.0539	.	-.0777	.0238	.0139	.2037	-.0686	-.0359
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .231	P= .356	P= .	P= .297	P= .	P= .257	P= .402	P= .446	P= .059	P= .234	P= .381
DAY	.1935	-.1466	.	-.1380	.	-.0072	.0688	.1569	-.2171	.2010	.2361
	(83)	(79)	(46)	(95)	(0)	(70)	(104)	(90)	(57)	(107)	(70)
	P= .040	P= .099	P= .	P= .091	P= .	P= .476	P= .244	P= .070	P= .052	P= .019	P= .025
TEMP	.1414	-.1056	.	-.0683	.	.1906	-.0363	-.0562	-.0646	-.1051	-.2012
	(55)	(51)	(46)	(67)	(0)	(44)	(82)	(66)	(30)	(82)	(42)
	P= .152	P= .230	P= .	P= .291	P= .	P= .108	P= .373	P= .327	P= .367	P= .174	P= .101
DO	-.0076	.1090	.	.1946	.	.0306	-.0405	.2201	-.0476	-.0206	-.0132
	(46)	(43)	(40)	(58)	(0)	(37)	(73)	(57)	(23)	(73)	(35)
	P= .480	P= .243	P= .	P= .072	P= .	P= .429	P= .367	P= .050	P= .415	P= .431	P= .470
PH	-.0527	-.0028	.	-.1106	.	.1313	-.1216	-.0697	.1979	-.2318	.0084
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .314	P= .490	P= .	P= .137	P= .	P= .134	P= .101	P= .249	P= .065	P= .007	P= .472
TURB	-.0835	.0433	.	.2087	.	-.2474	-.0654	-.1977	.2837	-.0797	.0421
	(46)	(42)	(39)	(58)	(0)	(35)	(73)	(57)	(21)	(73)	(33)
	P= .291	P= .393	P= .	P= .058	P= .	P= .076	P= .291	P= .070	P= .106	P= .251	P= .408
COND	-.0396	-.0417	.	.2828	.	.5025	-.4431	.0577	-.0749	-.5571	.2433
	(57)	(54)	(47)	(70)	(0)	(46)	(85)	(68)	(32)	(84)	(44)
	P= .385	P= .382	P= .	P= .009	P= .	P= .000	P= .000	P= .320	P= .342	P= .000	P= .056
TDS	-.1015	.0119	.	.3170	.	.4059	-.3166	-.0477	-.1777	-.5258	.4102
	(40)	(37)	(30)	(52)	(0)	(31)	(66)	(49)	(14)	(64)	(26)
	P= .267	P= .472	P= .	P= .011	P= .	P= .012	P= .005	P= .372	P= .272	P= .000	P= .019
TALK	.0396	-.1596	.	.2112	.	-.2713	.0050	-.1655	.0162	-.2229	.1319
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .358	P= .074	P= .	P= .017	P= .	P= .010	P= .479	P= .053	P= .451	P= .009	P= .131
HARD	.0155	.2053	.	.3185	.	.4056	-.0979	.0343	-.0738	-.3942	.2544
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .443	P= .030	P= .	P= .001	P= .	P= .000	P= .152	P= .369	P= .287	P= .000	P= .014
CA	-.1393	.0621	.	.1391	.	.2654	-.2292	.0221	.0875	-.1262	-.1268
	(85)	(82)	(45)	(98)	(0)	(68)	(107)	(97)	(60)	(112)	(72)
	P= .102	P= .290	P= .	P= .086	P= .	P= .014	P= .009	P= .415	P= .253	P= .092	P= .144
MG	.0831	-.0467	.	.3503	.	-.0446	-.1150	.1563	-.1391	-.0713	.1916
	(85)	(82)	(45)	(98)	(0)	(67)	(106)	(97)	(60)	(112)	(72)
	P= .225	P= .339	P= .	P= .000	P= .	P= .360	P= .120	P= .063	P= .145	P= .228	P= .053

(Coefficient / (Cases) / 1-tailed Significance)

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Correlations:	ZN	FE	AG	NA	BA	NH3	NO3	NO2	MN	ELEV	K
CL	.0469	-.1378	.	.3499	.	.1171	.0356	-.0326	-.0835	-.3902	.3607
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .333	P= .106	P= .	P= .000	P= .	P= .162	P= .355	P= .376	P= .263	P= .000	P= .001
FL	.4001	.1741	.	.0902	.	-.0979	.0771	.2024	.0816	-.2429	-.0299
	(86)	(82)	(47)	(98)	(0)	(72)	(110)	(96)	(59)	(113)	(73)
	P= .000	P= .059	P= .	P= .189	P= .	P= .207	P= .212	P= .024	P= .269	P= .005	P= .401
PO4	-.0104	.1192	.	.1807	.	-.0033	-.0383	.0584	-.1109	.0401	-.3333
	(78)	(77)	(43)	(80)	(0)	(73)	(91)	(76)	(58)	(88)	(72)
	P= .464	P= .151	P= .	P= .054	P= .	P= .489	P= .359	P= .308	P= .204	P= .355	P= .002
SI	.1319	.2758	.	-.0338	.	.2098	-.1192	.0468	.3131	-.0359	-.0605
	(47)	(43)	(40)	(59)	(0)	(37)	(75)	(59)	(22)	(74)	(34)
	P= .188	P= .037	P= .	P= .400	P= .	P= .106	P= .154	P= .362	P= .078	P= .381	P= .367
FCOLI	-.1497	-.1132	.	-.1643	.	-.2763	.0129	-.0755	-.0348	-.0510	.1577
	(51)	(49)	(47)	(61)	(0)	(35)	(65)	(57)	(29)	(73)	(39)
	P= .147	P= .219	P= .	P= .103	P= .	P= .054	P= .460	P= .288	P= .429	P= .334	P= .169
CR	-.0331	-.0747	.	.1737	.	.0121	-.0661	-.0169	.0341	.1085	.0435
	(86)	(82)	(46)	(87)	(0)	(55)	(68)	(70)	(59)	(87)	(73)
	P= .381	P= .252	P= .	P= .054	P= .	P= .465	P= .296	P= .445	P= .399	P= .159	P= .357
CU	-.0660	.0240	.	.0405	.	.0330	-.0033	.1522	-.0583	.1668	-.0412
	(87)	(83)	(47)	(88)	(0)	(56)	(69)	(71)	(60)	(88)	(74)
	P= .272	P= .415	P= .	P= .354	P= .	P= .405	P= .489	P= .103	P= .329	P= .060	P= .364
NI	-.0441	-.0015	.	.4048	.	-.0435	-.0916	.0299	.2331	.0706	-.1352
	(87)	(83)	(47)	(88)	(0)	(56)	(69)	(71)	(60)	(88)	(74)
	P= .343	P= .495	P= .	P= .000	P= .	P= .375	P= .227	P= .402	P= .037	P= .257	P= .125
PB	-.0634	.0639	.	-.2057	.	-.1462	-.0373	-.1965	.0430	-.1338	.0657
	(87)	(83)	(47)	(88)	(0)	(56)	(69)	(71)	(60)	(88)	(74)
	P= .280	P= .283	P= .	P= .027	P= .	P= .141	P= .380	P= .050	P= .372	P= .107	P= .289
ZN	1.0000	-.0516	.	.0145	.	.0873	.1882	.6633	-.0149	.1102	-.0727
	(87)	(82)	(46)	(87)	(0)	(55)	(68)	(70)	(59)	(87)	(73)
	P= .	P= .323	P= .	P= .447	P= .	P= .263	P= .062	P= .000	P= .455	P= .155	P= .271
FE	-.0516	1.0000	.	.0419	.	.0619	-.0512	.1439	.2661	-.1534	.0916
	(82)	(84)	(46)	(84)	(0)	(55)	(65)	(66)	(59)	(83)	(71)
	P= .323	P= .	P= .	P= .353	P= .	P= .327	P= .343	P= .125	P= .021	P= .083	P= .224
AG	.	.	1.0000	.	.	.	.	.	.	.	.
	(46)	(46)	(47)	(47)	(0)	(26)	(31)	(31)	(29)	(47)	(37)
	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .	P= .
NA	.0145	.0419	.	1.0000	.	.1900	-.1223	.0896	-.0200	-.2996	.0347
	(87)	(84)	(47)	(100)	(0)	(56)	(81)	(82)	(60)	(99)	(74)
	P= .447	P= .353	P= .	P= .	P= .	P= .080	P= .138	P= .212	P= .440	P= .001	P= .385

(Coefficient / (Cases) / 1-tailed Significance)

Correlations:	ZN	FE	AG	NA	BA	NH3	NO3	NO2	MN	ELEV	K
BA	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	1.0000 (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .
NH3	.0873 (55) P= .263	.0619 (55) P= .327	. (26) P= .	.1900 (56) P= .080	. (0) P= .	1.0000 (73) P= .	-.0399 (72) P= .370	.0106 (57) P= .469	-.0660 (54) P= .318	.2123 (58) P= .055	-.0876 (56) P= .260
NO3	.1882 (68) P= .062	-.0512 (65) P= .343	. (31) P= .	-.1223 (81) P= .138	. (0) P= .	-.0399 (72) P= .370	1.0000 (112) P= .	.0189 (95) P= .428	-.0970 (56) P= .239	.3618 (95) P= .000	-.0538 (63) P= .338
NO2	.6633 (70) P= .000	.1439 (66) P= .125	. (31) P= .	.0896 (82) P= .212	. (0) P= .	.0106 (57) P= .469	.0189 (95) P= .428	1.0000 (97) P= .	-.1143 (58) P= .197	.1052 (96) P= .154	.0431 (65) P= .367
MN	-.0149 (59) P= .455	.2661 (59) P= .021	. (29) P= .	-.0200 (60) P= .440	. (0) P= .	-.0660 (54) P= .318	-.0970 (56) P= .239	-.1143 (58) P= .197	1.0000 (60) P= .	-.1480 (60) P= .129	-.0104 (60) P= .469
ELEV	.1102 (87) P= .155	-.1534 (83) P= .083	. (47) P= .	-.2996 (99) P= .001	. (0) P= .	.2123 (58) P= .055	.3618 (95) P= .000	.1052 (96) P= .154	-.1480 (60) P= .129	1.0000 (114) P= .	-.0798 (74) P= .250
K	-.0727 (73) P= .271	.0916 (71) P= .224	. (37) P= .	.0347 (74) P= .385	. (0) P= .	-.0876 (56) P= .260	-.0538 (63) P= .338	.0431 (65) P= .367	-.0104 (60) P= .469	-.0798 (74) P= .250	1.0000 (74) P= .
SO4	-.0640 (85) P= .280	.0958 (82) P= .196	. (46) P= .	.3589 (98) P= .000	. (0) P= .	.6274 (73) P= .000	-.2670 (112) P= .002	.0031 (97) P= .488	.0707 (58) P= .299	-.3491 (112) P= .000	-.2013 (72) P= .045
CD	-.0130 (87) P= .452	. (83) P= .	. (47) P= .	-.0872 (88) P= .210	. (0) P= .	. (56) P= .	-.0631 (69) P= .303	-.0552 (71) P= .324	. (60) P= .	.1045 (88) P= .166	. (74) P= .
BR	-.8894 (25) P= .000	.2231 (21) P= .166	. (17) P= .	-.0799 (37) P= .319	. (0) P= .	.0108 (29) P= .478	-.2432 (67) P= .024	-.6809 (52) P= .000	.2223 (15) P= .213	-.1583 (52) P= .131	-.0738 (20) P= .379

(Coefficient / (Cases) / 1-tailed Significance)

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Correlations:	SO4	CD	BR
YEAR	.5359	.1206	.1729
	(129)	(88)	(67)
	P= .000	P= .132	P= .081
MONTH	-.0236	-.1287	.0059
	(129)	(88)	(67)
	P= .395	P= .116	P= .481
DAY	-.2092	-.1023	-.0903
	(121)	(84)	(63)
	P= .011	P= .177	P= .241
TEMP	.1981	-.1755	.3023
	(97)	(56)	(66)
	P= .026	P= .098	P= .007
DO	.0010	.	-.2006
	(88)	(47)	(64)
	P= .496	P= .	P= .056
PH	.2026	-.0205	.0859
	(129)	(88)	(67)
	P= .011	P= .425	P= .245
TURB	-.0168	-.1373	.1642
	(88)	(47)	(65)
	P= .438	P= .179	P= .096
COND	.4764	-.2186	.2795
	(100)	(58)	(66)
	P= .000	P= .050	P= .012
TDS	.5847	-.0368	-.1356
	(81)	(40)	(50)
	P= .000	P= .411	P= .174
TALK	-.0803	.2363	.1554
	(129)	(88)	(67)
	P= .183	P= .013	P= .105
HARD	.4919	.0000	.1420
	(129)	(88)	(67)
	P= .000	P= .500	P= .126
CA	.3070	.0519	.2389
	(122)	(86)	(62)
	P= .000	P= .318	P= .031
MG	.0236	-.0858	-.0189
	(121)	(86)	(61)
	P= .399	P= .216	P= .443

(Coefficient / (Cases) / 1-tailed Significance)

Correlations:

	SO4	CD	BR
CL	.1734	-.2033	-.0082
	(129)	(88)	(67)
	P= .025	P= .029	P= .474
FL	.0675	.2143	-.2374
	(127)	(87)	(67)
	P= .225	P= .023	P= .027
PO4	.2058	.	.0433
	(105)	(79)	(46)
	P= .018	P= .	P= .388
SI	.3275	.0919	-.3406
	(90)	(48)	(66)
	P= .001	P= .267	P= .003
FCOLI	-.2309	.	-.0277
	(80)	(52)	(50)
	P= .020	P= .	P= .424
CR	.2747	-.0128	.0548
	(85)	(87)	(25)
	P= .005	P= .453	P= .397
CU	.0550	-.0019	.0546
	(86)	(88)	(26)
	P= .307	P= .493	P= .396
NI	.0802	.0797	.0659
	(86)	(88)	(26)
	P= .232	P= .230	P= .375
PB	-.1825	.2123	.1552
	(86)	(88)	(26)
	P= .046	P= .024	P= .225
ZN	-.0640	-.0130	-.8894
	(85)	(87)	(25)
	P= .280	P= .452	P= .000
FE	.0958	.	.2231
	(82)	(83)	(21)
	P= .196	P= .	P= .166
AG	.	.	.
	(46)	(47)	(17)
	P= .	P= .	P= .
NA	.3589	-.0872	-.0799
	(98)	(88)	(37)
	P= .000	P= .210	P= .319

Correlations:

	SO4	CD	BR
BA	.	.	.
	(0)	(0)	(0)
	P= .	P= .	P= .
NH3	.6274	.	.0108
	(73)	(56)	(29)
	P= .000	P= .	P= .478
NO3	-.2670	-.0631	-.2432
	(112)	(69)	(67)
	P= .002	P= .303	P= .024
NO2	.0031	-.0552	-.6809
	(97)	(71)	(52)
	P= .488	P= .324	P= .000
MN	.0707	.	.2223
	(58)	(60)	(15)
	P= .299	P= .	P= .213
ELEV	-.3491	.1045	-.1583
	(112)	(88)	(52)
	P= .000	P= .166	P= .131
K	-.2013	.	-.0738
	(72)	(74)	(20)
	P= .045	P= .	P= .379
SO4	1.0000	.0290	.1283
	(129)	(86)	(67)
	P= .	P= .396	P= .150
CD	.0290	1.0000	-.0132
	(86)	(88)	(26)
	P= .396	P= .	P= .474
BR	.1283	-.0132	1.0000
	(67)	(26)	(67)
	P= .150	P= .474	P= .

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

This procedure was completed at 9:56:15

```
TITLE FORT PHANTOM HILL RESERVOIR QUALITY.
DATA LIST FILE='B:PHANTWQ.DAT' / YEAR 1-2 MONTH 3-4 DAY 5-6 TEMP 7-10
           DO 11-15 PH 16-20 TURB 21-25
           COND 26-30 TDS 31-35 TALK 36-40 HARD 41-45 CA 46-50 MG 51-55
           CL 56-60 FL 61-65 PO4 66-70 SI 71-75 FCOLI 76-80 / CR 7-10 CU 11-15
           NI 16-20 PB 21-25 ZN 26-30 FE 31-35 AG 36-40 NA 41-45 BA 46-50
           NH3 51-55 NO3 56-60 NO2 61-65 MN 66-70 ELEV 71-75 K 76-80 /
           SO4 7-10 CD 11-15 BR 16-20.
VALUE LABELS MONTH 01 'JANUARY'
                   02 'FEBRUARY'
                   03 'MARCH'
                   04 'APRIL'
                   05 'MAY'
                   06 'JUNE'
                   07 'JULY'
                   08 'AUGUST'
                   09 'SEPTEMBER'
                   10 'OCTOBER'
                   11 'NOVEMBER'
                   12 'DECEMBER'.
MISSING VALUE ALL (-1).
SORT CASES BY MONTH YEAR.
The raw data or transformation pass is proceeding
    133 cases are written to the uncompressed active file.

Size of File to Be Sorted:       133 Cases of    312 Bytes Each.
    133 cases are written to the uncompressed active file.
SORT completed successfully.
```

 5/

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This procedure was completed at 13:11:37
FORMATS TEMP (F8.2) DO (F8.2) PH (F8.2) FCOLI (F8.2) CL (F8.2) SO4 (F8.2)
        TDS (F8.2) COND (F8.2).
REPORT FORMAT = LIST(4) MISSING '*' BRKSPACE(-1)
       /VARIABLES = TEMP ' ' 'TEMPERATURE' 'DEGREES C' (11)
                    DO   'DISSOLVED' 'OXYGEN' 'MG/L' (9)
                    PH   ' ' 'PH' 'S.U.'
                    FCOLI 'FECAL' 'COLIFORM' '#/100 ML'
                    CL   ' ' 'CHLORIDE' 'MG/L'
                    SO4  ' ' 'SULFATE' 'MG/L'
                    TDS  'TOTAL DISSOLVED' 'SOLIDS' 'MG/L' (15)
                    COND 'SPECIFIC' 'CONDUCTANCE' 'UMHOS/CM @ 25C' (14)
       /BREAK = MONTH (LABEL) (PAGE)
       /SUMMARY = MIN
       /SUMMARY = MAX
       /SUMMARY = MEAN
       /SUMMARY = STDEV
       /SUMMARY=VALIDN
       /BREAK = YEAR.

REPORT REQUIRES     3856 BYTES FOR THIS TASK
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MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
JANUARY	76	*	*	8.50	*	114.00	66.00	*	*
	77	*	*	8.10	*	99.00	66.00	*	*
	78	*	*	8.40	*	128.80	101.00	*	*
	79	6.00	*	8.30	2.00	98.00	83.00	*	600.00
	80	10.00	9.80	8.50	86.00	106.00	75.20	546.00	675.00
	81	10.00	10.50	8.20	22.00	80.00	85.30	*	675.00
	82	2.00	11.80	8.40	*	56.00	71.00	350.00	520.00
	83	7.00	9.90	8.00	16.00	62.50	31.00	432.00	461.00
	84	2.00	*	8.60	0.00	55.20	90.00	330.00	442.00
	85	10.00	10.40	7.90	52.00	96.00	105.00	526.00	790.00
	86	7.00	8.40	8.40	0.00	94.00	150.00	530.00	795.00
	87	10.50	12.90	8.20	14.00	62.00	78.00	350.00	525.00
MIN		2.00	8.40	7.90	0.00	55.20	31.00	330.00	442.00
MAX		10.50	12.90	8.60	86.00	128.80	150.00	546.00	795.00
MEAN		7.1667	10.5286	8.2917	24.0000	87.6250	83.4583	437.7143	609.2222
STDEV		3.3541	1.4557	.2151	30.3127	24.2600	28.3815	95.7944	132.7213
VALIDN		9	7	12	8	12	12	7	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
FEBRUARY	76	*	*	8.40	*	107.00	75.00	*	*
	77	*	*	7.90	*	107.00	72.00	*	*
	78	*	*	8.40	*	139.50	113.00	*	*
	79	8.00	*	8.40	38.00	99.00	78.80	440.00	640.00
	80	11.00	9.70	8.60	11.00	110.00	83.40	549.00	680.00
	81	8.00	10.10	8.10	130.00	78.00	85.90	*	440.00
	82	5.00	12.00	8.50	24.00	57.00	66.00	340.00	375.00
	83	8.00	*	8.30	*	61.20	97.80	445.00	470.00
	84	7.10	13.00	8.50	0.00	80.00	100.00	467.00	700.00
	85	6.00	11.90	8.20	12.00	84.50	100.00	440.00	660.00
	86	7.00	11.10	8.17	*	94.00	148.00	560.00	840.00
MIN		5.00	9.70	7.90	0.00	57.00	66.00	340.00	375.00
MAX		11.00	13.00	8.60	130.00	139.50	148.00	560.00	840.00
MEAN		7.5125	11.3000	8.3155	35.8333	92.4727	92.7182	463.0000	600.6250
STDEV		1.7691	1.2474	.2060	47.9183	23.7712	23.2021	74.5341	156.8994
VALIDN		8	6	11	6	11	11	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
MARCH	76	*	*	8.30	*	99.00	75.00	*	*
	77	*	*	8.10	*	107.00	88.00	*	*
	78	*	*	*	*	*	*	*	*
	79	15.00	*	8.40	128.00	100.00	76.80	470.00	720.00
	80	15.00	9.20	8.50	4.00	114.00	86.20	578.00	780.00
	81	17.00	9.00	8.40	5.00	80.00	76.70	*	510.00
	82	13.00	10.00	8.60	2.00	51.00	77.00	360.00	460.00
	83	16.00	11.90	8.20	16.00	75.10	176.00	410.00	620.00
	84	8.00	11.10	8.50	0.00	80.00	95.00	480.00	720.00
	85	21.00	10.40	8.50	*	86.00	143.00	473.00	710.00
	86	17.00	9.60	8.20	30.00	94.00	153.00	567.00	850.00
MIN		8.00	9.00	8.10	0.00	51.00	75.00	360.00	460.00
MAX		21.00	11.90	8.60	128.00	114.00	176.00	578.00	850.00
MEAN		15.2500	10.1714	8.3700	26.4286	88.6100	104.6700	476.8571	671.2500
STDEV		3.7321	1.0468	.1636	45.9995	18.2626	37.7278	78.0522	132.7121
VALIDN		8	7	10	7	10	10	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
APRIL	76	*	*	8.50	*	135.00	78.30	*	*
	77	*	*	8.30	*	107.00	70.00	*	*
	78	*	*	8.30	*	127.00	104.00	610.00	1022.00
	79	*	*	8.20	10.00	90.00	73.90	440.00	500.00
	80	22.00	6.80	8.30	5.00	152.00	94.10	*	890.00
	81	16.00	11.50	8.70	108.00	78.00	79.80	*	430.00
	82	19.00	10.50	8.20	32.00	52.00	67.00	365.00	500.00
	83	14.00	12.60	8.80	0.00	71.80	75.40	420.00	630.00
	84	15.00	11.00	7.90	0.00	95.20	101.00	502.00	800.00
	85	20.00	15.00	9.00	6.00	92.00	123.00	493.00	740.00
	86	22.00	8.20	8.60	*	104.00	175.00	581.00	872.00
MIN		14.00	6.80	7.90	0.00	52.00	67.00	365.00	430.00
MAX		22.00	15.00	9.00	108.00	152.00	175.00	610.00	1022.00
MEAN		18.2857	10.8000	8.4364	23.0000	100.3636	94.6818	487.2857	709.3333
STDEV		3.3022	2.7160	.3171	39.0427	29.1407	31.7002	87.3760	205.5432
VALIDN		7	7	11	7	11	11	7	9

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
MAY	76	*	*	8.10	*	128.00	80.80	*	*
	77	*	*	7.90	*	99.00	55.00	*	*
	78	*	*	8.48	*	136.70	115.00	*	*
	79	21.00	*	8.40	132.00	92.00	74.20	390.00	580.00
	80	21.00	8.30	8.40	162.00	128.00	88.90	*	860.00
	81	23.00	9.70	8.40	300.00	82.00	72.80	*	550.00
	82	22.00	5.00	8.30	140.00	53.00	46.00	385.00	550.00
	83	19.00	9.00	8.30	*	71.80	155.00	425.00	630.00
	84	20.00	9.00	8.60	0.00	83.20	127.00	525.00	800.00
	85	19.00	8.70	8.20	*	85.00	55.00	563.00	845.00
	86	25.00	9.50	8.40	*	110.00	175.00	920.00	945.00
MIN		19.00	5.00	7.90	0.00	53.00	46.00	385.00	550.00
MAX		25.00	9.70	8.60	300.00	136.70	175.00	920.00	945.00
MEAN		21.2500	8.4571	8.3164	146.8000	97.1545	94.9727	534.6667	720.0000
STDEV		2.0529	1.5946	.1922	106.6733	26.1272	42.6489	202.3528	159.3514
VALIDN		8	7	11	5	11	11	6	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
JUNE	76	*	*	8.40	*	128.00	80.00	*	*
	77	*	*	8.20	*	107.00	60.00	*	*
	78	*	*	8.20	*	149.40	*	*	*
	79	25.00	*	8.10	28.00	90.00	73.50	470.00	750.00
	80	26.00	7.50	8.40	210.00	102.00	81.10	*	798.00
	81	27.00	6.00	8.50	62.00	100.00	119.00	*	550.00
	82	30.00	11.20	8.30	18.00	63.00	40.00	390.00	550.00
	83	25.00	8.20	8.40	0.00	71.80	123.00	430.00	640.00
	84	29.00	8.20	8.30	0.00	102.10	170.00	405.00	610.00
	85	29.00	7.80	8.40	24.00	147.00	200.00	600.00	900.00
	86	27.00	6.10	8.00	*	79.00	130.00	500.00	750.00
MIN		25.00	6.00	8.00	0.00	63.00	40.00	390.00	550.00
MAX		30.00	11.20	8.50	210.00	149.40	200.00	600.00	900.00
MEAN		27.2500	7.8571	8.2909	48.8571	103.5727	107.6600	465.8333	693.5000
STDEV		1.9086	1.7358	.1514	74.0708	28.3824	50.2910	77.3574	125.9059
VALIDN		8	7	11	7	11	10	6	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
JULY	76	*	*	8.50	*	121.00	61.00	*	*
	77	*	*	8.30	*	92.00	61.00	*	*
	78	*	*	8.20	*	149.40	108.00	*	*
	79	26.00	6.90	8.10	8.00	88.00	75.40	485.00	690.00
	80	30.00	6.40	8.50	50.00	110.00	87.10	*	710.00
	81	27.00	3.50	8.10	20.00	80.00	135.00	*	600.00
	82	28.00	7.30	8.80	14.00	64.00	68.00	405.00	600.00
	83	27.00	9.60	8.40	0.00	74.70	135.00	410.00	620.00
	84	29.00	8.40	8.50	10.00	107.70	130.00	445.00	665.00
	85	31.00	8.10	8.60	0.00	110.00	165.00	600.00	900.00
	86	29.50	6.50	8.40	0.00	83.00	130.00	503.00	755.00
MIN		26.00	3.50	8.10	0.00	64.00	61.00	405.00	600.00
MAX		31.00	9.60	8.80	50.00	149.40	165.00	600.00	900.00
MEAN		28.4375	7.0875	8.4000	12.7500	98.1636	105.0455	474.6667	692.5000
STDEV		1.7204	1.8059	.2145	16.7311	24.3652	36.1892	72.8469	100.2853
VALIDN		8	8	11	8	11	11	6	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
AUGUST	76	*	*	8.10	*	128.00	75.00	*	*
	77	*	*	8.30	*	109.40	46.00	*	*
	78	*	*	8.10	*	96.00	76.50	335.00	675.00
	79	27.00	6.20	8.00	46.00	88.00	73.60	435.00	520.00
	80	28.00	7.40	8.60	34.00	114.00	63.10	*	775.00
	81	25.00	7.20	8.50	0.00	96.00	122.00	500.00	450.00
	82	28.00	6.00	8.30	6.00	66.00	32.00	390.00	640.00
	83	34.00	8.80	8.80	*	70.00	75.00	390.00	588.00
	84	30.00	7.70	8.30	36.00	107.00	135.00	600.00	900.00
	85	29.00	7.60	8.40	4.00	101.00	160.00	567.00	850.00
	86	29.00	7.90	8.30	*	85.00	133.00	527.00	790.00
MIN		25.00	6.00	8.00	0.00	66.00	32.00	335.00	450.00
MAX		34.00	8.80	8.80	46.00	128.00	160.00	600.00	900.00
MEAN		28.7500	7.3500	8.3364	21.0000	96.4000	90.1091	468.0000	687.5556
STDEV		2.6049	.9071	.2335	19.8696	18.5278	40.8934	94.6241	152.6844
VALIDN		8	8	11	6	11	11	8	9

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
SEPTEMBER	76	*	*	*	*	*	*	*	*
	77	*	*	7.80	*	137.90	71.00	*	*
	78	*	*	8.10	*	84.00	72.80	*	*
	79	30.00	7.00	8.30	2.00	98.00	73.20	410.00	515.00
	80	26.00	6.70	8.40	36.00	116.00	77.40	*	840.00
	81	28.00	6.60	8.80	5.00	84.00	129.00	600.00	600.00
	82	24.00	6.30	8.30	6.00	70.00	30.00	415.00	560.00
	83	29.00	8.80	8.60	0.00	78.20	70.00	410.00	615.00
	84	28.00	9.10	8.60	34.00	105.00	164.00	607.00	910.00
	85	24.00	11.30	8.70	*	108.00	160.00	597.00	895.00
	86	25.00	6.60	8.20	*	75.00	133.00	480.00	720.00
MIN		24.00	6.30	7.80	0.00	70.00	30.00	410.00	515.00
MAX		30.00	11.30	8.80	36.00	137.90	164.00	607.00	910.00
MEAN		26.7500	7.8000	8.3800	13.8333	95.6100	98.0400	502.7143	706.8750
STDEV		2.3146	1.7696	.3048	16.5459	21.3566	44.9659	95.4214	157.1155
VALIDN		8	8	10	6	10	10	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
OCTOBER	76	*	*	8.40	*	107.00	60.00	*	*
	77	*	*	8.00	*	116.60	55.00	*	*
	78	*	*	8.60	*	108.00	81.50	*	*
	79	30.00	7.10	8.10	232.00	100.00	73.60	405.00	590.00
	80	22.00	7.80	8.10	150.00	76.00	39.20	*	690.00
	81	24.00	7.30	8.60	50.00	86.00	85.00	550.00	610.00
	82	20.00	8.10	8.60	14.00	70.00	38.00	410.00	690.00
	83	23.00	6.20	8.50	2.00	79.10	80.00	460.00	640.00
	84	22.00	11.40	8.90	40.00	112.00	160.00	573.00	860.00
	85	22.00	8.20	8.50	90.00	100.00	157.00	627.00	940.00
	86	19.00	7.10	8.20	*	60.00	85.00	375.00	560.00
MIN		19.00	6.20	8.00	2.00	60.00	38.00	375.00	560.00
MAX		30.00	11.40	8.90	232.00	116.60	160.00	627.00	940.00
MEAN		22.7500	7.9000	8.4091	82.5714	92.2455	83.1182	485.7143	697.5000
STDEV		3.3274	1.5547	.2773	82.6617	18.9206	40.9498	97.3648	134.5628
VALIDN		8	8	11	7	11	11	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
OCTOBER	76	*	*	8.40	*	107.00	60.00	*	*
	77	*	*	8.00	*	116.60	55.00	*	*
	78	*	*	8.60	*	108.00	81.50	*	*
	79	30.00	7.10	8.10	232.00	100.00	73.60	405.00	590.00
	80	22.00	7.80	8.10	150.00	76.00	39.20	*	690.00
	81	24.00	7.30	8.60	50.00	86.00	85.00	550.00	610.00
	82	20.00	8.10	8.60	14.00	70.00	38.00	410.00	690.00
	83	23.00	6.20	8.50	2.00	79.10	80.00	460.00	640.00
	84	22.00	11.40	8.90	40.00	112.00	160.00	573.00	860.00
	85	22.00	8.20	8.50	90.00	100.00	157.00	627.00	940.00
	86	19.00	7.10	8.20	*	60.00	85.00	375.00	560.00
MIN		19.00	6.20	8.00	2.00	60.00	38.00	375.00	560.00
MAX		30.00	11.40	8.90	232.00	116.60	160.00	627.00	940.00
MEAN		22.7500	7.9000	8.4091	82.5714	92.2455	83.1182	485.7143	697.5000
STDEV		3.3274	1.5547	.2773	82.6617	18.9206	40.9498	97.3648	134.5628
VALIDN		8	8	11	7	11	11	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
NOVEMBER	76	*	*	8.20	*	114.00	49.00	*	*
	77	*	*	8.20	*	118.50	67.00	*	*
	78	19.00	*	8.25	*	97.50	84.20	413.00	550.00
	79	18.00	9.90	8.70	64.00	108.00	77.80	*	710.00
	80	19.00	9.30	8.65	40.00	72.00	75.50	*	615.00
	81	17.00	7.60	8.00	65.00	62.00	90.00	300.00	400.00
	82	14.00	10.00	8.80	16.00	77.00	34.00	200.00	700.00
	83	20.00	6.30	8.60	0.00	90.00	270.00	475.00	700.00
	84	17.00	8.10	8.60	2.00	117.00	105.00	500.00	750.00
	85	16.00	13.40	8.40	18.00	93.00	152.00	543.00	815.00
	86	12.00	7.60	8.10	*	65.80	85.00	380.00	570.00
MIN		12.00	6.30	8.00	0.00	62.00	34.00	200.00	400.00
MAX		20.00	13.40	8.80	65.00	118.50	270.00	543.00	815.00
MEAN		16.8889	9.0250	8.4091	29.2857	92.2545	99.0455	401.5714	645.5556
STDEV		2.5712	2.1803	.2728	27.3905	20.7683	64.2905	120.1566	125.3855
VALIDN		9	8	11	7	11	11	7	9

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
DECEMBER	76	*	*	8.30	*	107.00	62.70	*	*
	77	*	*	8.20	*	120.50	65.50	*	*
	78	13.00	*	8.50	*	101.60	79.00	*	620.00
	79	12.00	10.20	8.60	22.00	116.00	*	*	790.00
	80	12.00	9.70	8.40	34.00	76.00	83.90	*	610.00
	81	8.00	10.10	8.30	53.00	52.00	73.00	340.00	425.00
	82	12.00	9.30	8.50	*	70.00	32.00	203.00	700.00
	83	11.00	7.70	8.40	0.00	90.00	120.00	435.00	700.00
	84	12.00	11.90	8.50	0.00	96.00	101.00	483.00	725.00
	85	13.00	10.70	8.40	28.00	95.00	130.00	576.00	850.00
	86	11.00	8.90	8.30	50.00	60.00	78.00	370.00	555.00
MIN		8.00	7.70	8.20	0.00	52.00	32.00	203.00	425.00
MAX		13.00	11.90	8.60	53.00	120.50	130.00	576.00	850.00
MEAN		11.5556	9.8125	8.4000	26.7143	89.4636	82.5100	401.1667	663.8889
STDEV		1.5092	1.2506	.1183	21.3597	22.4224	28.5983	128.3673	127.7883
VALIDN		9	8	11	7	11	10	6	9

```
TITLE FORT PHANTOM HILL RESERVOIR QUALITY.
DATA LIST FILE='B:PHANTWQ.DAT' / YEAR 1-2 MONTH 3-4 DAY 5-6 TEMP 7-10
           DO 11-15 PH 16-20 TURB 21-25
           COND 26-30 TDS 31-35 TALK 36-40 HARD 41-45 CA 46-50 MG 51-55
           CL 56-60 FL 61-65 PO4 66-70 SI 71-75 FCOLI 76-80 / CR 7-10 CU 11-15
           NI 16-20 PB 21-25 ZN 26-30 FE 31-35 AG 36-40 NA 41-45 BA 46-50
           NH3 51-55 NO3 56-60 NO2 61-65 MN 66-70 ELEV 71-75 K 76-80 /
           SO4 7-10 CD 11-15 BR 16-20.
VALUE LABELS MONTH 01 'JANUARY'
                   02 'FEBRUARY'
                   03 'MARCH'
                   04 'APRIL'
                   05 'MAY'
                   06 'JUNE'
                   07 'JULY'
                   08 'AUGUST'
                   09 'SEPTEMBER'
                   10 'OCTOBER'
                   11 'NOVEMBER'
                   12 'DECEMBER'.
MISSING VALUE ALL (-1).
SORT CASES BY MONTH YEAR.
The raw data or transformation pass is proceeding
    133 cases are written to the uncompressed active file.

Size of File to Be Sorted:       133 Cases of    312 Bytes Each.
    133 cases are written to the uncompressed active file.
SORT completed successfully.
```

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This procedure was completed at 10:02:43
FORMATS PO4 (F8.2) NO3 (F8.2) NO2 (F8.2) NH3 (F8.2) K (F8.2).
REPORT FORMAT = LIST (4) MISSING '*' BRKSPACE(-1)
       /VARIABLES = PO4 'DISSOLVED' 'ORTHO-P' 'MG/L AS P' (9)
                    NO3 'NITRATE' 'NITROGEN' 'MG/L AS N' (9)
                    NO2 'NITRITE' 'NITROGEN' 'MG/L AS N' (9)
                    NH3 'AMMONIA' 'NITROGEN' 'MG/L AS N' (9)
                    K    ' ' 'POTASSIUM' 'MG/L AS K' (9)
       /BREAK = MONTH (LABEL) (PAGE)
       /SUMMARY = MIN
       /SUMMARY = MAX
       /SUMMARY = MEAN
       /SUMMARY = STDEV
       /SUMMARY=VALIDN
       /BREAK = YEAR.

REPORT REQUIRES     3126 BYTES FOR THIS TASK
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FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
JANUARY	76	0.00	2.22	0.00	.40	7.50
	77	.09	.07	0.00	.24	7.20
	78	0.00	0.00	0.00	0.00	11.80
	79	0.00	0.00	0.00	0.00	8.20
	80	0.00	0.00	0.00	0.00	9.30
	81	0.00	0.00	0.00	.11	16.80
	82	*	.28	.03	*	*
	83	*	.75	0.00	*	*
	84	.40	.20	.01	*	*
	85	.07	*	*	*	7.40
	86	0.00	0.00	*	1.40	*
	87	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	7.20
MAX		.40	2.22	.03	1.40	16.80
MEAN		.0562	.3199	.0044	.2690	9.7429
STDEV		.1255	.6699	.0101	.4798	3.5023
VALIDN		10	11	9	8	7

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
FEBRUARY	76	0.00	.03	0.00	.20	11.00
	77	.09	.08	0.00	0.00	8.84
	78	0.00	.37	0.00	.70	8.48
	79	0.00	0.00	0.00	0.00	7.90
	80	0.00	0.00	0.00	0.00	7.80
	81	0.00	.45	0.00	0.00	9.30
	82	*	.30	.02	*	*
	83	*	0.00	0.00	*	*
	84	.40	*	*	*	*
	85	.23	0.00	.06	*	7.80
	86	0.00	0.00	*	.60	*
MIN		0.00	0.00	0.00	0.00	7.80
MAX		.40	.45	.06	.70	11.00
MEAN		.0802	.1224	.0089	.2143	8.7314
STDEV		.1429	.1783	.0203	.3078	1.1526
VALIDN		9	10	9	7	7

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
MARCH	76	.15	.28	0.00	.25	4.30
	77	0.00	.11	.03	.15	8.00
	78	*	*	*	*	*
	79	0.00	0.00	.05	0.00	7.40
	80	0.00	0.00	0.00	0.00	8.80
	81	0.00	0.00	0.00	.33	7.10
	82	*	.24	.03	*	*
	83	*	0.00	.01	*	*
	84	0.00	*	*	*	*
	85	.02	0.00	.08	*	*
	86	0.00	0.00	*	1.40	*
MIN		0.00	0.00	0.00	0.00	4.30
MAX		.15	.28	.08	1.40	8.80
MEAN		.0216	.0705	.0244	.3550	7.1200
STDEV		.0535	.1144	.0287	.5287	1.7050
VALIDN		8	9	8	6	5

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
APRIL	76	.15	.14	0.00	.51	12.00
	77	.06	.32	.04	.30	6.60
	78	0.00	0.00	*	*	*
	79	0.00	.23	0.00	0.00	6.90
	80	0.00	0.00	0.00	0.00	8.90
	81	0.00	0.00	0.00	*	7.70
	82	*	.38	0.00	*	*
	83	*	.20	.01	*	*
	84	.31	*	*	*	*
	85	.01	.10	.05	*	*
	86	0.00	0.00	*	1.60	*
MIN		0.00	0.00	0.00	0.00	6.60
MAX		.31	.38	.05	1.60	12.00
MEAN		.0593	.1374	.0129	.4822	8.4200
STDEV		.1070	.1426	.0211	.6611	2.1902
VALIDN		9	10	8	5	5

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
MAY	76	.25	.14	0.00	.10	8.60
	77	0.00	.29	.05	.39	7.95
	78	0.00	*	0.00	*	8.60
	79	0.00	0.00	0.00	.20	7.30
	80	0.00	0.00	0.00	0.00	9.70
	81	0.00	.20	.02	*	7.40
	82	*	.60	0.00	*	*
	83	0.00	0.00	0.00	*	0.00
	84	*	*	*	*	*
	85	.15	.15	.07	*	*
	86	0.00	0.00	*	.70	*
MIN		0.00	0.00	0.00	0.00	0.00
MAX		.25	.60	.07	.70	9.70
MEAN		.0439	.1533	.0159	.2768	7.0786
STDEV		.0903	.1985	.0270	.2766	3.2280
VALIDN		9	9	9	5	7

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
JUNE	76	.03	.11	.03	.08	24.00
	77	.03	.23	0.00	0.00	7.70
	78	*	*	*	*	10.40
	79	0.00	.29	.03	0.00	6.70
	80	0.00	0.00	0.00	0.00	8.80
	81	0.00	.53	0.00	*	*
	82	*	.70	.01	*	*
	83	.90	0.00	.02	*	.90
	84	0.00	0.00	.10	*	*
	85	0.00	.10	*	1.34	*
	86	0.00	0.00	*	1.10	*
MIN		0.00	0.00	0.00	0.00	.90
MAX		.90	.70	.10	1.34	24.00
MEAN		.1068	.1955	.0245	.4192	9.7500
STDEV		.2978	.2464	.0333	.6256	7.6969
VALIDN		9	10	8	6	6

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
JULY	76	.03	.10	.03	.07	26.00
	77	0.00	.07	0.00	0.00	9.18
	78	0.00	.34	0.00	*	10.90
	79	0.00	0.00	0.00	.22	7.40
	80	0.00	0.00	0.00	0.00	11.30
	81	0.00	.40	.05	*	*
	82	*	.22	0.00	*	*
	83	.20	.20	.01	*	.20
	84	.07	*	*	*	*
	85	.01	0.00	0.00	3.40	*
	86	0.00	0.00	*	.40	*
MIN		0.00	0.00	0.00	0.00	.20
MAX		.20	.40	.05	3.40	26.00
MEAN		.0310	.1326	.0100	.6822	10.8300
STDEV		.0635	.1500	.0180	1.3403	8.4598
VALIDN		10	10	9	6	6

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
AUGUST	76	.03	.12	.04	.07	9.00
	77	0.00	.58	.17	.36	8.65
	78	0.00	.15	.01	.92	10.60
	79	0.00	0.00	0.00	0.00	7.30
	80	0.00	0.00	0.00	.11	9.70
	81	*	.60	0.00	*	*
	82	*	0.00	.01	*	*
	83	.20	0.00	0.00	*	.20
	84	0.00	*	*	*	11.20
	85	0.00	0.00	0.00	*	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	.20
MAX		.20	.60	.17	.92	11.20
MEAN		.0257	.1456	.0257	.2433	8.0929
STDEV		.0662	.2410	.0556	.3571	3.7099
VALIDN		9	10	9	6	7

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
SEPTEMBER	76	*	*	*	*	*
	77	0.00	1.71	0.00	0.00	8.13
	78	0.00	.35	0.00	.19	7.40
	79	0.00	0.00	0.00	0.00	7.40
	80	0.00	0.00	0.00	0.00	9.80
	81	*	.37	.01	*	*
	82	*	0.00	0.00	*	*
	83	*	*	*	*	*
	84	0.00	*	*	*	10.70
	85	0.00	0.00	0.00	*	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	7.40
MAX		0.00	1.71	.01	.19	10.70
MEAN		0.000	.3034	.0014	.0380	8.6860
STDEV		0.000	.5894	.0038	.0850	1.4928
VALIDN		7	8	7	5	5

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
OCTOBER	76	0.00	.01	.03	0.00	9.20
	77	0.00	.10	0.00	1.28	8.27
	78	0.00	.19	0.00	.22	8.30
	79	0.00	0.00	0.00	0.00	8.50
	80	0.00	.32	.03	0.00	11.50
	81	*	.61	0.00	*	*
	82	*	.20	.01	*	*
	83	*	*	*	*	*
	84	.08	*	*	*	8.00
	85	0.00	0.00	0.00	*	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	8.00
MAX		.08	.61	.03	1.28	11.50
MEAN		.0100	.1590	.0091	.2500	8.9617
STDEV		.0283	.2044	.0143	.5122	1.3080
VALID N		8	9	8	6	6

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
NOVEMBER	76	.18	.34	.04	.41	5.60
	77	.01	*	0.00	.12	9.55
	78	0.00	.75	0.00	.40	8.70
	79	0.00	0.00	0.00	0.00	8.40
	80	0.00	0.00	0.00	0.00	10.50
	81	*	.51	0.00	*	*
	82	*	.78	.01	*	*
	83	.65	*	*	*	*
	84	.11	*	*	*	5.20
	85	.10	0.00	*	.60	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	5.20
MAX		.65	.78	.04	.60	10.50
MEAN		.1171	.2980	.0071	.2186	7.9917
STDEV		.2107	.3462	.0150	.2477	2.1402
VALIDN		9	8	7	7	6

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
DECEMBER	76	0.00	.29	.06	.17	5.96
	77	0.00	.53	0.00	0.00	8.55
	78	0.00	0.00	0.00	0.00	8.80
	79	*	*	*	*	7.70
	80	0.00	0.00	0.00	0.00	10.50
	81	*	.37	.04	*	*
	82	*	0.00	.02	*	*
	83	.10	*	*	*	6.80
	84	.36	*	*	*	8.00
	85	0.00	0.00	*	.70	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	5.96
MAX		.36	.53	.06	.70	10.50
MEAN		.0575	.1489	.0205	.1447	8.0443
STDEV		.1271	.2155	.0266	.2802	1.4646
VALIDN		8	8	6	6	7

This procedure was completed at 10:14:45
review.

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SET ECHO=ON/ PRINTER=ON/ EJECT=ON/ SCREEN = OFF/ WIDTH=WIDE.
TITLE FORT PHANTOM HILL RESERVOIR QUALITY.
DATA LIST FILE='B:PHANTWQ.DAT' / YEAR 1-2 MONTH 3-4 DAY 5-6 TEMP 7-10
           DO 11-15 PH 16-20 TURB 21-25
           COND 26-30 TDS 31-35 TALK 36-40 HARD 41-45 CA 46-50 MG 51-55
           CL 56-60 FL 61-65 PO4 66-70 SI 71-75 FCOLI 76-80 / CR 7-10 CU 11-15
           NI 16-20 PB 21-25 ZN 26-30 FE 31-35 AG 36-40 NA 41-45 BA 46-50
           NH3 51-55 NO3 56-60 NO2 61-65 MN 66-70 ELEV 71-75 K 76-80 /
           SO4 7-10 CD 11-15 BR 16-20.
VALUE LABELS MONTH 01 'JANUARY'
                   02 'FEBRUARY'
                   03 'MARCH'
                   04 'APRIL'
                   05 'MAY'
                   06 'JUNE'
                   07 'JULY'
                   08 'AUGUST'
                   09 'SEPTEMBER'
                   10 'OCTOBER'
                   11 'NOVEMBER'
                   12 'DECEMBER'.
MISSING VALUE ALL (-1).
SORT CASES BY MONTH YEAR.
The raw data or transformation pass is proceeding
    133 cases are written to the uncompressed active file.

Size .. File to Be Sorted:       133 Cases of     312 Bytes Each.
    133 cases are written to the uncompressed active file.
SORT completed successfully.
```

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This procedure was completed at  9:47:47
FORMATS TURB (F8.2) TALK (F8.2) HARD (F8.2) CA (F8.2) MG (F8.2) NA (F8.2)
        MN (F8.2).
REPORT FORMAT = LIST (4) MISSING '*' BRKSPACE(-1)
       /VARIABLES = TURB 'TURBIDITY' 'FORMAZIN' 'T. UNITS' (9)
                    TALK 'TOTAL' 'ALKALINITY' 'MG/L AS CACO3' (13)
                    HARD 'HARDNESS' 'MG/L' 'AS CACO3'
                    CA    ' ' 'CALCIUM' 'MG/L'
                    MG    ' ' 'MAGNESIUM' 'MG/L' (9)
                    NA    ' ' 'SODIUM' 'MG/L'
                    MN    ' ' 'MANGANESE' 'MG/L' (9)
       /BREAK = MONTH (LABEL) (PAGE)
       /SUMMARY = MIN
       /SUMMARY = MAX
       /SUMMARY = MEAN
       /SUMMARY = STDEV
       /SUMMARY=VALIDN
       /BREAK = YEAR.

 REPORT REQUIRES     3598 BYTES FOR THIS TASK
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This procedure was completed at 9:56:15

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
JANUARY	76	*	152.00	240.00	52.00	22.30	48.50	0.00
	77	*	124.00	228.00	37.00	43.00	54.20	0.00
	78	*	163.00	270.00	51.80	34.60	88.70	0.00
	79	*	150.00	212.00	62.00	14.00	75.00	0.00
	80	30.00	153.00	226.00	55.00	21.00	94.00	0.00
	81	120.00	141.00	220.00	54.00	21.00	67.00	.01
	82	17.00	141.00	190.00	62.00	9.00	48.00	*
	83	6.80	195.00	214.00	53.70	13.00	43.70	*
	84	4.00	92.00	159.00	43.00	13.00	64.20	*
	85	19.00	90.00	212.00	*	*	57.00	*
	86	4.90	125.00	270.00	67.40	24.80	*	*
	87	10.00	124.00	200.00	*	*	*	*
MIN		4.00	90.00	159.00	37.00	9.00	43.70	0.00
MAX		120.00	195.00	270.00	67.40	43.00	94.00	.01
MEAN		26.4625	137.5000	220.0833	53.7900	21.5700	64.0300	.0017
STDEV		38.7927	29.2870	31.1666	8.9879	10.5559	17.2996	.0041
VALIDN		8	12	12	10	10	10	6

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
FEBRUARY	76	*	145.00	245.00	77.00	24.00	61.50	0.00
	77	*	135.00	210.00	58.00	20.00	56.00	0.00
	78	*	167.00	270.00	50.30	31.60	79.70	*
	79	*	143.00	210.00	52.00	19.00	60.00	0.00
	80	40.50	166.00	244.00	60.00	23.00	63.00	0.00
	81	26.00	142.00	226.00	56.00	21.00	50.00	.01
	82	28.00	130.00	168.00	60.00	4.00	*	*
	83	5.60	195.00	232.00	65.00	17.00	50.60	*
	84	11.00	147.00	238.00	63.40	19.40	48.60	*
	85	16.00	120.00	236.00	57.70	22.40	59.00	*
	86	13.00	130.00	272.00	65.00	27.00	*	*
MIN		5.60	120.00	168.00	50.30	4.00	48.60	0.00
MAX		40.50	195.00	272.00	77.00	31.60	79.70	.01
MEAN		20.0143	147.2727	231.9091	60.4000	20.7636	58.7111	.0020
STDEV		12.0665	21.3546	29.1700	7.2951	6.8939	9.4849	.0045
VALIDN		7	11	11	11	11	9	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
MARCH	76	*	168.00	210.00	48.00	24.00	45.00	0.00
	77	*	133.00	220.00	42.00	26.00	60.00	0.00
	78	*	*	*	*	*	*	*
	79	*	159.00	218.00	66.00	12.00	67.00	0.00
	80	57.00	176.00	224.00	58.00	19.00	77.00	0.00
	81	105.00	150.00	268.00	74.00	24.00	57.00	.09
	82	47.00	130.00	180.00	56.00	10.00	34.00	*
	83	9.40	184.10	218.00	51.30	21.90	102.10	*
	84	34.00	153.00	238.00	52.10	26.20	123.90	*
	85	35.00	120.00	232.00	58.00	21.00	*	*
	86	35.00	134.00	274.00	86.00	15.00	*	*
MIN		9.40	120.00	180.00	42.00	10.00	34.00	0.00
MAX		105.00	184.10	274.00	86.00	26.20	123.90	.09
MEAN		46.0571	150.7100	228.2000	59.1400	19.9100	70.7500	.0180
STDEV		29.8008	21.3249	27.3650	13.0414	5.7828	29.7108	.0402
VALIDN		7	10	10	10	10	8	5

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
APRIL	76	*	180.00	240.00	50.00	30.60	56.00	0.00
	77	*	145.00	235.00	36.00	22.00	57.00	0.00
	78	*	171.00	266.00	52.00	33.00	85.00	*
	79	*	135.00	200.00	46.00	20.00	53.00	0.00
	80	74.00	204.00	260.00	85.00	12.00	64.00	0.00
	81	18.00	76.00	232.00	54.00	24.00	50.00	.01
	82	39.00	137.00	184.00	45.00	17.00	*	*
	83	64.00	154.00	218.00	59.30	14.60	57.50	*
	84	29.00	152.00	242.00	72.20	15.10	120.00	*
	85	13.00	112.00	230.00	152.00	78.00	*	*
	86	27.00	134.00	270.00	88.20	12.20	*	*
MIN		13.00	76.00	184.00	36.00	12.00	50.00	0.00
MAX		74.00	204.00	270.00	152.00	78.00	120.00	.01
MEAN		37.7143	145.4545	234.2727	67.2455	25.3182	67.8125	.0020
STDEV		23.0919	34.1244	26.5107	32.6391	18.8182	23.7034	.0045
VALIDN		7	11	11	11	11	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
MAY	76	*	152.00	248.00	46.00	28.00	58.00	0.00
	77	*	130.00	224.00	35.90	22.70	95.00	0.00
	78	*	180.00	270.00	59.20	33.20	86.10	0.00
	79	*	136.00	192.00	48.00	17.00	49.00	0.00
	80	*	182.00	256.00	65.00	23.00	72.00	0.00
	81	13.00	140.00	290.00	90.00	16.00	45.00	.02
	82	27.00	132.00	200.00	53.00	16.00	32.00	*
	83	36.00	162.00	224.00	65.80	14.60	92.00	*
	84	18.00	150.00	250.00	51.30	29.60	90.00	*
	85	28.00	126.00	264.00	66.00	24.00	*	*
	86	26.00	138.00	298.00	87.00	19.00	*	*
MIN		13.00	126.00	192.00	35.90	14.60	32.00	0.00
MAX		36.00	182.00	298.00	90.00	33.20	95.00	.02
MEAN		24.6667	148.0000	246.9091	60.6545	22.1000	68.7889	.0033
STDEV		8.0911	19.4113	34.1334	16.6285	6.2076	23.4867	.0082
VALIDN		6	11	11	11	11	9	6

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
JUNE	76	*	164.00	256.00	53.00	41.50	80.00	0.00
	77	*	152.00	184.00	55.00	23.60	45.40	0.00
	78	*	171.00	254.00	48.00	32.40	94.80	0.00
	79	*	153.00	210.00	59.00	15.00	52.00	0.00
	80	59.00	167.00	232.00	63.00	18.00	51.00	.03
	81	27.00	158.00	236.00	67.00	16.00	*	*
	82	42.00	131.00	194.00	43.00	21.00	30.00	*
	83	140.00	156.00	232.00	172.00	60.00	152.00	*
	84	10.00	164.00	296.00	80.20	23.30	80.20	*
	85	32.00	116.00	272.00	72.00	22.00	*	*
	86	63.00	128.00	240.00	68.00	17.00	*	*
MIN		10.00	116.00	184.00	43.00	15.00	30.00	0.00
MAX		140.00	171.00	296.00	172.00	60.00	152.00	.03
MEAN		53.2857	150.9091	236.9091	70.9273	26.3455	73.1750	.0060
STDEV		42.4096	17.9636	32.8678	35.2315	13.6233	38.4570	.0134
VALIDN		7	11	11	11	11	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
JULY	76	*	151.00	252.00	61.00	30.70	65.00	0.00
	77	*	158.00	241.00	46.80	27.00	71.10	*
	78	*	162.00	264.00	45.20	37.00	106.40	.05
	79	170.00	150.00	214.00	50.00	20.00	58.00	0.00
	80	57.00	190.00	246.00	58.00	24.00	61.00	.02
	81	40.00	140.00	246.00	68.00	18.00	*	*
	82	14.00	131.00	186.00	52.00	14.00	48.00	*
	83	17.00	153.00	230.00	61.80	18.50	45.00	*
	84	12.00	155.00	270.00	80.00	20.00	68.00	*
	85	13.00	124.00	270.00	72.00	22.00	*	*
	86	26.00	122.00	240.00	69.00	17.00	*	*
MIN		12.00	122.00	186.00	45.20	14.00	45.00	0.00
MAX		170.00	190.00	270.00	80.00	37.00	106.40	.05
MEAN		43.6250	148.7273	241.7273	60.3455	22.5636	65.3125	.0175
STDEV		53.4494	19.3551	25.0044	11.1947	6.7190	18.9488	.0236
VALIDN		8	11	11	11	11	8	4

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
AUGUST	76	*	142.00	240.00	53.00	35.00	71.00	0.00
	77	*	149.00	220.00	33.70	31.60	73.20	0.00
	78	*	121.00	174.00	31.00	28.00	78.20	0.00
	79	130.00	143.00	200.00	49.00	19.00	59.00	0.00
	80	120.00	170.00	246.00	58.00	24.00	63.00	.11
	81	25.00	137.00	278.00	76.00	21.00	*	*
	82	15.00	137.00	216.00	69.00	10.00	26.00	*
	83	13.00	135.00	214.00	53.70	19.40	47.00	*
	84	18.00	144.00	252.00	66.00	21.00	66.00	*
	85	14.00	136.00	274.00	70.00	24.00	*	*
	86	36.00	138.00	234.00	70.00	*	*	*
MIN		13.00	121.00	174.00	31.00	10.00	26.00	0.00
MAX		130.00	170.00	278.00	76.00	35.00	78.20	.11
MEAN		46.3750	141.0909	231.6364	57.2182	23.3000	60.4250	.0220
STDEV		49.1788	11.9202	31.0718	14.9474	7.0712	16.8863	.0492
VALIDN		8	11	11	11	10	8	5

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
SEPTEMBER	76	*	*	*	*	*	*	*
	77	*	125.00	250.00	39.50	20.10	47.30	0.00
	78	*	130.00	202.00	33.20	17.30	49.20	0.00
	79	110.00	150.00	208.00	45.00	23.00	62.00	0.00
	80	35.00	167.00	252.00	61.00	24.00	66.00	0.00
	81	150.00	137.00	250.00	66.00	21.00	*	*
	82	18.00	140.00	200.00	70.00	12.00	28.00	*
	83	21.00	137.00	210.00	57.50	16.00	53.00	*
	84	34.00	140.00	260.00	75.00	17.70	67.00	*
	85	16.00	117.00	272.00	78.00	19.00	*	*
	86	28.00	126.00	232.00	*	*	*	*
MIN		16.00	117.00	200.00	33.20	12.00	28.00	0.00
MAX		150.00	167.00	272.00	78.00	24.00	67.00	0.00
MEAN		51.5000	136.9000	233.6000	58.3556	18.9000	53.2143	0.000
STDEV		50.0970	14.1457	26.6467	15.9350	3.6861	13.6480	0.000
VALIDN		8	10	10	9	9	7	4

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
OCTOBER	76	*	126.00	224.00	55.00	32.00	68.00	0.00
	77	*	148.00	266.00	36.90	25.60	74.20	0.00
	78	*	120.00	186.00	38.40	19.30	45.20	0.00
	79	*	149.00	222.00	66.00	14.00	65.00	0.00
	80	18.00	131.00	224.00	61.00	18.00	43.00	.01
	81	53.00	167.00	258.00	68.00	21.00	*	*
	82	9.00	160.00	200.00	52.00	17.00	45.00	*
	83	27.00	150.00	226.00	70.60	12.20	49.00	*
	84	18.00	134.00	248.00	56.10	26.20	90.00	*
	85	26.00	138.00	276.00	66.00	27.00	*	*
	86	19.00	110.00	194.00	*	*	*	*
MIN		9.00	110.00	186.00	36.90	12.20	43.00	0.00
MAX		53.00	167.00	276.00	70.60	32.00	90.00	.01
MEAN		24.2857	139.3636	229.4545	57.0000	21.2300	59.9250	.0020
STDEV		13.9966	17.2816	29.6660	11.8497	6.3158	17.0907	.0045
VALIDN		7	11	11	10	10	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
NOVEMBER	76	*	125.00	220.00	33.00	23.70	60.00	0.00
	77	*	139.00	254.00	67.80	26.60	99.80	0.00
	78	*	140.00	190.00	44.80	18.90	131.20	.03
	79	26.00	160.00	226.00	57.00	20.00	66.00	0.00
	80	27.00	138.00	276.00	70.00	26.00	47.00	0.00
	81	54.00	112.00	174.00	62.00	5.00	*	*
	82	36.00	156.00	222.00	64.00	15.00	56.00	*
	83	100.00	148.00	244.00	65.00	19.90	53.00	*
	84	22.00	132.00	216.00	52.90	20.40	52.00	*
	85	11.00	122.00	254.00	62.00	24.00	*	*
	86	20.20	108.00	190.00	*	*	*	*
MIN		11.00	108.00	174.00	33.00	5.00	47.00	0.00
MAX		100.00	160.00	276.00	70.00	26.60	131.20	.03
MEAN		37.0250	134.5455	224.1818	57.8500	19.9500	70.6250	.0060
STDEV		28.4435	16.7891	31.3108	11.4652	6.3299	29.4821	.0134
VALIDN		8	11	11	10	10	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
DECEMBER	76	*	127.00	228.00	30.30	25.20	73.00	0.00
	77	*	138.00	276.00	50.70	28.50	88.40	0.00
	78	*	142.00	194.00	52.00	15.60	57.80	.30
	79	19.00	160.00	236.00	56.00	23.00	62.00	0.00
	80	32.00	130.00	220.00	56.00	19.00	66.00	.03
	81	23.00	136.00	172.00	56.00	8.00	53.00	*
	82	23.00	156.00	212.00	138.00	74.00	32.00	*
	83	125.00	140.00	237.30	63.00	19.50	60.00	*
	84	21.00	122.00	224.00	*	*	54.00	*
	85	17.00	126.00	268.00	64.00	26.00	*	*
	86	17.00	114.00	206.00	*	*	*	*
MIN		17.00	114.00	172.00	30.30	8.00	32.00	0.00
MAX		125.00	160.00	276.00	138.00	74.00	88.40	.30
MEAN		34.6250	135.5455	224.8455	62.8889	26.5333	60.6889	.0660
STDEV		36.8314	13.8807	30.0949	29.8213	18.8439	15.3506	.1315
VALIDN		8	11	11	9	9	9	5

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TITLE FORT PHANTOM HILL RESERVOIR QUALITY.
DATA LIST FILE='B:PHANTWQ.DAT' / YEAR 1-2 MONTH 3-4 DAY 5-6 TEMP 7-10
           DO 11-15 PH 16-20 TURB 21-25
           COND 26-30 TDS 31-35 TALK 36-40 HARD 41-45 CA 46-50 MG 51-55
           CL 56-60 FL 61-65 PO4 66-70 SI 71-75 FCOLI 76-80 / CR 7-10 CU 11-15
           NI 16-20 PB 21-25 ZN 26-30 FE 31-35 AG 36-40 NA 41-45 BA 46-50
           NH3 51-55 NO3 56-60 NO2 61-65 MN 66-70 ELEV 71-75 K 76-80 /
           SO4 7-10 CD 11-15 BR 16-20.
VALUE LABELS MONTH 01 'JANUARY'
                   02 'FEBRUARY'
                   03 'MARCH'
                   04 'APRIL'
                   05 'MAY'
                   06 'JUNE'
                   07 'JULY'
                   08 'AUGUST'
                   09 'SEPTEMBER'
                   10 'OCTOBER'
                   11 'NOVEMBER'
                   12 'DECEMBER'.
MISSING VALUE ALL (-1).
SORT CASES BY MONTH YEAR.
The raw data or transformation pass is proceeding
    133 cases are written to the uncompressed active file.

Size of File to Be Sorted:       133 Cases of    312 Bytes Each.
    133 cases are written to the uncompressed active file.
SORT completed successfully.
```

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This procedure was completed at  9:35:26
FORMATS FL (F8.2) SI (F8.2) CR (F8.2) CU (F8.2) NI (F8.2) PB (F8.2)
        ZN (F8.2).
REPORT FORMAT = LIST (4) MISSING '*' BRKSPACE(-1)
       /VARIABLES = FL    ' ' 'FLUORIDE' 'MG/L AS F'
                    SI    'DISSOLVED' 'SILICA' 'MG/L AS SIO2' (12)
                    CR    'TOTAL' 'CHROMIUM' 'MG/L AS CR' (10)
                    CU    'TOTAL' 'COPPER' 'MG/L AS CU' (10)
                    NI    'TOTAL' 'NICKEL' 'MG/L AS NI' (10)
                    PB    'TOTAL' 'LEAD' 'MG/L AS PB' (10)
                    ZN    'TOTAL' 'ZINC' 'MG/L AS ZN' (10)
       /BREAK = MONTH (LABEL) (PAGE)
       /SUMMARY = MIN
       /SUMMARY = MAX
       /SUMMARY = MEAN
       /SUMMARY = STDEV
       /SUMMARY=VALIDN
       /BREAK = YEAR.

 REPORT REQUIRES     3630 BYTES FOR THIS TASK
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FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
JANUARY	76	*	*	0.00	0.00	0.00	0.00	0.00
	77	.20	*	0.00	0.00	0.00	0.00	0.00
	78	.37	*	0.00	0.00	0.00	0.00	.02
	79	.24	*	0.00	0.00	0.00	0.00	0.00
	80	.25	.80	0.00	0.00	0.00	.01	.03
	81	.37	4.00	.01	0.00	0.00	.01	.01
	82	.28	9.00	*	*	*	*	*
	83	.24	.73	0.00	.04	0.00	.04	.03
	84	.03	4.50	0.00	0.00	0.00	0.00	.01
	85	.34	5.20	0.00	0.00	0.00	0.00	0.00
	86	.24	4.80	*	*	*	*	*
	87	.28	6.60	*	*	*	*	*
MIN		.03	.73	0.00	0.00	0.00	0.00	0.00
MAX		.37	9.00	.01	.04	0.00	.04	.03
MEAN		.2582	4.4537	.0011	.0044	0.000	.0067	.0113
STDEV		.0944	2.7614	.0033	.0133	0.000	.0132	.0125
VALIDN		11	8	9	9	9	9	9

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
FEBRUARY	76	.20	*	0.00	.10	0.00	0.00	0.00
	77	.25	*	0.00	0.00	0.00	0.00	.00
	78	.33	*	0.00	0.00	0.00	0.00	0.00
	79	.27	*	0.00	0.00	0.00	0.00	0.00
	80	.33	.30	0.00	0.00	0.00	.01	0.00
	81	.30	3.70	0.00	0.00	0.00	.01	.02
	82	.20	6.50	*	*	*	*	*
	83	.62	6.14	0.00	.01	.01	.02	.03
	84	.21	8.00	0.00	0.00	0.00	0.00	.04
	85	.20	5.60	0.00	0.00	0.00	0.00	0.00
	86	.28	4.20	*	*	*	*	*
MIN		.20	.30	0.00	0.00	0.00	0.00	0.00
MAX		.62	8.00	0.00	.10	.01	.02	.04
MEAN		.2900	4.9200	0.000	.0122	.0011	.0044	.0102
STDEV		.1204	2.4928	0.000	.0331	.0033	.0073	.0155
VALIDN		11	7	9	9	9	9	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
MARCH	76	0.00	*	.03	.02	0.00	0.00	0.00
	77	.22	*	0.00	0.00	0.00	0.00	0.00
	78	*	*	*	*	*	*	*
	79	.23	*	0.00	0.00	0.00	0.00	0.00
	80	.28	.10	0.00	0.00	0.00	.02	.10
	81	.35	5.10	*	0.00	.01	.01	.02
	82	.24	6.00	*	*	*	*	*
	83	0.00	4.46	1.70	.20	0.00	0.00	0.00
	84	.26	7.20	0.00	0.00	0.00	0.00	.09
	85	.23	3.60	*	*	*	*	*
	86	.26	3.60	*	*	*	*	*
MIN		0.00	.10	0.00	0.00	0.00	0.00	0.00
MAX		.35	7.20	1.70	.20	.01	.02	.10
MEAN		.2070	4.2943	.2883	.0314	.0014	.0043	.0304
STDEV		.1152	2.2578	.6917	.0747	.0038	.0079	.0450
VALIDN		10	7	6	7	7	7	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
APRIL	76	.29	*	.02	.03	0.00	0.00	0.00
	77	.28	*	0.00	0.00	0.00	0.00	.30
	78	*	*	*	*	*	*	*
	79	0.00	*	0.00	0.00	0.00	0.00	0.00
	80	.31	1.90	0.00	0.00	0.00	.02	0.00
	81	.45	2.40	0.00	0.00	0.00	.01	0.00
	82	.23	4.90	*	*	*	*	*
	83	.32	3.60	0.00	0.00	0.00	0.00	0.00
	84	.33	7.40	0.00	0.00	0.00	0.00	.10
	85	.28	.80	*	*	*	*	*
	86	.30	.40	*	*	*	*	*
MIN		0.00	.40	0.00	0.00	0.00	0.00	0.00
MAX		.45	7.40	.02	.03	0.00	.02	.30
MEAN		.2790	3.0571	.0029	.0043	0.000	.0043	.0571
STDEV		.1132	2.4657	.0076	.0113	0.000	.0079	.1134
VALIDN		10	7	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
MAY	76	.26	*	.06	.02	0.00	0.00	0.00
	77	.24	*	0.00	0.00	0.00	0.00	0.00
	78	.35	*	0.00	0.00	0.00	0.00	0.00
	79	0.00	*	0.00	0.00	0.00	0.00	0.00
	80	.30	1.50	.01	0.00	0.00	.01	0.00
	81	.36	2.80	0.00	0.00	.01	0.00	.02
	82	.31	3.90	*	*	*	*	*
	83	.36	.50	0.00	0.00	0.00	0.00	0.00
	84	.26	.80	0.00	0.00	0.00	0.00	0.00
	85	.30	2.60	*	*	*	*	*
	86	.30	1.30	*	*	*	*	*
MIN		0.00	.50	0.00	0.00	0.00	0.00	0.00
MAX		.36	3.90	.06	.02	.01	.01	.02
MEAN		.2759	1.9143	.0087	.0025	.0013	.0013	.0025
STDEV		.1003	1.2240	.0210	.0071	.0035	.0035	.0071
VALIDN		11	7	8	8	8	8	8

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
JUNE	76	.29	*	0.00	0.00	.01	0.00	0.00
	77	.26	*	0.00	0.00	0.00	0.00	0.00
	78	.22	*	0.00	0.00	0.00	0.00	.20
	79	.20	*	0.00	0.00	0.00	0.00	0.00
	80	.28	2.20	0.00	0.00	0.00	0.00	0.00
	81	.40	4.40	*	*	*	*	*
	82	.50	.75	*	*	*	*	*
	83	.49	.79	0.00	0.00	.10	0.00	0.00
	84	.39	3.00	0.00	0.00	0.00	0.00	.10
	85	.25	5.60	*	*	*	*	*
	86	.30	5.00	*	*	*	*	*
MIN		.20	.75	0.00	0.00	0.00	0.00	0.00
MAX		.50	5.60	0.00	0.00	.10	0.00	.20
MEAN		.3256	3.1057	0.000	0.000	.0157	0.000	.0429
STDEV		.1038	1.9676	0.000	0.000	.0374	0.000	.0787
VALIDN		11	7	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
JULY	76	.20	*	0.00	.01	.01	0.00	.01
	77	.27	*	0.00	0.00	0.00	0.00	.26
	78	.38	*	0.00	0.00	0.00	0.00	0.00
	79	0.00	4.60	0.00	0.00	0.00	0.00	0.00
	80	.50	4.30	.01	0.00	0.00	0.00	.03
	81	.68	.40	*	*	*	*	*
	82	.30	.74	*	*	*	*	*
	83	.82	5.10	0.00	0.00	0.00	0.00	.50
	84	.45	4.80	0.00	0.00	0.00	0.00	.20
	85	.12	7.20	*	*	*	*	*
	86	.33	6.80	*	*	*	*	*
MIN		0.00	.40	0.00	0.00	0.00	0.00	0.00
MAX		.82	7.20	.01	.01	.01	0.00	.50
MEAN		.3685	4.2425	.0014	.0014	.0014	0.000	.1424
STDEV		.2381	2.4928	.0038	.0038	.0038	0.000	.1899
VALIDN		11	8	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
AUGUST	76	.27	*	0.00	.02	0.00	0.00	.03
	77	.76	*	0.00	0.00	0.00	0.00	1.62
	78	.28	*	0.00	0.00	0.00	0.00	0.00
	79	0.00	2.80	0.00	0.00	0.00	0.00	0.00
	80	.45	2.10	.02	0.00	.01	.02	.03
	81	.27	5.50	*	*	*	*	*
	82	.19	.84	*	*	*	*	*
	83	.11	7.80	0.00	0.00	0.00	0.00	0.00
	84	.38	5.20	0.00	0.00	0.00	0.00	0.00
	85	.20	7.00	*	*	*	*	*
	86	.36	6.80	*	*	*	*	*
MIN		0.00	.84	0.00	0.00	0.00	0.00	0.00
MAX		.76	7.80	.02	.02	.01	.02	1.62
MEAN		.2970	4.7550	.0029	.0029	.0014	.0029	.2396
STDEV		.1987	2.5480	.0076	.0076	.0038	.0076	.6089
VALIDN		11	8	7	7	7	7	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
SEPTEMBER	76	*	*	*	*	*	*	*
	77	.35	*	0.00	0.00	0.00	0.00	.24
	78	.25	*	0.00	0.00	0.00	0.00	0.00
	79	.31	2.10	0.00	0.00	0.00	.02	.04
	80	.53	.70	0.00	0.00	0.00	.01	0.00
	81	.35	4.00	*	*	*	*	*
	82	.29	.85	*	*	*	*	*
	83	.60	9.00	0.00	0.00	0.00	0.00	0.00
	84	.39	7.40	0.00	0.00	0.00	0.00	0.00
	85	.26	6.10	*	*	*	*	*
	86	.40	7.90	*	*	*	*	*
MIN		.25	.70	0.00	0.00	0.00	0.00	0.00
MAX		.60	9.00	0.00	0.00	0.00	.02	.24
MEAN		.3728	4.7563	0.000	0.000	0.000	.0050	.0473
STDEV		.1143	3.2956	0.000	0.000	0.000	.0084	.0968
VALIDN		10	8	6	6	6	6	6

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
OCTOBER	76	.24	*	0.00	0.00	0.00	0.00	0.00
	77	.38	*	0.00	0.00	0.00	0.00	.02
	78	.28	*	0.00	0.00	0.00	.05	.01
	79	.30	2.70	0.00	0.00	0.00	0.00	.06
	80	.29	4.20	.01	0.00	0.00	.01	*
	81	.22	3.40	*	*	*	*	*
	82	.15	.82	*	*	*	*	*
	83	.80	13.00	0.00	0.00	0.00	0.00	0.00
	84	.50	6.00	0.00	0.00	0.00	0.00	0.00
	85	.25	6.60	*	*	*	*	*
	86	.32	7.00	*	*	*	*	*
MIN		.15	.82	0.00	0.00	0.00	0.00	0.00
MAX		.80	13.00	.01	0.00	0.00	.05	.06
MEAN		.3388	5.4650	.0014	0.000	0.000	.0086	.0153
STDEV		.1774	3.6993	.0038	0.000	0.000	.0186	.0249
VALIDN		11	8	7	7	7	7	6

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
NOVEMBER	76	.26	*	0.00	0.00	0.00	0.00	0.00
	77	.36	*	0.00	0.00	0.00	0.00	.03
	78	.27	*	0.00	0.00	0.00	0.00	.02
	79	.38	2.60	0.00	0.00	0.00	0.00	.01
	80	.30	2.10	0.00	0.00	0.00	.01	0.00
	81	.32	1.76	*	*	*	*	*
	82	0.00	.87	*	*	*	*	*
	83	.14	12.70	0.00	0.00	0.00	0.00	.10
	84	.10	5.80	0.00	0.00	0.00	0.00	0.00
	85	.24	6.40	*	*	*	*	*
	86	.18	7.60	*	*	*	*	*
MIN		0.00	.87	0.00	0.00	0.00	0.00	0.00
MAX		.38	12.70	0.00	0.00	0.00	.01	.10
MEAN		.2314	4.9788	0.000	0.000	0.000	.0014	.0231
STDEV		.1162	3.9708	0.000	0.000	0.000	.0038	.0360
VALIDN		11	8	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
DECEMBER	76	.22	*	0.00	.30	0.00	0.00	0.00
	77	.40	*	0.00	0.00	0.00	0.00	.01
	78	.25	*	0.00	0.00	0.00	0.00	.07
	79	.34	*	0.00	0.00	0.00	0.00	.05
	80	.32	3.00	0.00	0.00	.01	.01	0.00
	81	.02	6.70	*	*	*	*	*
	82	.26	.78	*	*	*	*	*
	83	.60	8.70	0.00	0.00	0.00	0.00	.09
	84	.29	6.00	0.00	.20	0.00	0.00	0.00
	85	.26	6.40	*	*	*	*	*
	86	.22	7.40	*	*	*	*	*
MIN		.02	.78	0.00	0.00	0.00	0.00	0.00
MAX		.60	8.70	0.00	.30	.01	.01	.09
MEAN		.2882	5.5686	0.000	.0714	.0014	.0014	.0320
STDEV		.1404	2.7339	0.000	.1254	.0038	.0038	.0380
VALIDN		11	7	7	7	7	7	7

This procedure was completed at 9:43:54

REVIEW.

```
[illegible]
DATA LIST FILE = [illegible]
           DO 11-15 PH 16-20 TURB 21-25
           COND 26-30 TDS 31-35 TALK 36-40 HARD 41-45 CA 46-50 MG 51-55
           CL 56-60 FL 61-65 PO4 66-70 SI 71-75 FCOLI 76-80 / CR 7-10 CU 11-15
           NI 16-20 PB 21-25 ZN 26-30 FE 31-35 AG 36-40 NA 41-45 BA 46-50
           NH3 51-55 NO3 56-60 NO2 61-65 MN 66-70 ELEV 71-75 K 76-80 /
           SO4 7-10 CD 11-15 BR 16-20.
VALUE LABELS MONTH 01 'JANUARY'
                   02 'FEBRUARY'
                   03 'MARCH'
                   04 'APRIL'
                   05 'MAY'
                   06 'JUNE'
                   07 'JULY'
                   08 'AUGUST'
                   09 'SEPTEMBER'
                   10 'OCTOBER'
                   11 'NOVEMBER'
                   12 'DECEMBER'.
MISSING VALUE ALL (-1).
SORT CASES BY MONTH YEAR.
The raw data or transformation pass is proceeding
    133 cases are written to the uncompressed active file.

Size of File to Be Sorted:       133 Cases of     312 Bytes Each.
    133 cases are written to the uncompressed active file.
SORT completed successfully.
```

```
This procedure was completed at 20:10:04
FORMATS FE (F8.2) AG (F8.2) BA (F8.2) CD (F8.2) BR (F8.2) ELEV (F8.2).
REPORT FORMAT = LIST (4) MISSING '*' BRKSPACE(-1)
       /VARIABLES = FE 'TOTAL' 'IRON' 'MG/L AS FE' (10)
                    AG 'TOTAL' 'SILVER' 'MG/L AS AG' (10)
                    BA 'TOTAL' 'BARIUM' 'MG/L AS BA' (10)
                    CD 'TOTAL' 'CADMIUM' 'MG/L AS CD' (10)
                    BR ' ' 'BROMIDE' 'MG/L AS BR' (10)
                    ELEV 'LAKE ELEV' 'ON SAMPLING' 'DATE FMSL' (11)
       /BREAK = MONTH (LABEL) (PAGE)
       /SUMMARY = MIN
       /SUMMARY = MAX
       /SUMMARY = MEAN
       /SUMMARY = STDEV
       /SUMMARY=VALIDN
       /BREAK = YEAR.

REPORT REQUIRES     3380 BYTES FOR THIS TASK
```

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
JANUARY	76	.05	*	*	0.00	*	1634.00
	77	0.00	*	*	0.00	*	1633.00
	78	0.00	*	*	0.00	*	1627.00
	79	0.00	0.00	*	0.00	*	1626.00
	80	.01	0.00	*	0.00	*	1622.00
	81	.43	0.00	*	0.00	.74	1625.00
	82	*	*	*	*	.29	1635.00
	83	*	*	*	0.00	.60	1631.00
	84	.18	0.00	*	0.00	0.00	1625.00
	85	.60	0.00	*	0.00	*	1624.00
	86	*	*	*	*	.74	*
	87	*	*	*	*	.40	*
MIN		0.00	0.00	*	0.00	0.00	1622.00
MAX		.60	0.00	*	0.00	.74	1635.00
MEAN		.1588	0.000	*	0.000	.4617	1628.2000
STDEV		.2325	0.000	*	0.000	.2900	4.6380
VALIDN		8	5	0	9	6	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
FEBRUARY	76	.12	*	*	0.00	*	1633.00
	77	.10	*	*	0.00	*	1633.00
	78	.05	*	*	0.00	*	1626.00
	79	0.00	0.00	*	0.00	*	1626.00
	80	.01	0.00	*	0.00	*	1621.00
	81	.47	0.00	*	0.00	.13	1626.00
	82	*	*	*	*	.38	1634.00
	83	*	*	*	.02	.33	1631.00
	84	.13	0.00	*	0.00	*	1625.00
	85	.50	0.00	*	0.00	.08	1624.00
	86	*	*	*	*	.50	*
MIN		0.00	0.00	*	0.00	.08	1621.00
MAX		.50	0.00	*	.02	.50	1634.00
MEAN		.1725	0.000	*	.0022	.2840	1627.9000
STDEV		.1988	0.000	*	.0067	.1756	4.4833
VALIDN		8	5	0	9	5	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
MARCH	76	.16	*	*	0.00	*	1633.00
	77	.50	*	*	0.00	*	1632.00
	78	*	*	*	*	*	*
	79	0.00	0.00	*	0.00	*	1625.00
	80	.14	0.00	*	0.00	*	1620.00
	81	.97	0.00	*	0.00	.66	1626.00
	82	*	*	*	*	.36	1633.00
	83	0.00	*	*	0.00	.75	1631.00
	84	1.20	0.00	*	0.00	*	1625.00
	85	*	*	*	*	.45	1626.00
	86	*	*	*	*	.36	*
MIN		0.00	0.00	*	0.00	.36	1620.00
MAX		1.20	0.00	*	0.00	.75	1633.00
MEAN		.4243	0.000	*	0.000	.5160	1627.8889
STDEV		.4858	0.000	*	0.000	.1792	4.5399
VALIDN		7	4	0	7	5	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
APRIL	76	.14	*	*	0.00	*	1632.00
	77	0.00	*	*	0.00	*	1634.00
	78	.32	*	*	*	*	*
	79	0.00	0.00	*	0.00	*	1629.00
	80	0.00	0.00	*	0.00	1.01	1619.00
	81	.62	0.00	*	0.00	.45	1625.00
	82	*	*	*	*	.37	1632.00
	83	0.00	*	*	0.00	.60	1630.00
	84	.90	0.00	*	0.00	*	1624.00
	85	*	*	*	*	.07	1626.00
	86	*	*	*	*	.56	*
MIN		0.00	0.00	*	0.00	.07	1619.00
MAX		.90	0.00	*	0.00	1.01	1634.00
MEAN		.2475	0.000	*	0.000	.5100	1627.8889
STDEV		.3436	0.000	*	0.000	.3090	4.7813
VALIDN		8	4	0	7	6	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
MAY	76	.40	*	*	0.00	*	1632.00
	77	.40	*	*	0.00	*	1635.00
	78	0.00	*	*	0.00	*	1617.00
	79	0.00	0.00	*	0.00	*	1630.00
	80	.01	0.00	*	0.00	.99	1619.00
	81	.41	0.00	*	0.00	.59	1628.00
	82	*	*	*	*	.36	1635.00
	83	*	*	*	0.00	.78	1629.00
	84	0.00	0.00	*	0.00	*	1623.00
	85	*	*	*	*	.56	1627.00
	86	*	*	*	*	.35	*
MIN		0.00	0.00	*	0.00	.35	1617.00
MAX		.41	0.00	*	0.00	.99	1635.00
MEAN		.1743	0.000	*	0.000	.6050	1627.5000
STDEV		.2143	0.000	*	0.000	.2474	6.1869
VALIDN		7	4	0	8	6	10

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
JUNE	76	0.00	*	*	0.00	*	1631.00
	77	0.00	*	*	0.00	*	1633.00
	78	0.00	*	*	0.00	*	1622.00
	79	0.00	0.00	*	0.00	*	1629.00
	80	*	0.00	*	0.00	.68	1622.00
	81	*	*	*	*	.51	1630.00
	82	*	*	*	*	.61	1636.00
	83	0.00	*	*	0.00	.73	1629.00
	84	.80	0.00	*	0.00	.80	1620.00
	85	*	*	*	*	.76	1630.00
	86	*	*	*	*	0.00	*
MIN		0.00	0.00	*	0.00	0.00	1620.00
MAX		.80	0.00	*	0.00	.80	1636.00
MEAN		.1333	0.000	*	0.000	.5843	1628.2000
STDEV		.3266	0.000	*	0.000	.2755	5.2026
VALIDN		6	3	0	7	7	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
JULY	76	.63	*	*	0.00	*	1630.00
	77	0.00	*	*	0.00	*	1632.00
	78	.51	*	*	0.00	*	1620.00
	79	0.00	0.00	*	0.00	*	1629.00
	80	.50	0.00	*	0.00	1.08	1619.00
	81	*	*	*	*	.82	1632.00
	82	*	*	*	*	.30	1634.00
	83	*	*	*	0.00	1.47	1628.00
	84	.50	0.00	*	0.00	*	1619.00
	85	*	*	*	*	.60	1629.00
	86	*	*	*	*	.48	*
MIN		0.00	0.00	*	0.00	.30	1619.00
MAX		.63	0.00	*	0.00	1.47	1634.00
MEAN		.3567	0.000	*	0.000	.7917	1627.2000
STDEV		.2806	0.000	*	0.000	.4289	5.7116
VALIDN		6	3	0	7	6	10

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
AUGUST	76	.04	*	*	0.00	*	1630.00
	77	0.00	*	*	0.00	*	1631.00
	78	0.00	*	*	0.00	*	1629.00
	79	0.00	0.00	*	0.00	*	1626.00
	80	1.31	0.00	*	0.00	1.13	1617.00
	81	*	*	*	*	.77	1630.00
	82	*	*	*	*	.73	1635.00
	83	0.00	*	*	0.00	.60	1628.00
	84	0.00	0.00	*	0.00	*	1617.00
	85	*	*	*	*	.69	1629.00
	86	*	*	*	*	.38	*
MIN		0.00	0.00	*	0.00	.38	1617.00
MAX		1.31	0.00	*	0.00	1.13	1635.00
MEAN		.1929	0.000	*	0.000	.7167	1627.2000
STDEV		.4928	0.000	*	0.000	.2456	5.8462
VALIDN		7	3	0	7	6	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
SEPTEMBER	76	*	*	*	*	*	*
	77	.13	*	*	0.00	*	1630.00
	78	0.00	*	*	0.00	*	1628.00
	79	0.00	0.00	*	0.00	*	1623.00
	80	0.00	0.00	*	0.00	.91	1615.00
	81	*	*	*	*	.26	1627.00
	82	*	*	*	*	.35	1633.00
	83	.60	0.00	*	0.00	*	1626.00
	84	0.00	0.00	*	0.00	*	1616.00
	85	*	*	*	*	.40	1628.00
	86	*	*	*	*	.38	*
MIN		0.00	0.00	*	0.00	.26	1615.00
MAX		.60	0.00	*	0.00	.91	1633.00
MEAN		.1217	0.000	*	0.000	.4600	1625.1111
STDEV		.2400	0.000	*	0.000	.2572	6.0919
VALIDN		6	4	0	6	5	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
OCTOBER	76	.20	*	*	0.00	*	1631.00
	77	.16	*	*	0.00	*	1629.00
	78	.07	*	*	0.00	*	1628.00
	79	0.00	0.00	*	0.00	*	1623.00
	80	.46	0.00	*	0.00	.60	1625.00
	81	*	*	*	*	.56	1636.00
	82	*	*	*	*	.86	1632.00
	83	.10	0.00	*	0.00	*	1625.00
	84	0.00	0.00	*	0.00	*	1616.00
	85	*	*	*	*	.66	*
	86	*	*	*	*	.25	*
MIN		0.00	0.00	*	0.00	.25	1616.00
MAX		.46	0.00	*	0.00	.86	1636.00
MEAN		.1414	0.000	*	0.000	.5860	1627.2222
STDEV		.1592	0.000	*	0.000	.2204	5.8262
VALIDN		7	4	0	7	5	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
NOVEMBER	76	.80	*	*	0.00	*	1633.00
	77	0.00	*	*	0.00	*	1628.00
	78	.20	*	*	0.00	*	1627.00
	79	.06	0.00	*	0.00	*	1623.00
	80	.17	0.00	*	0.00	.53	1625.00
	81	*	*	*	*	.38	1637.00
	82	*	*	*	*	.77	1632.00
	83	.51	0.00	*	0.00	*	1626.00
	84	.60	0.00	*	0.00	*	1620.00
	85	*	*	*	*	*	*
	86	*	*	*	*	.16	*
MIN		0.00	0.00	*	0.00	.16	1620.00
MAX		.80	0.00	*	0.00	.77	1637.00
MEAN		.3343	0.000	*	0.000	.4550	1627.8889
STDEV		.3029	0.000	*	0.000	.2588	5.3020
VALIDN		7	4	0	7	4	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
DECEMBER	76	.20	*	*	0.00	*	1633.00
	77	.23	*	*	0.00	*	1627.00
	78	0.00	*	*	0.00	*	1627.00
	79	.02	0.00	*	0.00	*	1622.00
	80	.31	0.00	*	0.00	.61	1626.00
	81	*	*	*	*	.32	1634.00
	82	*	*	*	*	1.60	1632.00
	83	.74	0.00	*	0.00	*	1626.00
	84	.70	0.00	*	0.00	*	1620.00
	85	*	*	*	*	.44	*
	86	*	*	*	*	.23	*
MIN		0.00	0.00	*	0.00	.23	1620.00
MAX		.74	0.00	*	0.00	1.60	1634.00
MEAN		.3143	0.000	*	0.000	.6400	1627.4444
STDEV		.2988	0.000	*	0.000	.5552	4.7987
VALIDN		7	4	0	7	5	9

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TITLE FORT PHANTOM HILL RESERVOIR QUALITY.
DATA LIST FILE='B:PHANTWQ.DAT' / YEAR 1-2 MONTH 3-4 DAY 5-6 TEMP 7-10
           DO 11-15 PH 16-20 TURB 21-25
           COND 26-30 TDS 31-35 TALK 36-40 HARD 41-45 CA 46-50 MG 51-55
           CL 56-60 FL 61-65 PO4 66-70 SI 71-75 FCOLI 76-80 / CR 7-10 CU 11-15
           NI 16-20 PB 21-25 ZN 26-30 FE 31-35 AG 36-40 NA 41-45 BA 46-50
           NH3 51-55 NO3 56-60 NO2 61-65 MN 66-70 ELEV 71-75 K 76-80 /
           SO4 7-10 CD 11-15 BR 16-20.
VALUE LABELS MONTH 01 'JANUARY'
                   02 'FEBRUARY'
                   03 'MARCH'
                   04 'APRIL'
                   05 'MAY'
                   06 'JUNE'
                   07 'JULY'
                   08 'AUGUST'
                   09 'SEPTEMBER'
                   10 'OCTOBER'
                   11 'NOVEMBER'
                   12 'DECEMBER'.
MISSING VALUE ALL (-1).
CORRELATION VARIABLES=ALL
The raw data or transformation pass is proceeding
    133 cases are written to the uncompressed active file.
            /OPTIONS=2 5
            /STATISTICS=1.
```

Variable	Cases	Mean	Std Dev
YEAR	133	81.0451	3.2048
MONTH	133	6.4586	3.4848
DAY	123	11.8780	9.4683
TEMP	98	19.1031	7.9981
DO	89	8.9247	2.0914
PH	131	8.3622	.2251
TURB	89	37.4652	35.6806
COND	101	674.2376	141.9099
TDS	81	466.4938	104.8803
TALK	131	142.9473	20.7422
HARD	131	231.9031	29.3995
CA	124	60.5944	19.3952
MG	123	22.4106	10.2599
CL	131	94.4786	22.8382
FL	129	.2946	.1452
PO4	105	.0522	.1338
SI	90	4.3248	2.8016
FCOLI	81	38.3951	57.1736
CR	87	.0215	.1822
CU	88	.0108	.0447
NI	88	.0019	.0109
PB	88	.0034	.0084
ZN	87	.0524	.1871
FE	84	.2306	.3076
AG	47	0.0	0.0
NA	100	64.5070	21.7961
BA	0	.	.
NH3	73	.2977	.5412
NO3	112	.1813	.3182
NO2	97	.0138	.0263
MN	60	.0120	.0428
ELEV	114	1627.4825	5.1167
K	74	8.6238	3.7855
SO4	129	94.4721	39.5731
CD	88	.0002	.0021
BR	67	.4604	.8570

Correlations:	YEAR	MONTH	DAY	TEMP	DO	PH	TURB	COND	TDS	TALK	HARD
YEAR	1.0000	-.0222	-.1056	-.0255	.2345	.2149	-.4234	.2892	.2889	-.3252	.1112
	(133)	(133)	(123)	(98)	(89)	(131)	(89)	(101)	(81)	(131)	(131)
	P= .	P= .400	P= .123	P= .402	P= .013	P= .007	P= .000	P= .002	P= .004	P= .000	P= .103
MONTH	-.0222	1.0000	.0167	.3699	-.3393	.1218	.0750	.0887	-.1049	-.1566	-.0182
	(133)	(133)	(123)	(98)	(89)	(131)	(89)	(101)	(81)	(131)	(131)
	P= .400	P= .	P= .427	P= .000	P= .001	P= .083	P= .243	P= .189	P= .176	P= .037	P= .418
DAY	-.1056	.0167	1.0000	.1586	-.1844	-.0913	-.2478	.0542	-.0762	.0587	.0420
	(123)	(123)	(123)	(94)	(85)	(123)	(85)	(96)	(76)	(123)	(123)
	P= .123	P= .427	P= .	P= .063	P= .046	P= .158	P= .011	P= .300	P= .257	P= .260	P= .322
TEMP	-.0255	.3699	.1586	1.0000	-.5926	.1011	.2068	.2626	.2583	.1002	.3178
	(98)	(98)	(94)	(98)	(89)	(98)	(89)	(98)	(78)	(98)	(98)
	P= .402	P= .000	P= .063	P= .	P= .000	P= .161	P= .026	P= .004	P= .011	P= .163	P= .001
DO	.2345	-.3393	-.1844	-.5926	1.0000	.2129	-.3156	-.0008	-.0220	-.1940	-.0736
	(89)	(89)	(85)	(89)	(89)	(89)	(87)	(89)	(71)	(89)	(89)
	P= .013	P= .001	P= .046	P= .000	P= .	P= .023	P= .001	P= .497	P= .428	P= .034	P= .247
PH	.2149	.1218	-.0913	.1011	.2129	1.0000	-.0753	.1321	.1108	.0497	.1186
	(131)	(131)	(123)	(98)	(89)	(131)	(89)	(101)	(81)	(131)	(131)
	P= .007	P= .083	P= .158	P= .161	P= .023	P= .	P= .241	P= .094	P= .162	P= .286	P= .089
TURB	-.4234	.0750	-.2478	.2068	-.3156	-.0753	1.0000	-.0536	.0202	.2176	-.0287
	(89)	(89)	(85)	(89)	(87)	(89)	(89)	(89)	(72)	(89)	(89)
	P= .000	P= .243	P= .011	P= .026	P= .001	P= .241	P= .	P= .309	P= .433	P= .020	P= .395
COND	.2892	.0887	.0542	.2626	-.0008	.1321	-.0536	1.0000	.7347	.1184	.6292
	(101)	(101)	(96)	(98)	(89)	(101)	(89)	(101)	(81)	(101)	(101)
	P= .002	P= .189	P= .300	P= .004	P= .497	P= .094	P= .309	P= .	P= .000	P= .119	P= .000
TDS	.2889	-.1049	-.0762	.2583	-.0220	.1108	.0202	.7347	1.0000	.0043	.7529
	(81)	(81)	(76)	(78)	(71)	(81)	(72)	(81)	(81)	(81)	(81)
	P= .004	P= .176	P= .257	P= .011	P= .428	P= .162	P= .433	P= .000	P= .	P= .485	P= .000
TALK	-.3252	-.1566	.0587	.1002	-.1940	.0497	.2176	.1184	.0043	1.0000	.2476
	(131)	(131)	(123)	(98)	(89)	(131)	(89)	(101)	(81)	(131)	(131)
	P= .000	P= .037	P= .260	P= .163	P= .034	P= .286	P= .020	P= .119	P= .485	P= .	P= .002
HARD	.1112	-.0182	.0420	.3178	-.0736	.1186	-.0287	.6292	.7529	.2476	1.0000
	(131)	(131)	(123)	(98)	(89)	(131)	(89)	(101)	(81)	(131)	(131)
	P= .103	P= .418	P= .322	P= .001	P= .247	P= .089	P= .395	P= .000	P= .000	P= .002	P= .
CA	.4665	-.0061	.0110	.1387	.0642	.2913	.0553	.2085	.1079	.0443	.2974
	(124)	(124)	(116)	(91)	(82)	(124)	(82)	(94)	(74)	(124)	(124)
	P= .000	P= .473	P= .453	P= .095	P= .283	P= .001	P= .311	P= .022	P= .180	P= .312	P= .000
MG	-.1559	.0248	.0130	.0489	.2321	.1134	.0783	.2543	.0474	.0519	.2669
	(123)	(123)	(115)	(90)	(81)	(123)	(81)	(93)	(73)	(123)	(123)
	P= .043	P= .393	P= .445	P= .324	P= .019	P= .106	P= .243	P= .007	P= .345	P= .284	P= .001

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

5/5/87

Correlations:

	YEAR	MONTH	DAY	TEMP	DO	PH	TURB	COND	TDS	TALK	HARD
CL	-.4720 (131) P= .000	.0079 (131) P= .464	.1141 (123) P= .104	.2817 (98) P= .002	-.1223 (89) P= .127	-.0457 (131) P= .302	.1109 (89) P= .150	.6972 (101) P= .000	.6748 (81) P= .000	.3331 (131) P= .000	.5503 (131) P= .000
FL	.0635 (129) P= .237	.1023 (129) P= .124	.0154 (122) P= .433	.2313 (98) P= .011	-.1713 (89) P= .054	.0479 (129) P= .295	.0247 (89) P= .409	.0607 (100) P= .274	.1233 (80) P= .138	.1350 (129) P= .064	.2469 (129) P= .002
PO4	.1401 (105) P= .077	-.0102 (105) P= .459	-.1974 (97) P= .026	-.1213 (73) P= .153	.1135 (65) P= .184	.0969 (105) P= .163	.1905 (64) P= .066	-.0897 (76) P= .220	-.1963 (57) P= .072	-.0315 (105) P= .375	-.1049 (105) P= .143
SI	.4077 (90) P= .000	.1675 (90) P= .057	-.1817 (86) P= .047	-.1092 (90) P= .153	.0654 (88) P= .272	-.0202 (90) P= .425	-.0759 (88) P= .241	.0112 (90) P= .458	.0244 (73) P= .419	-.2633 (90) P= .006	-.0283 (90) P= .396
FCOLI	-.3523 (81) P= .001	.0083 (81) P= .471	-.0534 (79) P= .320	.1004 (80) P= .188	-.1077 (74) P= .180	-.1685 (81) P= .066	-.1127 (73) P= .171	-.0717 (81) P= .262	-.0695 (62) P= .296	.0203 (81) P= .429	.0471 (81) P= .338
CR	.1122 (87) P= .150	-.1036 (87) P= .170	-.1521 (83) P= .085	-.0391 (55) P= .389	.2294 (46) P= .063	-.0707 (87) P= .258	-.1178 (46) P= .218	-.0520 (57) P= .350	-.1240 (40) P= .223	.1890 (87) P= .040	-.0560 (87) P= .303
CU	-.0283 (88) P= .397	.1056 (88) P= .164	-.1171 (84) P= .144	-.1397 (56) P= .152	.3402 (47) P= .010	-.0260 (88) P= .405	-.1716 (47) P= .124	-.0298 (58) P= .412	-.0584 (40) P= .360	-.0099 (88) P= .463	-.0460 (88) P= .335
NI	.1104 (88) P= .153	-.0085 (88) P= .469	.0265 (84) P= .405	.1009 (56) P= .230	-.0765 (47) P= .305	.0546 (88) P= .307	.3440 (47) P= .009	-.0741 (58) P= .290	-.0777 (40) P= .317	.0711 (88) P= .255	.0582 (88) P= .295
PB	.0700 (88) P= .259	-.0802 (88) P= .229	-.0726 (84) P= .256	-.1545 (56) P= .128	-.0886 (47) P= .277	.0702 (88) P= .258	.0775 (47) P= .302	-.1689 (58) P= .102	.0822 (40) P= .307	.1954 (88) P= .034	-.1022 (88) P= .172
ZN	-.0713 (87) P= .256	.0799 (87) P= .231	.1935 (83) P= .040	.1414 (55) P= .152	-.0076 (46) P= .480	-.0527 (87) P= .314	-.0835 (46) P= .291	-.0396 (57) P= .385	-.1015 (40) P= .267	.0396 (87) P= .358	.0155 (87) P= .443
FE	.3165 (84) P= .002	.0408 (84) P= .356	-.1466 (79) P= .099	-.1056 (51) P= .230	.1090 (43) P= .243	-.0028 (84) P= .490	.0433 (42) P= .393	-.0417 (54) P= .382	.0119 (37) P= .472	-.1596 (84) P= .074	.2053 (84) P= .030
AG	. (47) P= .	. (47) P= .	. (46) P= .	. (46) P= .	. (40) P= .	. (47) P= .	. (39) P= .	. (47) P= .	. (30) P= .	. (47) P= .	. (47) P= .
NA	-.0609 (100) P= .274	-.0539 (100) P= .297	-.1380 (95) P= .091	-.0683 (67) P= .291	.1946 (58) P= .072	-.1106 (100) P= .137	.2087 (58) P= .058	.2828 (70) P= .009	.3170 (52) P= .011	.2112 (100) P= .017	.3185 (100) P= .001

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

Correlations:	YEAR	MONTH	DAY	TEMP	DO	PH	TURB	COND	TDS	TALK	HARD
BA	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .
NH3	.3755 (73) P= .001	-.0777 (73) P= .257	-.0072 (70) P= .476	.1906 (44) P= .108	.0306 (37) P= .429	.1313 (73) P= .134	-.2474 (35) P= .076	.5025 (46) P= .000	.4059 (31) P= .012	-.2713 (73) P= .010	.4056 (73) P= .000
NO3	-.2818 (112) P= .001	.0238 (112) P= .402	.0688 (104) P= .244	-.0363 (82) P= .373	-.0405 (73) P= .367	-.1216 (112) P= .101	-.0654 (73) P= .291	-.4431 (85) P= .000	-.3166 (66) P= .005	.0050 (112) P= .479	-.0979 (112) P= .152
NO2	.0552 (97) P= .296	.0139 (97) P= .446	.1569 (90) P= .070	-.0562 (66) P= .327	.2201 (57) P= .050	-.0697 (97) P= .249	-.1977 (57) P= .070	.0577 (68) P= .320	-.0477 (49) P= .372	-.1655 (97) P= .053	.0343 (97) P= .369
MN	.1478 (60) P= .130	.2037 (60) P= .059	-.2171 (57) P= .052	-.0646 (30) P= .367	-.0476 (23) P= .415	.1979 (60) P= .065	.2837 (21) P= .106	-.0749 (32) P= .342	-.1777 (14) P= .272	.0162 (60) P= .451	-.0738 (60) P= .287
ELEV	-.2527 (114) P= .003	-.0686 (114) P= .234	.2010 (107) P= .019	-.1051 (82) P= .174	-.0206 (73) P= .431	-.2318 (114) P= .007	-.0797 (73) P= .251	-.5571 (84) P= .000	-.5258 (64) P= .000	-.2229 (114) P= .009	-.3942 (114) P= .000
K	-.3041 (74) P= .004	-.0359 (74) P= .381	.2361 (70) P= .025	-.2012 (42) P= .101	-.0132 (35) P= .470	.0084 (74) P= .472	.0421 (33) P= .408	.2433 (44) P= .056	.4102 (26) P= .019	.1319 (74) P= .131	.2544 (74) P= .014
SO4	.5359 (129) P= .000	-.0236 (129) P= .395	-.2092 (121) P= .011	.1981 (97) P= .026	.0010 (88) P= .496	.2026 (129) P= .011	-.0168 (88) P= .438	.4764 (100) P= .000	.5847 (81) P= .000	-.0803 (129) P= .183	.4919 (129) P= .000
CD	.1206 (88) P= .132	-.1287 (88) P= .116	-.1023 (84) P= .177	-.1755 (56) P= .098	. (47) P= .	-.0205 (88) P= .425	-.1373 (47) P= .179	-.2186 (58) P= .050	-.0368 (40) P= .411	.2363 (88) P= .013	.0000 (88) P= .500
BR	.1729 (67) P= .081	.0059 (67) P= .481	-.0903 (63) P= .241	.3023 (66) P= .007	-.2006 (64) P= .056	.0859 (67) P= .245	.1642 (65) P= .096	.2795 (66) P= .012	-.1356 (50) P= .174	.1554 (67) P= .105	.1420 (67) P= .126

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

5/5/87

Correlations:	CA	MG	CL	FL	PO4	SI	FCOLI	CR	CU	NI	PB
YEAR	.4665	-.1559	-.4720	.0635	.1401	.4077	-.3523	.1122	-.0283	.1104	.0700
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .000	P= .043	P= .000	P= .237	P= .077	P= .000	P= .001	P= .150	P= .397	P= .153	P= .259
MONTH	-.0061	.0248	.0079	.1023	-.0102	.1675	.0083	-.1036	.1056	-.0085	-.0802
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .473	P= .393	P= .464	P= .124	P= .459	P= .057	P= .471	P= .170	P= .164	P= .469	P= .229
DAY	.0110	.0130	.1141	.0154	-.1974	-.1817	-.0534	-.1521	-.1171	.0265	-.0726
	(116)	(115)	(123)	(122)	(97)	(86)	(79)	(83)	(84)	(84)	(84)
	P= .453	P= .445	P= .104	P= .433	P= .026	P= .047	P= .320	P= .085	P= .144	P= .405	P= .256
TEMP	.1387	.0489	.2817	.2313	-.1213	-.1092	.1004	-.0391	-.1397	.1009	-.1545
	(91)	(90)	(98)	(98)	(73)	(90)	(80)	(55)	(56)	(56)	(56)
	P= .095	P= .324	P= .002	P= .011	P= .153	P= .153	P= .188	P= .389	P= .152	P= .230	P= .128
DO	.0642	.2321	-.1223	-.1713	.1135	.0654	-.1077	.2294	.3402	-.0765	-.0886
	(82)	(81)	(89)	(89)	(65)	(88)	(74)	(46)	(47)	(47)	(47)
	P= .283	P= .019	P= .127	P= .054	P= .184	P= .272	P= .180	P= .063	P= .010	P= .305	P= .277
PH	.2913	.1134	-.0457	.0479	.0969	-.0202	-.1685	-.0707	-.0260	.0546	.0702
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .001	P= .106	P= .302	P= .295	P= .163	P= .425	P= .066	P= .258	P= .405	P= .307	P= .258
TURB	.0553	.0783	.1109	.0247	.1905	-.0759	-.1127	-.1178	-.1716	.3440	.0775
	(82)	(81)	(89)	(89)	(64)	(88)	(73)	(46)	(47)	(47)	(47)
	P= .311	P= .243	P= .150	P= .409	P= .066	P= .241	P= .171	P= .218	P= .124	P= .009	P= .302
COND	.2085	.2543	.6972	.0607	-.0897	.0112	-.0717	-.0520	-.0298	-.0741	-.1689
	(94)	(93)	(101)	(100)	(76)	(90)	(81)	(57)	(58)	(58)	(58)
	P= .022	P= .007	P= .000	P= .274	P= .220	P= .458	P= .262	P= .350	P= .412	P= .290	P= .102
TDS	.1079	.0474	.6748	.1233	-.1963	.0244	-.0695	-.1240	-.0584	-.0777	.0822
	(74)	(73)	(81)	(80)	(57)	(73)	(62)	(40)	(40)	(40)	(40)
	P= .180	P= .345	P= .000	P= .138	P= .072	P= .419	P= .296	P= .223	P= .360	P= .317	P= .307
TALK	.0443	.0519	.3331	.1350	-.0315	-.2633	.0203	.1890	-.0099	.0711	.1954
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .312	P= .284	P= .000	P= .064	P= .375	P= .006	P= .429	P= .040	P= .463	P= .255	P= .034
HARD	.2974	.2669	.5503	.2469	-.1049	-.0283	.0471	-.0560	-.0460	.0582	-.1022
	(124)	(123)	(131)	(129)	(105)	(90)	(81)	(87)	(88)	(88)	(88)
	P= .000	P= .001	P= .000	P= .002	P= .143	P= .396	P= .338	P= .303	P= .335	P= .295	P= .172
CA	1.0000	.4192	-.1315	.1445	.3320	-.1669	-.0272	-.0356	-.1273	.7390	-.0043
	(124)	(123)	(124)	(122)	(98)	(83)	(77)	(85)	(86)	(86)	(86)
	P= .	P= .000	P= .073	P= .056	P= .000	P= .066	P= .407	P= .373	P= .121	P= .000	P= .484
MG	.4192	1.0000	.3069	.0730	.2086	-.2093	-.1248	-.0114	.0296	.5356	-.1942
	(123)	(123)	(123)	(121)	(97)	(82)	(77)	(85)	(86)	(86)	(86)
	P= .000	P= .	P= .000	P= .213	P= .020	P= .030	P= .140	P= .459	P= .394	P= .000	P= .037

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

Correlations:	CA	MG	CL	FL	PO4	SI	FCOLI	CR	CU	NI	PB
CL	-.1315 (124) P= .073	.3069 (123) P= .000	1.0000 (131) P= .	.0696 (129) P= .216	-.2034 (105) P= .019	-.1163 (90) P= .138	.0548 (81) P= .313	-.1263 (87) P= .122	-.0385 (88) P= .361	-.1665 (88) P= .061	-.0986 (88) P= .180
FL	.1445 (122) P= .056	.0730 (121) P= .213	.0696 (129) P= .216	1.0000 (129) P= .	-.0338 (103) P= .367	.0441 (90) P= .340	-.0226 (81) P= .421	-.2117 (86) P= .025	-.1790 (87) P= .049	.1525 (87) P= .079	.0794 (87) P= .232
PO4	.3320 (98) P= .000	.2086 (97) P= .020	-.2034 (105) P= .019	-.0338 (103) P= .367	1.0000 (105) P= .	.2447 (66) P= .024	-.2656 (59) P= .021	.1136 (78) P= .161	.0804 (79) P= .241	.5933 (79) P= .000	-.1771 (79) P= .059
SI	-.1669 (83) P= .066	-.2093 (82) P= .030	-.1163 (90) P= .138	.0441 (90) P= .340	.2447 (66) P= .024	1.0000 (90) P= .	-.2019 (74) P= .042	.0076 (47) P= .480	.0451 (48) P= .380	-.1813 (48) P= .109	-.4325 (48) P= .001
FCOLI	-.0272 (77) P= .407	-.1248 (77) P= .140	.0548 (81) P= .313	-.0226 (81) P= .421	-.2656 (59) P= .021	-.2019 (74) P= .042	1.0000 (81) P= .	-.0601 (51) P= .338	-.1184 (52) P= .202	-.0526 (52) P= .356	-.0321 (52) P= .411
CR	-.0356 (35) P= .373	-.0114 (85) P= .459	-.1263 (87) P= .122	-.2117 (86) P= .025	.1136 (78) P= .161	.0076 (47) P= .480	-.0601 (51) P= .338	1.0000 (87) P= .	.4574 (87) P= .000	-.0189 (87) P= .431	-.0418 (87) P= .350
CU	-.1273 (86) P= .121	.0296 (86) P= .394	-.0385 (88) P= .361	-.1790 (87) P= .049	.0804 (79) P= .241	.0451 (48) P= .380	-.1184 (52) P= .202	.4574 (87) P= .000	1.0000 (88) P= .	-.0385 (88) P= .361	-.0439 (88) P= .342
NI	.7390 (86) P= .000	.5356 (86) P= .000	-.1665 (88) P= .061	.1525 (87) P= .079	.5933 (79) P= .000	-.1813 (48) P= .109	-.0526 (52) P= .356	-.0189 (87) P= .431	-.0385 (88) P= .361	1.0000 (88) P= .	.0026 (88) P= .491
PB	-.0043 (86) P= .484	-.1942 (86) P= .037	-.0986 (88) P= .180	.0794 (87) P= .232	-.1771 (79) P= .059	-.4325 (48) P= .001	-.0321 (52) P= .411	-.0418 (87) P= .350	-.0439 (88) P= .342	.0026 (88) P= .491	1.0000 (88) P= .
ZN	-.1393 (85) P= .102	.0831 (85) P= .225	.0469 (87) P= .333	.4001 (86) P= .000	-.0104 (78) P= .464	.1319 (47) P= .188	-.1497 (51) P= .147	-.0331 (86) P= .381	-.0660 (87) P= .272	-.0441 (87) P= .343	-.0634 (87) P= .280
FE	.0621 (82) P= .290	-.0467 (82) P= .339	-.1378 (84) P= .106	.1741 (82) P= .059	.1192 (77) P= .151	.2758 (43) P= .037	-.1132 (49) P= .219	-.0747 (82) P= .252	.0240 (83) P= .415	-.0015 (83) P= .495	.0639 (83) P= .283
AG	. (45) P= .	. (45) P= .	. (47) P= .	. (47) P= .	. (43) P= .	. (40) P= .	. (47) P= .	. (46) P= .	. (47) P= .	. (47) P= .	. (47) P= .
NA	.1391 (98) P= .086	.3503 (98) P= .000	.3499 (100) P= .000	.0902 (98) P= .189	.1807 (80) P= .054	-.0338 (59) P= .400	-.1643 (61) P= .103	.1737 (87) P= .054	.0405 (88) P= .354	.4048 (88) P= .000	-.2057 (88) P= .027

(Coefficient / (Cases) / 1-tailed Significance)

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Correlations:

	CA	MG	CL	FL	PO4	SI	FCOLI	CR	CU	NI	PB
BA	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .
NH3	.2654 (68) P= .014	-.0446 (67) P= .360	.1171 (73) P= .162	-.0979 (72) P= .207	-.0033 (73) P= .489	.2098 (37) P= .106	-.2763 (35) P= .054	.0121 (55) P= .465	.0330 (56) P= .405	-.0435 (56) P= .375	-.1462 (56) P= .141
NO3	-.2292 (107) P= .009	-.1150 (106) P= .120	.0356 (112) P= .355	.0771 (110) P= .212	-.0383 (91) P= .359	-.1192 (75) P= .154	.0129 (65) P= .460	-.0661 (68) P= .296	-.0033 (69) P= .489	-.0916 (69) P= .227	-.0373 (69) P= .380
NO2	.0221 (97) P= .415	.1563 (97) P= .063	-.0326 (97) P= .376	.2024 (96) P= .024	.0584 (76) P= .308	.0468 (59) P= .362	-.0755 (57) P= .288	-.0169 (70) P= .445	.1522 (71) P= .103	.0299 (71) P= .402	-.1965 (71) P= .050
MN	.0875 (60) P= .253	-.1391 (60) P= .145	-.0835 (60) P= .263	.0816 (59) P= .269	-.1109 (58) P= .204	.3131 (22) P= .078	-.0348 (29) P= .429	.0341 (59) P= .399	-.0583 (60) P= .329	.2331 (60) P= .037	.0430 (60) P= .372
ELEV	-.1262 (112) P= .092	-.0713 (112) P= .228	-.3902 (114) P= .000	-.2429 (113) P= .005	.0401 (88) P= .355	-.0359 (74) P= .381	-.0510 (73) P= .334	.1085 (87) P= .159	.1668 (88) P= .060	.0706 (88) P= .257	-.1338 (88) P= .107
K	-.1268 (72) P= .144	.1916 (72) P= .053	.3607 (74) P= .001	-.0299 (73) P= .401	-.3333 (72) P= .002	-.0605 (34) P= .367	.1577 (39) P= .169	.0435 (73) P= .357	-.0412 (74) P= .364	-.1352 (74) P= .125	.0657 (74) P= .289
SO4	.3070 (122) P= .000	.0236 (121) P= .399	.1734 (129) P= .025	.0675 (127) P= .225	.2058 (105) P= .018	.3275 (90) P= .001	-.2309 (80) P= .020	.2747 (85) P= .005	.0550 (86) P= .307	.0802 (86) P= .232	-.1825 (86) P= .046
CD	.0519 (86) P= .318	-.0858 (86) P= .216	-.2033 (88) P= .029	.2143 (87) P= .023	. (79) P= .	.0919 (48) P= .267	. (52) P= .	-.0128 (87) P= .453	-.0019 (88) P= .493	.0797 (88) P= .230	.2123 (88) P= .024
BR	.2389 (62) P= .031	-.0189 (61) P= .443	-.0082 (67) P= .474	-.2374 (67) P= .027	.0433 (46) P= .388	-.3406 (66) P= .003	-.0277 (50) P= .424	.0548 (25) P= .397	.0546 (26) P= .396	.0659 (26) P= .375	.1552 (26) P= .225

(Coefficient (Cases) 1-tailed Significance)

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Correlations:

	ZN	FE	AG	NA	BA	NH3	NO3	NO2	MN	ELEV	K
YEAR	-.0713	.3165	.	-.0609	.	.3755	-.2818	.0552	.1478	-.2527	-.3041
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .256	P= .002	P= .	P= .274	P= .	P= .001	P= .001	P= .296	P= .130	P= .003	P= .004
MONTH	.0799	.0408	.	-.0539	.	-.0777	.0238	.0139	.2037	-.0686	-.0359
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .231	P= .356	P= .	P= .297	P= .	P= .257	P= .402	P= .446	P= .059	P= .234	P= .381
DAY	.1935	-.1466	.	-.1380	.	-.0072	.0688	.1569	-.2171	.2010	.2361
	(83)	(79)	(46)	(95)	(0)	(70)	(104)	(90)	(57)	(107)	(70)
	P= .040	P= .099	P= .	P= .091	P= .	P= .476	P= .244	P= .070	P= .052	P= .019	P= .025
TEMP	.1414	-.1056	.	-.0683	.	.1906	-.0363	-.0562	-.0646	-.1051	-.2012
	(55)	(51)	(46)	(67)	(0)	(44)	(82)	(66)	(30)	(82)	(42)
	P= .152	P= .230	P= .	P= .291	P= .	P= .108	P= .373	P= .327	P= .367	P= .174	P= .101
DO	-.0076	.1090	.	.1946	.	.0306	-.0405	.2201	-.0476	-.0206	-.0132
	(46)	(43)	(40)	(58)	(0)	(37)	(73)	(57)	(23)	(73)	(35)
	P= .480	P= .243	P= .	P= .072	P= .	P= .429	P= .367	P= .050	P= .415	P= .431	P= .470
PH	-.0527	-.0028	.	-.1106	.	.1313	-.1216	-.0697	.1979	-.2318	.0084
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .314	P= .490	P= .	P= .137	P= .	P= .134	P= .101	P= .249	P= .065	P= .007	P= .472
TURB	-.0835	.0433	.	.2087	.	-.2474	-.0654	-.1977	.2837	-.0797	.0421
	(46)	(42)	(39)	(58)	(0)	(35)	(73)	(57)	(21)	(73)	(33)
	P= .291	P= .393	P= .	P= .058	P= .	P= .076	P= .291	P= .070	P= .106	P= .251	P= .408
COND	-.0396	-.0417	.	.2828	.	.5025	-.4431	.0577	-.0749	-.5571	.2433
	(57)	(54)	(47)	(70)	(0)	(46)	(85)	(68)	(32)	(84)	(44)
	P= .385	P= .382	P= .	P= .009	P= .	P= .000	P= .000	P= .320	P= .342	P= .000	P= .056
TDS	-.1015	.0119	.	.3170	.	.4059	-.3166	-.0477	-.1777	-.5258	.4102
	(40)	(37)	(30)	(52)	(0)	(31)	(66)	(49)	(14)	(64)	(26)
	P= .267	P= .472	P= .	P= .011	P= .	P= .012	P= .005	P= .372	P= .272	P= .000	P= .019
TALK	.0396	-.1596	.	.2112	.	-.2713	.0050	-.1655	.0162	-.2229	.1319
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .358	P= .074	P= .	P= .017	P= .	P= .010	P= .479	P= .053	P= .451	P= .009	P= .131
HARD	.0155	.2053	.	.3185	.	.4056	-.0979	.0343	-.0738	-.3942	.2544
	(87)	(84)	(47)	(100)	(0)	(73)	(112)	(97)	(60)	(114)	(74)
	P= .443	P= .030	P= .	P= .001	P= .	P= .000	P= .152	P= .369	P= .287	P= .000	P= .014
CA	-.1393	.0621	.	.1391	.	.2654	-.2292	.0221	.0875	-.1262	-.1268
	(85)	(82)	(45)	(98)	(0)	(68)	(107)	(97)	(60)	(112)	(72)
	P= .102	P= .290	P= .	P= .086	P= .	P= .014	P= .009	P= .415	P= .253	P= .092	P= .144
MG	.0831	-.0467	.	.3503	.	-.0446	-.1150	.1563	-.1391	-.0713	.1916
	(85)	(82)	(45)	(98)	(0)	(67)	(106)	(97)	(60)	(112)	(72)
	P= .225	P= .339	P= .	P= .000	P= .	P= .360	P= .120	P= .063	P= .145	P= .228	P= .053

(Coefficient / (Cases) / 1-tailed Significance)

5/5/87

Correlations:	ZN	FE	AG	NA	BA	NH3	NO3	NO2	MN	ELEV	K
CL	.0469 (87) P= .333	-.1378 (84) P= .106	. (47) P= .	.3499 (100) P= .000	. (0) P= .	.1171 (73) P= .162	.0356 (112) P= .355	-.0326 (97) P= .376	-.0835 (60) P= .263	-.3902 (114) P= .000	.3607 (74) P= .001
FL	.4001 (86) P= .000	.1741 (82) P= .059	. (47) P= .	.0902 (98) P= .189	. (0) P= .	-.0979 (72) P= .207	.0771 (110) P= .212	.2024 (96) P= .024	.0816 (59) P= .269	-.2429 (113) P= .005	-.0299 (73) P= .401
PO4	-.0104 (78) P= .464	.1192 (77) P= .151	. (43) P= .	.1807 (80) P= .054	. (0) P= .	-.0033 (73) P= .489	-.0383 (91) P= .359	.0584 (76) P= .308	-.1109 (58) P= .204	.0401 (88) P= .355	-.3333 (72) P= .002
SI	.1319 (47) P= .188	.2758 (43) P= .037	. (40) P= .	-.0338 (59) P= .400	. (0) P= .	.2098 (37) P= .106	-.1192 (75) P= .154	.0468 (59) P= .362	.3131 (22) P= .078	-.0359 (74) P= .381	-.0605 (34) P= .367
FCOLI	-.1497 (51) P= .147	-.1132 (49) P= .219	. (47) P= .	-.1643 (61) P= .103	. (0) P= .	-.2763 (35) P= .054	.0129 (65) P= .460	-.0755 (57) P= .288	-.0348 (29) P= .429	-.0510 (73) P= .334	.1577 (39) P= .169
CR	-.0331 (86) P= .381	-.0747 (82) P= .252	. (46) P= .	.1737 (87) P= .054	. (0) P= .	.0121 (55) P= .465	-.0661 (68) P= .296	-.0169 (70) P= .445	.0341 (59) P= .399	.1085 (87) P= .159	.0435 (73) P= .357
CU	-.0660 (87) P= .272	.0240 (83) P= .415	. (47) P= .	.0405 (88) P= .354	. (0) P= .	.0330 (56) P= .405	-.0033 (69) P= .489	.1522 (71) P= .103	-.0583 (60) P= .329	.1668 (88) P= .060	-.0412 (74) P= .364
NI	-.0441 (87) P= .343	-.0015 (83) P= .495	. (47) P= .	.4048 (88) P= .000	. (0) P= .	-.0435 (56) P= .375	-.0916 (69) P= .227	.0299 (71) P= .402	.2331 (60) P= .037	.0706 (88) P= .257	-.1352 (74) P= .125
PB	-.0634 (87) P= .280	.0639 (83) P= .283	. (47) P= .	-.2057 (88) P= .027	. (0) P= .	-.1462 (56) P= .141	-.0373 (69) P= .380	-.1965 (71) P= .050	.0430 (60) P= .372	-.1338 (88) P= .107	.0657 (74) P= .289
ZN	1.0000 (87) P= .	-.0516 (82) P= .323	. (46) P= .	.0145 (87) P= .447	. (0) P= .	.0873 (55) P= .263	.1882 (68) P= .062	.6633 (70) P= .000	-.0149 (59) P= .455	.1102 (87) P= .155	-.0727 (73) P= .271
FE	-.0516 (82) P= .323	1.0000 (84) P= .	. (46) P= .	.0419 (84) P= .353	. (0) P= .	.0619 (55) P= .327	-.0512 (65) P= .343	.1439 (66) P= .125	.2661 (59) P= .021	-.1534 (83) P= .083	.0916 (71) P= .224
AG	. (46) P= .	. (46) P= .	1.0000 (47) P= .	. (47) P= .	. (0) P= .	. (26) P= .	. (31) P= .	. (31) P= .	. (29) P= .	. (47) P= .	. (37) P= .
NA	.0145 (87) P= .447	.0419 (84) P= .353	. (47) P= .	1.0000 (100) P= .	. (0) P= .	.1900 (56) P= .080	-.1223 (81) P= .138	.0896 (82) P= .212	-.0200 (60) P= .440	-.2996 (99) P= .001	.0347 (74) P= .385

(Coefficient / (Cases) / 1-tailed Significance)

Correlations:	ZN	FE	AG	NA	BA	NH3	NO3	NO2	MN	ELEV	K
BA	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	1.0000 (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .	. (0) P= .
NH3	.0873 (55) P= .263	.0619 (55) P= .327	. (26) P= .	.1900 (56) P= .080	. (0) P= .	1.0000 (73) P= .	-.0399 (72) P= .370	.0106 (57) P= .469	-.0660 (54) P= .318	.2123 (58) P= .055	-.0876 (56) P= .260
NO3	.1882 (68) P= .062	-.0512 (65) P= .343	. (31) P= .	-.1223 (81) P= .138	. (0) P= .	-.0399 (72) P= .370	1.0000 (112) P= .	.0189 (95) P= .428	-.0970 (56) P= .239	.3618 (95) P= .000	-.0538 (63) P= .338
NO2	.6633 (70) P= .000	.1439 (66) P= .125	. (31) P= .	.0896 (82) P= .212	. (0) P= .	.0106 (57) P= .469	.0189 (95) P= .428	1.0000 (97) P= .	-.1143 (58) P= .197	.1052 (96) P= .154	.0431 (65) P= .367
MN	-.0149 (59) P= .455	.2661 (59) P= .021	. (29) P= .	-.0200 (60) P= .440	. (0) P= .	-.0660 (54) P= .318	-.0970 (56) P= .239	-.1143 (58) P= .197	1.0000 (60) P= .	-.1480 (60) P= .129	-.0104 (60) P= .469
ELEV	.1102 (87) P= .155	-.1534 (83) P= .083	. (47) P= .	-.2996 (99) P= .001	. (0) P= .	.2123 (58) P= .055	.3618 (95) P= .000	.1052 (96) P= .154	-.1480 (60) P= .129	1.0000 (114) P= .	-.0798 (74) P= .250
K	-.0727 (73) P= .271	.0916 (71) P= .224	. (37) P= .	.0347 (74) P= .385	. (0) P= .	-.0876 (56) P= .260	-.0538 (63) P= .338	.0431 (65) P= .367	-.0104 (60) P= .469	-.0798 (74) P= .250	1.0000 (74) P= .
SO4	-.0640 (85) P= .280	.0958 (82) P= .196	. (46) P= .	.3589 (98) P= .000	. (0) P= .	.6274 (73) P= .000	-.2670 (112) P= .002	.0031 (97) P= .488	.0707 (58) P= .299	-.3491 (112) P= .000	-.2013 (72) P= .045
CD	-.0130 (87) P= .452	. (83) P= .	. (47) P= .	-.0872 (88) P= .210	. (0) P= .	. (56) P= .	-.0631 (69) P= .303	-.0552 (71) P= .324	. (60) P= .	.1045 (88) P= .166	. (74) P= .
BR	-.8894 (25) P= .000	.2231 (21) P= .166	. (17) P= .	-.0799 (37) P= .319	. (0) P= .	.0108 (29) P= .478	-.2432 (67) P= .024	-.6809 (52) P= .000	.2223 (15) P= .213	-.1583 (52) P= .131	-.0738 (20) P= .379

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

Correlations:

	SO4	CD	BR
YEAR	.5359	.1206	.1729
	(129)	(88)	(67)
	P= .000	P= .132	P= .081
MONTH	-.0236	-.1287	.0059
	(129)	(88)	(67)
	P= .395	P= .116	P= .481
DAY	-.2092	-.1023	-.0903
	(121)	(84)	(63)
	P= .011	P= .177	P= .241
TEMP	.1981	-.1755	.3023
	(97)	(56)	(66)
	P= .026	P= .098	P= .007
DO	.0010	.	-.2006
	(88)	(47)	(64)
	P= .496	P= .	P= .056
PH	.2026	-.0205	.0859
	(129)	(88)	(67)
	P= .011	P= .425	P= .245
TURB	-.0168	-.1373	.1642
	(88)	(47)	(65)
	P= .438	P= .179	P= .096
COND	.4764	-.2186	.2795
	(100)	(58)	(66)
	P= .000	P= .050	P= .012
TDS	.5847	-.0368	-.1356
	(81)	(40)	(50)
	P= .000	P= .411	P= .174
TALK	-.0803	.2363	.1554
	(129)	(88)	(67)
	P= .183	P= .013	P= .105
HARD	.4919	.0000	.1420
	(129)	(88)	(67)
	P= .000	P= .500	P= .126
CA	.3070	.0519	.2389
	(122)	(86)	(62)
	P= .000	P= .318	P= .031
MG	.0236	-.0858	-.0189
	(121)	(86)	(61)
	P= .399	P= .216	P= .443

(Coefficient / (Cases) / 1-tailed Significance)

Correlations:

	SO4	CD	BR
CL	.1734	-.2033	-.0082
	(129)	(88)	(67)
	P= .025	P= .029	P= .474
FL	.0675	.2143	-.2374
	(127)	(87)	(67)
	P= .225	P= .023	P= .027
PO4	.2058	.	.0433
	(105)	(79)	(46)
	P= .018	P= .	P= .388
SI	.3275	.0919	-.3406
	(90)	(48)	(66)
	P= .001	P= .267	P= .003
FCOLI	-.2309	.	-.0277
	(80)	(52)	(50)
	P= .020	P= .	P= .424
CR	.2747	-.0128	.0548
	(85)	(87)	(25)
	P= .005	P= .453	P= .397
CU	.0550	-.0019	.0546
	(86)	(88)	(26)
	P= .307	P= .493	P= .396
NI	.0802	.0797	.0659
	(86)	(88)	(26)
	P= .232	P= .230	P= .375
PB	-.1825	.2123	.1552
	(86)	(88)	(26)
	P= .046	P= .024	P= .225
ZN	-.0640	-.0130	-.8894
	(85)	(87)	(25)
	P= .280	P= .452	P= .000
FE	.0958	.	.2231
	(82)	(83)	(21)
	P= .196	P= .	P= .166
AG	.	.	.
	(46)	(47)	(17)
	P= .	P= .	P= .
NA	.3589	-.0872	-.0799
	(98)	(88)	(37)
	P= .000	P= .210	P= .319

(Coefficient / (Cases) / 1-tailed Significance)

Correlations:

	SO4	CD	BR
BA	.	.	.
	(0)	(0)	(0)
	P= .	P= .	P= .
NH3	.6274	.	.0108
	(73)	(56)	(29)
	P= .000	P= .	P= .478
NO3	-.2670	-.0631	-.2432
	(112)	(69)	(67)
	P= .002	P= .303	P= .024
NO2	.0031	-.0552	-.6809
	(97)	(71)	(52)
	P= .488	P= .324	P= .000
MN	.0707	.	.2223
	(58)	(60)	(15)
	P= .299	P= .	P= .213
ELEV	-.3491	.1045	-.1583
	(112)	(88)	(52)
	P= .000	P= .166	P= .131
K	-.2013	.	-.0738
	(72)	(74)	(20)
	P= .045	P= .	P= .379
SO4	1.0000	.0290	.1283
	(129)	(86)	(67)
	P= .	P= .396	P= .150
CD	.0290	1.0000	-.0132
	(86)	(88)	(26)
	P= .396	P= .	P= .474
BR	.1283	-.0132	1.0000
	(67)	(26)	(67)
	P= .150	P= .474	P= .

(Coefficient / (Cases) / 1-tailed Significance)

" . " is printed if a coefficient cannot be computed

APPENDIX B

Lake Fort Phantom Hill
1987 Water Quality Sampling Results
Lake Station No. 1
(mg/l except as noted)

	March	April	May	June	July	August	September
Alkalinity	142	146	143	141	147	145	145
Aluminum	0.59	2.6	0.88	0.05	1.2	1.1	0.63
Ammonia-N	0.34	0.1	0.19	0.23	0.6	0.98	1.0
Arsenic	0.0	0.0	0.01	0.003	0.0	0.0	0.004
Barium	-	0.18	0.07	0.13	0.12	0.15	0.152
Boron	-	0.05	0.17	0.16	0.15	0.31	0.17
Bromide	0.46	0.38	0.44	0.24	0.23	-	0.49
Cadmium	0.0	0.0	0.0	0.0	0.007	0.0	0.49
Calcium	-	55.7	74.5	34.6	48.0	45.9	51.8
Chloride	81.0	8.4	80.8	78.0	78.0	82.3	86
Chlorophyll a	0.0	1.61	3.2	4.8	-	-	3.2
Chromium	0.002	0.01	0.002	-	0.008	0.007	0.002
Cobalt	-	0.002	0.001	0.0	0.0	0.0	0.0
Color	-	.06	.05	40.0	-	15	-
Copper	-	-	0.01	0.007	0.006	0.01	0.008
Cyanide	0.005	-	-	0.02	-	-	-
2,4-D, ug/l	BDL	-	-	-	-	-	-
Dissolved oxygen	-	6.4	7.0	4.3	6.4	6.2	6.6
Endrin, ug/l	BDL	-	-	-	-	-	-
Fecal Colif. (#/100 ml)	0.0	0.0	0.0	5.0	5	0.0	4
Fecal Strep. (#/100 ml)	100.0	0.0	0.0	15.0	0.0	0.0	12
Fluoride	0.5	0.43	0.29	0.27	0.33	-	-
Iodide	-	0.25	1.11	0.95	1.27	-	-
Iron	0.28	1.4	0.51	0.64	0.78	0.72	0.69
Lead	0.02	0.01	0.01	0.0	0.03	0.0	0.0
Lindane	-	-	-	-	-	-	-
Magnesium	-	27.9	34.3	11.9	17.7	17.0	19.53
Manganese	0.01	0.05	0.03	0.05	0.08	0.04	0.03
MBAS	-	0.4	0.15	0.28	0.37	-	0.04
Mercury	0.005	0.01	0.065	0.01	0.0	0.0	0.02
Methoxychlor, ug/l	BDL	-	-	-	-	-	-
Nitrate-N	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nitrite-N	-	0.1	0.03	0.003	0.04	0.01	0.01
Nitrogen, TKN	4.0	1.0	1.0	1.0	2.0	2.0	1.31
pH	8.0	8.1	7.7	8.2	8.0	8.2	8.3
Phosphate, dissolved ortho (P)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Phosphorus (total)	0.21	0.23	0.1	0.1	0.1	0.1	0.1
Potassium	-	8.5	18.8	7.6	5.5	25.5	6.5
Selenium	0.0	0.005	0.0	0.01	0.03	0.0	0.0
Silica	3.0	5.6	4.4	7.0	7.4	-	-
Silver	-	0.02	0.0	0.05	0.0	0.02	0.00
Sodium	-	69.9	47.24	50.6	49.2	44.8	50.6
Specific conductance, umhos/cm^3	630	641	667	660	630	600	630
Standard plate count(#/100 ml)	2200	5100	3500	1946	2600	2222	3385

Lake Station No. 1, Continued

	March	April	May	June	July	August	September
Strontium	-	0.58	0.23	0.08	0.49	0.55	0.54
Sulfate	8.75	82.5	76.0	73.0	74.0	71.0	75
2,4,5-T, ug/l	BDL	-	-	-	-	-	-
Threshold odor,#	6.0	3.0	3.0	2.0	-	-	3.0
Total dissolved solids	438.0	427.5	481.5	389.0	473.0	496	496
Total hardness	220.0	233.0	229.0	211.0	220.0	228.0	228.0
Total organic carbon	35.9	41.2	27.5	32.2	-	31.6	35.7
Total organic halogen, ug/l	14.0	20.0	7.0	-	-	-	10
Total suspended solids	2.0	42.5	79.0	27.0	9.0	24.0	40.0
TTHM	-	0.0	-	-	-	ID	ID
TTHMFP, ug/l	ID	ID	-	-	-	ID	ID
Toxaphene, ug/l	BDL	-	-	-	-	-	-
Turbidity (NTU)	14.0	36.0	18.5	31.0	36.0	28.0	34
Volatile organic carbon	20.0	9.3	23.1	-	22.0	27.0	33.1
Water temperature (°C)	14.0	16.5	24.0	26.0	26.0	29.5	-
Zinc	0.02	0.002	0.01	0.01	0	0.01	0.015

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill
1987 Water Quality Sampling Results
Lake Station No. 2
(mg/l except as noted)

	March	April	May	June	July	August	September
Alkalinity	146	145	142	142	145	14.6	145
Aluminum	0.58	1.3	1.01	0.3	0.37	0.89	0.05
Ammonia-N	0.34	0.1	0.14	0.17	0.38	0.94	0.5
Arsenic	0.0	0.0	0.01	0.002	0.0	0.0	0.0
Barium	-	0.15	0.23	0.12	0.12	0.14	0.15
Boron	-	0.15	0.13	0.14	0.001	0.16	0.14
Bromide	0.51	0.6	0.55	0.52	0.8	-	0.42
Cadmium	0.0	0.001	0.003	0.0	0.001	0.0	0.0
Calcium	-	62.8	71.4	57.9	45.7	52.5	51.4
Chloride	85.0	85.0	81.0	78.0	78.0	82.3	86.0
Chlorophyll <u>a</u>	0.27	-	-	-	-	-	-
Chromium	0.0	0.0	0.002	0.001	0.001	0.003	0.001
Cobalt	-	0.002	0.0	0.0	0.0	0.0	0.00
Color	-	6.0	5.0	40.0	-	10.0	15
Copper	-	0.001	0.01	0.03	0.007	0.014	0.003
Cyanide	0.005	-	-	0.02	-	-	-
2,4-D, ug/l	BDL	-	-	-	-	-	-
Dissolved oxygen	5.8	8.4	6.9	5.9	3.8	8.2	6.6
Endrin	BDL	-	-	-	-	-	-
Fecal Colif. (#/100 ml)	300.0	0.0	0.0	10.0	2.0	2.0	6.0
Fecal Strep. (#/100 ml)	100.0	0.0	0.0	0.0	0.0	2.0	1.0
Fluoride	0.5	0.43	0.3	0.47	0.32	-	-
Iodide	-	0.2	0.59	0.48	0.95	-	-
Iron	0.28	0.17	0.45	0.5	0.31	0.29	0.22
Lead	0.0	0.01	0.0	0.0	0.0	0.0	0.004
Lindane	-	-	-	-	-	-	-
Magnesium	-	21.6	33.3	28.2	15.8	19.1	18.8
Manganese	0.01	0.008	0.02	0.02	0.02	1.82	0.002
MBAS	-	0.4	0.16	0.04	0.36	-	0.04
Mercury	0.009	0.0	0.0	-	0.0	0.0	0.0
Methoxychlor, ug/l	BDL	-	-	-	-	-	-
Nitrate-N	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nitrite-N	-	0.23	0.05	0.003	0.01	0.01	0.01
Nitrogen, TKN	5.0	3.0	3.0	1.6	-	2.0	1.8
pH	8.0	8.6	7.7	8.3	8.3	6.4	8.3
Phosphate, dissolved ortho (P)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Phosphorus (total)	0.21	0.25	0.1	0.1	0.1	0.1	0.1
Potassium	-	6.8	18.6	0.64	4.5	26.1	6.3
Selenium	0.0	0.01	0.002	0.0	0.02	0.0	0.0
Silica	2.9	2.9	4.0	6.2	-	-	-
Silver	0.0	0.01	0.0	0.11	0.0	0.01	0.001
Sodium	-	55.4	27	41	43.2	91.7	53.6
Specific conductance, umhos/cm^3	582	626	690	645	630	600	680
Standard plate count(#/100 ml)	2600	875	5000	13,622	-	1666	2777
Strontium	-	0.61	0.62	0.25	0.48	0.51	0.53

Lake Station No. 2

	March	April	May	June	July	August	September
Sulfate	82	85	80	71	74	71	76.0
2,4,5-T, ug/l	BDL	-	-	-	-	-	-
Threshold odor, #	6.0	8.0	4.0	2.0	-	-	-
Total dissolved solids	448	417	484	401	-	490	666
Total hardness	224	234	179	210	218	226	222
Total organic carbon	37.9	40.1	26.1	32.5	-	32.5	36.6
Total organic halogen	8.0	18.0	15.0	-	-	-	10.0
Total suspended solids	6.0	13.0	9.0	9.0	-	22.0	6.0
TTHM	0.0	0.0	-	-	-	ID	ID
TTHMFP, ug/l	ID	ID	-	-	-	ID	ID
Toxaphene, ug/l	BDL	-	-	-	-	-	-
Turbidity (NTU)	15.0	6.0	11.0	23.0	18.0	21.0	12.0
Volatile organic carbon	21.7	13	21.9	25.6	-	27.2	31.5
Water temperature (°C)	14.0	21.5	24.0	27.0	-	28.5	27.0
Zinc	0.02	0.0	0.22	0.15	0.0	0.01	0.01

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill
1987 Water Quality Sampling Results
Creek Composite
(mg/l except as noted)

	March	April	May	June	July	August	September
Alkalinity	206	-	105	116	-	-	105
Aluminum	2.7	-	2.2	0.15	-	-	1.3
Ammonia-N	4.8	-	0.45	0.26	-	-	0.16
Arsenic	0.04	-	0.03	0.004	-	-	0.002
Barium	-	-	0.18	0.28	-	-	0.09
Boron	-	-	0.165	0.11	-	-	0.19
Bromide	-	-	0.1	0.43	-	-	-
Cadmium	0.0	-	0.0	0.0	-	-	0.0
Calcium	-		64	53.7	-	-	28.2
Chloride	148	-	82.7	74.0	-	-	47
Chlorophyll *a*	2.67	-	5.3	-	-	-	3.86
Chromium	0.003	-	0.003	0.002	-	-	0.005
Cobalt	-	-	0.0	0.002	-	-	0.0
Color	-	-	-	50.0	-	-	80.0
Copper	0.01	-	0.01	0.03	-	-	0.01
Cyanide	0.005	-	-	-	-	-	-
2,4-D, ug/l	BDL	-	-	BDL	-	-	BDL
Dissolved oxygen	9.7	-	5.2	5.7	-	-	5.1
Endrin, ug/l	BDL	-	BDL	BDL	-	-	BDL
Fecal Colif. (#/100 ml)	800	-	265	TNTC	-	-	TNTC
Fecal Strep. (#/100 ml)	400	-	3,000	TNTC	-	-	700
Fluoride	0.5		0.27	0.37	-	-	0.38
Iodide	-	-	0.75	0.75	-	-	1.11
Iron	1.5	-	0.0	1.3	-	-	1.4
Lead	0.0	-	0.0	0.0	-	-	0.0
Lindane, ug/l	-	-	-	-	-	-	-
Magnesium	-	-	29.0	26.2	-	-	12.9
Manganese	0.08	-	0.09	0.05	-	-	0.07
MBAS	-	-	0.28	0.07	-	-	0.65
Mercury	0.013	-	0.0	0.0	-	-	1.2
Methoxychlor, ug/l	BDL	-	BDL	BDL	-	-	BDL
Nitrate-N	0.1	-	0.5	0.1	-	-	0.1
Nitrite-N	-	-	0.35	0.1	-	-	0.01
Nitrogen, TKN	10.0	-	4.7	0.56	-	-	0.3
pH	7.9	-	7.6	8.2	-	-	8.2
Phosphate, dissolved ortho (P)	0.1	-	0.13	0.1	-	-	0.1
Phosphorus (total)	0.23	-	0.16	0.1	-	-	0.1
Potassium	-	-	17.4	4.6	-	-	4.7
Selenium	0.0	-	0.002	0.003	-	-	0.0
Silica	8.4	-	7.2	5.6	-	-	7.2
Silver	0.0	-	0.0	0.076	-	-	0.0
Sodium	-	-	42.2	45.3	-	-	46.7
Specific conductance, umhos/cm^3	617.5	-	420	465	-	-	420
Standard plate count(#/100 ml)	6,000	-	-	TNTC	-	-	TNTC

Creek Composite, Continued

	March	April	May	June	July	August	September
Strontium	-	-	0.18	0.32	-	-	0.34
Sulfate	94.0	-	49.0	66.0	-	-	59
2,4,5-T, ug/l	BDL	-	-	BDL	-	-	BDL
Threshold odor, #	10.0	-	3.5	-	-	-	-
Total dissolved solids	674	-	416.5	383.5	-	-	428
Total hardness	324	-	178	176	-	-	126
Total organic carbon	54.1	-	23.9	35.4	-	-	34.9
Total organic halogen (ug/l)	15.0	-	150	25.0	-	-	11.0
Total suspended solids	170	-	55.5	83.0	-	-	56.0
TTHM	ID	-	-	-	-	-	ID
TTHMFP (ug/l)	ID	-	-	-	-	-	ID
Toxaphene, ug/l	BDL	-	BDL	BDL	-	-	BDL
Turbidity (NTU)	90.0	-	41.5	91.0	-	-	58
Volatile organic carbon	38.2	-	17.5	25.5	-	-	27.4
Water temperature (°C)	14.5	-	23	25.5	-	-	28.0
Zinc	0.03	-	0.013	0.02	-	-	0.01

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill
1987 Water Quality Sampling Results
Wastewater Plant Effluent
(mg/l except as noted)

	March	April	May	June	July	August	September
Alkalinity	220	155	167	174	192	179	159
Aluminum	0.18	0.07	0.0	0.01	-	0.17	0.04
Ammonia-N	1.0	5.5	1.65	1.4	12.4	7.6	13.3
Arsenic	0.0	0.003	0.01	0.003	0.0	0.0	0.007
Barium	-	0.05	0.075	0.05	0.025	0.058	0.06
Boron	-	0.44	0.45	0.37	0.26	0.48	0.51
Bromide	-	-	-	-	-	-	-
Cadmium	0.0	0.0	0.0	0.0	0.001	0.0	0.0
Calcium	-	61.3	73.0	159.7	40.8	44.1	42.6
Chloride	296	256	215.7	196	202	208	208.7
Chlorophyll a	0.53	-	-	-	-	-	-
Chromium	0.006	0.003	0.004	0.002	0.005	0.008	0.008
Cobalt	-	0.001	0.002	0.0	0.0	0.0	0.0
Color		15.0	12.0	15.0	15.0	15.0	20.0
Copper	0.015	0.009	0.013	0.007	0.012	0.006	0.02
Cyanide	0.005	-	-	-	-	-	-
2,4-D, ug/l	BDL	-	-	-	-	-	-
Dissolved oxygen	-	5.9	6.0	5.5	3.4	5.3	6.6
Endrin, ug/l	BDL	-	-	-	-	-	-
Fecal Colif. (#/100 ml)	0.0	0.0	0.0	2.5	0.0	0.0	0.0
Fecal Strep. (#/100 ml)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fluoride	1.3	1.6	1.14	0.99	1.67	-	-
Iodide	-	1.3	1.19	1.19	1.9	-	-
Iron	0.15	0.1	0.13	0.17	0.07	0.09	0.16
Lead	0.0	0.004	0.0	0.012	0.0	0.0	0.001
Lindane	-	-	-	-	-	-	-
Magnesium	-	38.8	58	145.7	25.9	24.9	25.1
Manganese	0.02	0.01	0.03	0.11	0.03	0.05	0.02
MBAS	-	0.91	1.02	0.175	1.99	-	0.17
Mercury	0.0	0.04	0.0	0.0	0.0	0.0	0.0
Methoxychlor, ug/l	BDL	-	-	-	-	-	-
Nitrate-N	9.0	18.0	9.3	5.8	5.8	3.8	6.4
Nitrite-N	-	61.0	6.5	0.175	0.15	0.31	0.02
Nitrogen, TKN	15.0	7.0	5.0	1.33	-	9.9	5.8
pH	7.1	6.8	6.8	7.2	7.2	7.3	6.6
Phosphate, dissolved ortho (P)	4.0	6.25	6.5	7.5	8.9	-	7.4
Phosphorus (total)	7.5	7.7	7.0	8.4	10.6	7.4	9.3
Potassium	-	11.2	17.6	11.8	10.7	27.7	13.7
Selenium	0.008	0.001	0.0	0.004	0.0	0.003	0.0
Silica	15.0	17.6	14.8	14.3	14.2	-	-
Silver	0.0	0.02	0.003	0.19	0.0	0.01	0.02
Sodium	-	161.5	170	143.2	161.8	146.7	174.3
Specific conductance, umhos/cm^3	1675	1493	1275	1250	1200	1200	1200
Standard plate count(#/100 ml)	4100	275	26,000	2224	1667	1666	555

Wastewater Plant Effluent, Continued

	March	April	May	June	July	August	September
Strontium	-	0.75	1.07	0.06	0.34	0.68	0.65
Sulfate	279	227	205	150	153	136	151
2,4,5-T, ug/l	BDL	-	-	-	-	-	-
Threshold odor, #	35.0	35.0	-	-	-	-	-
Total dissolved solids	1223	995	957	792	-	-	580
Total hardness	452	350	319	261	254	251	231
Total organic carbon	72.3	52.5	35.7	50.1	-	47.3	-
Total organic halogen	340	280	220	-	-	-	320
Total suspended solids	4.0	145	10.0	6.75	-	24.0	12.0
TTHM, ug/l	ID	ID	-	-	-	ID	ID
TTHMFP, ug/l	ID	ID	-	-	-	ID	ID
Toxaphene, ug/l	BDL	-	-	-	-	-	-
Turbidity (NTU)	16.0	17.0	3.6	7.5	3.0	5.0	6.0
Volatile organic carbon	38.4	17.2	25.1	35.7	-	35.8	41.9
Water temperature (°C)	18	22	24	25	-	28.0	28.0
Zinc	0.03	0.03	-	1.4	0.03	0.12	0.06

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill Water Quality
Lake Station No. 1

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Alkalinity	144.143	2.193	147	141	7
Aluminum	1.007	0.799	2.6	0.05	7
Ammonia-N	0.477	0.394	1.0	0	7
Arsenic	0.002	0.004	0.010	0	7
Barium	0.134	0.037	0.180	0.070	6
Boron	0.168	0.083	0.310	0.050	6
Bromide	0.373	0.113	0.490	0.230	6
Cadmium	0.071	0.185	0.490	0	7
Calcium	51.75	13.233	74.5	34.6	6
Chloride	81.443	2.954	86.000	78.000	7
Chlorophyll a	2.562	1.823	4.8	0	5
Chromium	0.005	0.004	0.010	0.002	6
Cobalt	0.001	0.001	0.002	0	6
Color	16.5	16.299	40	5	4
Copper	0.008	0.002	0.010	0.006	5
Cyanide	0	0	0	0	2
2,4-D	BDL				1
Dissolved Oxygen	6.060	1.029	8.3	7	7
Endrin	BDL				1
Fecal Colif. (#/100 ml)	2	2.517	5.000	0	7
Fecal Strep. (#/100 ml)	18.143	36,663	100.000	0	7
Fluoride	0.264	0.160	0.430	0	5
Iodide	0.895	0.449	1.270	0.250	4
Iron	0.717	0.344	1.4	0.280	7
Lead	0.010	0.012	0.030	0	7
Lindane	BDL				0
Magnesium	21.383	8.192	34.300	11.9	6
Manganese	0.041	0.022	0.080	0.010	6
MBAS	0.168	0.157	0.370	0	5
Mercury	0.016	0.023	0.065	0	7
Methoxychlor	BDL				1
Nitrate-N	0.1	0	0.1	0.1	7
Nitrite-N	0.014	0.017	0.040	0	6
Nitrogen, TKN	1.759	1.085	4	1	7
Odor	3.4	1.517	6	2	5
Pesticides	0	0	0	0	6
pH	8.071	0.198	8.3	7.7	7
Phosphate, ortho	0.014	0.038	0.100	0	7
Phosphorus, total	0.077	0.104	0.230	0	7
Potassium	12.067	8.156	25.5	5.50	6
Selenium	0.006	0.011	0.030	0	7
Silica	5.480	1.825	7.400	3	5
Silver	0.015	0.020	0.050	0	6
Sodium	52.1	10.051	69.900	44.800	5

Lake Station No. 1

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Specific Conductance	636.857	22.214	667	600	7
Standard count (#/100 ml)	3064.714	1149.646	5100	1946	7
Strontium	0.412	0.206	0.580	0.08	6
Sulfate	64.750	25.392	82.5	8.750	7
2,4,5-T	BDL				1
Total dissolved solids	457.286	40.317	596.0	389	7
Total hardness	224.143	7.515	233	211	7
Total organic carbon	34.017	4.682	41.2	27.5	6
Total organic halogen	12.75	5.620	20	7	4
Total suspended solids	31.929	25.499	79	2	7
TTHM (mg/l)	ID	ID	ID	ID	2
TTHMFP (mg/l)	ID	ID	ID	ID	4
Toxaphene	BDL				1
Turbidity	28.214	8.746	36.0	14.0	7
Volatile organic carbon	22.417	7.920	33.1	9.3	6
Water temperature (°C)	22.667	6.064	29.5	14	6
Zinc	0.010	0.007	0.020	0	7

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill Water Quality
Lake Station No. 2

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Alkalinity	144.429	1.718	146	142	7
Aluminum	0.742	0.391	1.3	0.3	6
Ammonia-N	0.353	0.308	0.94	0.0	7
Arsenic	0.002	0.004	0.010	0.0	7
Barium	0.152	0.045	0.230	0.120	6
Boron	0.12	0.059	0.16	0.001	6
Bromide	0.567	0.129	0.8	0.42	6
Cadmium	0.001	0.001	0.003	0.0	7
Calcium	56.950	9.177	71.4	45.7	6
Chloride	82.186	3.338	86.0	78.0	7
Chlorophyll _a_	0.27	-	0.27	0.27	1
Chromium	0.001	0.001	0.003	0.0	7
Cobalt	0.0	0.001	0.002	0.0	6
Color	15.2	14.412	40.0	5.0	5
Copper	0.011	0.010	0.03	0.001	6
Cyanide	0.0	0.0	0.0	0.0	2
Dissolved oxygen	6.314	1.571	8.4	3.8	7
2,4-D	BDL	-	-	-	1
Endrin	BDL	-	-	-	1
Fecal Colif. (#/100 ml)	45.714	112.187	300	0.0	7
Fecal Strep. (#/100 ml)	14.857	37.556	100	0.0	7
Fluoride	0.304	0.184	0.47	0.0	5
Iodide	0.555	0.31	0.95	0.2	4
Iron	0.17	0.119	0.50	0.17	7
Lead	0.002	0.004	0.01	0.0	7
Lindane	ND	-	-	-	0
Magnesium	22.8	6.626	33.3	15.8	6
Manganese	0.269	0.676	1.801	0.002	7
MBAS	0.120	0.147	0.36	0.0	5
Mercury	0.001	0.004	0.009	0.0	6
Methoxychlor	BDL	-	-	-	1
Nitrate-N	0.029	0.049	0.100	0.0	7
Nitrite-N	0.051	0.090	0.230	0.0	6
Nitrogen, TKN	2.733	1.263	5.0	1.6	6
Odor	5.0	2.582	8.0	2.0	4
pH	7.943	0.737	8.6	6.4	7
Phosphate, ortho	0.029	0.049	0.01	0.0	7
Phosphate, total	0.080	0.109	0.0	0.25	7
Potassium	10.490	9.732	26.1	0.64	6
Selenium	0.005	0.008	0.02	0.0	7
Silica	4.0	1.556	6.2	2.9	4
Silver	0.019	0.041	0.11	0.0	7
Sodium	51.983	21.971	91.7	27.0	6
Specific conductance	636.143	49.329	582	690	7

Lake Station No. 2

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Standard count (#/100 ml)	4752.6	5194.325	13622	875	5
Strontium	0.502	0.134	0.62	0.25	6
Sulfate	6.457	26.174	85.0	8.2	7
2,4,5-T	BDL	-	-	-	1
Total dissolved solids	484.333	95.743	666	401	6
Total hardness	216.143	17.948	234	179	7
Total organic carbon	34.283	5.012	40.1	26.1	6
Total organic halogen	12.750	4.573	18.0	8.0	4
Total suspended solids	10.833	6.047	22	6.0	6
TTHM (ug/l)	ID	ID	ID	ID	3
TTHMFP (ug/l)	ID	ID	ID	ID	7
Toxaphene	BDL	-	-	-	1
Turbidity	15.143	5.984	23.0	6.0	7
Volatile organic carbon	23.483	6.295	31.5	13.0	6
Water temperature	23.667	5.363	28.5	14	6
Zinc	0.059	0.059	0.220	0.0	7

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill Water Quality
Creek Composite

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Alkalinity	133	18.9	206	105	4
Aluminum	1.56	1.12	2.7	0.15	4
Ammonia-N	1.42	2.26	4.8	0.16	4
Arsenic	0.019	0.019	0.04	0.002	4
Barium	0.183	0.095	0.28	0.04	3
Boron	0.155	0.041	0.19	0.11	3
Bromide	0.215	0.304	0.43	0.0	2
Cadmium	0.0	0.0	0.0	0.0	4
Calcium	48.6	18.4	64.0	28.2	3
Chloride	87.9	42.8	148	47	4
Chlorophyll a	3.94	1.32	5.3	2.67	3
Chromium	0.003	0.001	0.005	0.002	4
Cobalt	0.001	0.001	0.002	0.0	3
Color	65.0	21.2	80.0	50.0	2
Copper	0.015	0.010	0.03	0.01	4
Cyanide	0.0	0.0	0.0	0.0	1
Dissolved oxygen	6.4	2.2	9.7	5.1	4
2,4-D	BDL	-	-	-	2
Endrin	BDL	-	-	-	3
Fecal Colif. (#/100 ml)	532	378	800	265	2
Fecal Strep. (#/100 ml)	1367	1838	3000	400	3
Fluoride	0.255	0.177	0.38	0.0	4
Iodide	0.87	0.21	1.11	0.75	3
Iron	1.05	0.71	1.5	0.0	4
Lead	0.0	0.0	0.0	0.0	4
Lindane	ND	-	-	-	0
Magnesium	22.7	8.6	29.0	12.9	3
Manganese	0.073	0.017	0.09	0.05	4
MBAS	0.333	0.294	0.65	0.07	3
Mercury	0.303	0.598	0.12	0.0	4
Methoxychlor	LD	-	-	-	3
Nitrate-N	0.150	0.238	0.5	0.0	4
Nitrite-N	0.15	0.18	0.35	0.01	3
Nitrogen, TKN	3.89	4.54	10.0	0.30	4
Odor	6.75	4.6	10.0	3.5	2
pH	8.0	0.3	8.2	7.6	4
Phosphate, ortho	0.06	0.07	0.13	0.0	4
Phosphorus, total	0.15	0.06	0.23	0.1	4
Potassium	8.9	7.4	17.4	4.6	3
Selenium	0.001	0.002	0.003	0.0	4
Silica	7.1	1.15	8.4	5.6	4
Silver	0.019	0.038	0.076	0.0	4
Sodium	44.7	2.3	46.7	42.2	3
Special conductance	481	94	618	420	4

Creek Composite, Continued

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Standard count (#/100 ml)	6000	-	-	-	1
Strontium	0.28	0.087	0.34	0.18	3
Sulfate	67.0	19.3	94.0	49.0	4
2,4,5-T	BDL	-	-	-	2
Total dissolved solids	475.5	133.7	674	383.5	4
Total hardness	201	85	324	126	4
Total organic carbon	37.1	12.5	54.1	23.9	4
Total organic halogen	50.2	66.8	150	11.0	4
Total suspended solids	91.1	54.1	170	55.5	4
TTHM (ug/l)	ID	ID	ID	ID	2
TTHMFP (ug/l)	ID	ID	ID	ID	2
Toxaphene	BDL	-	-	-	3
Turbidity	70.1	24.5	91.0	41.5	4
Volatile organic carbon	27.2	8.5	38.2	17.5	4
Water temperature	21.5	4.8	25.5	14.5	4
Zinc	0.018	0.009	0.03	0.01	4

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill Water Quality
Wastewater Plant Effluent

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Alkalinity	178	22.316	220	155	7
Aluminum	0.078	0.079	0.18	0.0	6
Ammonia-N	6.121	5.197	13.3	1.0	7
Arsenic	0.003	0.004	0.01	0.0	7
Barium	0.053	0.016	0.075	0.025	6
Boron	0.418	0.091	0.510	0.26	6
Bromide	-	-	-	-	0
Cadmium	0.0	0.0	0.001	0.0	7
Calcium	70.25	45.617	159.7	40.8	6
Chloride	226.057	36.527	296	196	7
Chlorophyll a	0.53	-	0.53	0.53	1
Chromium	0.005	0.002	0.008	0.002	7
Cobalt	0.001	0.001	0.002	0.0	6
Color	15.333	2.582	20	12.0	6
Copper	0.012	0.005	0.02	0.006	7
Cyanide	0.0	0.0	0.0	0.0	1
Dissolved oxygen	5.45	1.1	3.4	6.6	6
2,4-D	BDL	-	-	-	1
Endrin	BDL	-	-	-	1
Fecal Colif. (#/100 ml)	0.357	0.945	2.5	0.0	7
Fecal Strep. (#/100 ml)	0.0	0.0	0.0	0.0	7
Fluoride	1.34	0.292	1.67	0.99	5
Iodide	1.395	0.341	1.9	1.19	4
Iron	0.124	0.038	0.17	0.07	7
Lead	0.002	0.004	0.012	0.0	7
Lindane	ND	-	-	-	0
Magnesium	53.067	47.164	145.7	24.9	6
Manganese	0.039	0.034	0.11	0.01	7
MBAS	0.853	0.75	1.99	0.17	5
Mercury	0.006	0.015	0.04	0.0	7
Methoxychlor	BDL	-	-	-	1
Nitrate-N	8.3	4.689	18.0	3.8	7
Nitrite-N	11.359	24.451	61.0	0.02	6
Nitrogen, TKN	7.338	4.676	15.0	1.33	6
Odor	35.0	0.0	35.0	35.0	2
pH	7.0	0.265	7.3	6.6	7
Phosphate, ortho	758	1.642	8.9	4.0	6
Phosphorus, total	8.271	1.278	10.6	7	7
Potassium	15.367	6.319	27.2	10.7	6
Selenium	0.002	0.003	0.008	0.0	7
Silica	15.18	1.394	17.6	14.2	5
Silver	0.035	0.069	0.19	0.0	7
Sodium	159.583	12.394	174.3	143.2	6
Specific conductance	1327.571	185.148	1675	1200	7

Wastewater Plant Effluent, Continued

Parameter	Mean	Standard Deviation	Maximum	Minimum	Number
Standard count (#/100 ml)	6853	10790.956	26000	275	5
Strontium	0.592	0.35	1.07	0.06	6
Sulfate	185.857	52.916	279	136	7
2,4,5-T	BDL	-	-	-	1
Total dissolved solids	909.4	239.909	1223	580	5
Total hardness	302.571	78.228	452	231	7
Total organic carbon	51.58	13.256	72.3	35.7	5
Total organic halogen	290	52.915	340	220	4
Total suspended solids	13.542	5.858	24	6.75	6
TTHM (mg/l)	ID	ID	ID	ID	4
TTHMFP (mg/l)	ID	ID	ID	ID	4
Toxaphene	BDL	-	-	-	1
Turbidity	8.3	5.802	17.0	3	7
Volatile organic carbon	32.35	9.306	41.9	17.2	6
Water temperature	24.167	3.817	28	18	6
Zinc	0.278	0.551	1.4	0.03	6

BDL = Below Detection Limit
ID = Invalid Data

Lake Fort Phantom Hill
1987-88 Water Quality Sampling Results
Sediment Analysis
(mg/l except as noted)

	Pump Station Intake		West Texas Utilities Intake	
	Total Metals	Leachate	Total Metals	Leachate
	2/25/88	3/15/88	2/25/88	3/15/88
As	0	0	0	0
Hg	0	0	0	0
Se	0	0	0	0
Zn	2.567	0	2.009	0.072
Cd	0.061	0	0	0
Pb	0.400	0	0.880	0
Ni	0.009	0	1.184	0
B	2.074	0.944	1.189	0.889
Cr	0	0	0.43	0
Cu	0.065	0	0.804	0
Ag	0	0	0.001	0
Ba	10.93/10.45*	20.617	5.19/5.04*	18.403
Mn	113.93	115.355	127.53	89.798

*Samples Reanalyzed on 3/16/88

APPENDIX C

QUALITY CONTROL PROGRAM

A quality control program was in place for laboratory analysis during the seven-month sampling program. Both the City of Abilene laboratory and the CH2M Hill laboratory participated in the quality control program.

The City of Abilene laboratory performed two sets of analysis for each parameter sampled. From the two data, a percent relative deviation was determined. In addition, two known spike concentrations were added to the sample and the percent recovery determined for each spike added.

The CH2M Hill laboratory performed quality control measures for the parameters they analyzed. In addition, surrogate recoveries were identified and the percent recovery determined for analysis of pesticides, organic and inorganic priority pollutants.

APPENDIX D

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
JANUARY	76	*	*	8.50	*	114.00	66.00	*	*
	77	*	*	8.10	*	99.00	66.00	*	*
	78	*	*	8.40	*	128.80	101.00	*	*
	79	6.00	*	8.30	2.00	98.00	83.00	*	600.00
	80	10.00	9.80	8.50	86.00	106.00	75.20	546.00	675.00
	81	10.00	10.50	8.20	22.00	80.00	85.30	*	675.00
	82	2.00	11.80	8.40	*	56.00	71.00	350.00	520.00
	83	7.00	9.90	8.00	16.00	62.50	31.00	432.00	461.00
	84	2.00	*	8.60	0.00	55.20	90.00	330.00	442.00
	85	10.00	10.40	7.90	52.00	96.00	105.00	526.00	790.00
	86	7.00	8.40	8.40	0.00	94.00	150.00	530.00	795.00
	87	10.50	12.90	8.20	14.00	62.00	78.00	350.00	525.00
MIN		2.00	8.40	7.90	0.00	55.20	31.00	330.00	442.00
MAX		10.50	12.90	8.60	86.00	128.80	150.00	546.00	795.00
MEAN		7.1667	10.5286	8.2917	24.0000	87.6250	83.4583	437.7143	609.2222
STDEV		3.3541	1.4557	.2151	30.3127	24.2600	28.3815	95.7944	132.7213
VALIDN		9	7	12	8	12	12	7	9

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
FEBRUARY	76	.	.	8.40	.	107.00	75.00	.	.
	77	.	.	7.90	.	107.00	72.00	.	.
	78	.	.	8.40	.	139.50	113.00	.	.
	79	8.00	.	8.40	38.00	99.00	78.80	440.00	640.00
	80	11.00	9.70	8.60	11.00	110.00	83.40	549.00	680.00
	81	8.00	10.10	8.10	130.00	78.00	85.90	.	440.00
	82	5.00	12.00	8.50	24.00	57.00	66.00	340.00	375.00
	83	8.00	.	8.30	.	61.20	97.80	445.00	470.00
	84	7.10	13.00	8.50	0.00	80.00	100.00	467.00	700.00
	85	6.00	11.90	8.20	12.00	84.50	100.00	440.00	660.00
	86	7.00	11.10	8.17	.	94.00	148.00	560.00	840.00
MIN		5.00	9.70	7.90	0.00	57.00	66.00	340.00	375.00
MAX		11.00	13.00	8.60	130.00	139.50	148.00	560.00	840.00
MEAN		7.5125	11.3000	8.3155	35.8333	92.4727	92.7182	463.0000	600.6250
STDEV		1.7691	1.2474	.2060	47.9183	23.7712	23.2021	74.5341	156.8994
VALIDN		8	6	11	6	11	11	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
MARCH	76	*	*	8.30	*	99.00	75.00	*	*
	77	*	*	8.10	*	107.00	88.00	*	*
	78	*	*	*	*	*	*	*	*
	79	15.00	*	8.40	128.00	100.00	76.80	470.00	720.00
	80	15.00	9.20	8.50	4.00	114.00	86.20	578.00	780.00
	81	17.00	9.00	8.40	5.00	80.00	76.70	*	510.00
	82	13.00	10.00	8.60	2.00	51.00	77.00	360.00	460.00
	83	16.00	11.90	8.20	16.00	75.10	176.00	410.00	620.00
	84	8.00	11.10	8.50	0.00	80.00	95.00	480.00	720.00
	85	21.00	10.40	8.50	*	86.00	143.00	473.00	710.00
	86	17.00	9.60	8.20	30.00	94.00	153.00	567.00	850.00
MIN		8.00	9.00	8.10	0.00	51.00	75.00	360.00	460.00
MAX		21.00	11.90	8.60	128.00	114.00	176.00	578.00	850.00
MEAN		15.2500	10.1714	8.3700	26.4286	88.6100	104.6700	476.8571	671.2500
STDEV		3.7321	1.0468	.1636	45.9995	18.2626	37.7278	78.0522	132.7121
VALIDN		8	7	10	7	10	10	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
APRIL	76	*	*	8.50	*	135.00	78.30	*	*
	77	*	*	8.30	*	107.00	70.00	*	*
	78	*	*	8.30	*	127.00	104.00	610.00	1022.00
	79	*	*	8.20	10.00	90.00	73.90	440.00	500.00
	80	22.00	6.80	8.30	5.00	152.00	94.10	*	890.00
	81	16.00	11.50	8.70	108.00	78.00	79.80	*	430.00
	82	19.00	10.50	8.20	32.00	52.00	67.00	365.00	500.00
	83	14.00	12.60	8.80	0.00	71.80	75.40	420.00	630.00
	84	15.00	11.00	7.90	0.00	95.20	101.00	502.00	800.00
	85	20.00	15.00	9.00	6.00	92.00	123.00	493.00	740.00
	86	22.00	8.20	8.60	*	104.00	175.00	581.00	872.00
MIN		14.00	6.80	7.90	0.00	52.00	67.00	365.00	430.00
MAX		22.00	15.00	9.00	108.00	152.00	175.00	610.00	1022.00
MEAN		18.2857	10.8000	8.4364	23.0000	100.3636	94.6818	487.2857	709.3333
STDEV		3.3022	2.7160	.3171	39.0427	29.1407	31.7002	87.3760	205.5432
VALIDN		7	7	11	7	11	11	7	9

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
MAY	76	.	.	8.10	.	128.00	80.80	.	.
	77	.	.	7.90	.	99.00	55.00	.	.
	78	.	.	8.48	.	136.70	115.00	.	.
	79	21.00	.	8.40	132.00	92.00	74.20	390.00	580.00
	80	21.00	8.30	8.40	162.00	128.00	88.90	.	860.00
	81	23.00	9.70	8.40	300.00	82.00	72.80	.	550.00
	82	22.00	5.00	8.30	140.00	53.00	46.00	385.00	550.00
	83	19.00	9.00	8.30	.	71.80	155.00	425.00	630.00
	84	20.00	9.00	8.60	0.00	83.20	127.00	525.00	800.00
	85	19.00	8.70	8.20	.	85.00	55.00	563.00	845.00
	86	25.00	9.50	8.40	.	110.00	175.00	920.00	945.00
MIN		19.00	5.00	7.90	0.00	53.00	46.00	385.00	550.00
MAX		25.00	9.70	8.60	300.00	136.70	175.00	920.00	945.00
MEAN		21.2500	8.4571	8.3164	146.8000	97.1545	94.9727	534.6667	720.0000
STDEV		2.0529	1.5946	.1922	106.6733	26.1272	42.6489	202.3528	159.3514
VALIDN		8	7	11	5	11	11	6	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
JUNE	76	*	*	8.40	*	128.00	80.00	*	*
	77	*	*	8.20	*	107.00	60.00	*	*
	78	*	*	8.20	*	149.40	*	*	*
	79	25.00	*	8.10	28.00	90.00	73.50	470.00	750.00
	80	26.00	7.50	8.40	210.00	102.00	81.10	*	798.00
	81	27.00	6.00	8.50	62.00	100.00	119.00	*	550.00
	82	30.00	11.20	8.30	18.00	63.00	40.00	390.00	550.00
	83	25.00	8.20	8.40	0.00	71.80	123.00	430.00	640.00
	84	29.00	8.20	8.30	0.00	102.10	170.00	405.00	610.00
	85	29.00	7.80	8.40	24.00	147.00	200.00	600.00	900.00
	86	27.00	6.10	8.00	*	79.00	130.00	500.00	750.00
MIN		25.00	6.00	8.00	0.00	63.00	40.00	390.00	550.00
MAX		30.00	11.20	8.50	210.00	149.40	200.00	600.00	900.00
MEAN		27.2500	7.8571	8.2909	48.8571	103.5727	107.6600	465.8333	693.5000
STDEV		1.9086	1.7358	.1514	74.0708	28.3824	50.2910	77.3574	125.9059
VALIDN		8	7	11	7	11	10	6	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
JULY	76	.	.	8.50	.	121.00	61.00	.	.
	77	.	.	8.30	.	92.00	61.00	.	.
	78	.	.	8.20	.	149.40	108.00	.	.
	79	26.00	6.90	8.10	8.00	88.00	75.40	485.00	690.00
	80	30.00	6.40	8.50	50.00	110.00	87.10	.	710.00
	81	27.00	3.50	8.10	20.00	80.00	135.00	.	600.00
	82	28.00	7.30	8.80	14.00	64.00	68.00	405.00	600.00
	83	27.00	9.60	8.40	0.00	74.70	135.00	410.00	620.00
	84	29.00	8.40	8.50	10.00	107.70	130.00	445.00	665.00
	85	31.00	8.10	8.60	0.00	110.00	165.00	600.00	900.00
	86	29.50	6.50	8.40	0.00	83.00	130.00	503.00	755.00
MIN		26.00	3.50	8.10	0.00	64.00	61.00	405.00	600.00
MAX		31.00	9.60	8.80	50.00	149.40	165.00	600.00	900.00
MEAN		28.4375	7.0875	8.4000	12.7500	98.1636	105.0455	474.6667	692.5000
STDEV		1.7204	1.8059	.2145	16.7311	24.3652	36.1892	72.8469	100.2853
VALIDN		8	8	11	8	11	11	6	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
AUGUST	76	*	*	8.10	*	128.00	75.00	*	*
	77	*	*	8.30	*	109.40	46.00	*	*
	78	*	*	8.10	*	96.00	76.50	335.00	675.00
	79	27.00	6.20	8.00	46.00	88.00	73.60	435.00	520.00
	80	28.00	7.40	8.60	34.00	114.00	63.10	*	775.00
	81	25.00	7.20	8.50	0.00	96.00	122.00	500.00	450.00
	82	28.00	6.00	8.30	6.00	66.00	32.00	390.00	640.00
	83	34.00	8.80	8.80	*	70.00	75.00	390.00	588.00
	84	30.00	7.70	8.30	36.00	107.00	135.00	600.00	900.00
	85	29.00	7.60	8.40	4.00	101.00	160.00	567.00	850.00
	86	29.00	7.90	8.30	*	85.00	133.00	527.00	790.00
MIN		25.00	6.00	8.00	0.00	66.00	32.00	335.00	450.00
MAX		34.00	8.80	8.80	46.00	128.00	160.00	600.00	900.00
MEAN		28.7500	7.3500	8.3364	21.0000	96.4000	90.1091	468.0000	687.5556
STDEV		2.6049	.9071	.2335	19.8696	18.5278	40.8934	94.6241	152.6844
VALIDN		8	8	11	6	11	11	8	9

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
SEPTEMBER	76	.	.	.	.	.	.	.	.
	77	.	.	7.80	.	137.90	71.00	.	.
	78	.	.	8.10	.	84.00	72.80	.	.
	79	30.00	7.00	8.30	2.00	98.00	73.20	410.00	515.00
	80	26.00	6.70	8.40	36.00	116.00	77.40	.	840.00
	81	28.00	6.60	8.80	5.00	84.00	129.00	600.00	600.00
	82	24.00	6.30	8.30	6.00	70.00	30.00	415.00	560.00
	83	29.00	8.80	8.60	0.00	78.20	70.00	410.00	615.00
	84	28.00	9.10	8.60	34.00	105.00	164.00	607.00	910.00
	85	24.00	11.30	8.70	.	108.00	160.00	597.00	895.00
	86	25.00	6.60	8.20	.	75.00	133.00	480.00	720.00
MIN		24.00	6.30	7.80	0.00	70.00	30.00	410.00	515.00
MAX		30.00	11.30	8.80	36.00	137.90	164.00	607.00	910.00
MEAN		26.7500	7.8000	8.3800	13.8333	95.6100	98.0400	502.7143	706.8750
STDEV		2.3146	1.7696	.3048	16.5459	21.3566	44.9659	95.4214	157.1155
VALIDN		8	8	10	6	10	10	7	8

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
OCTOBER	76	.	.	8.40	.	107.00	60.00	.	.
	77	.	.	8.00	.	116.60	55.00	.	.
	78	.	.	8.60	.	108.00	81.50	.	.
	79	30.00	7.10	8.10	232.00	100.00	73.60	405.00	590.00
	80	22.00	7.80	8.10	150.00	76.00	39.20	.	690.00
	81	24.00	7.30	8.60	50.00	86.00	85.00	550.00	610.00
	82	20.00	8.10	8.60	14.00	70.00	38.00	410.00	690.00
	83	23.00	6.20	8.50	2.00	79.10	80.00	460.00	640.00
	84	22.00	11.40	8.90	40.00	112.00	160.00	573.00	860.00
	85	22.00	8.20	8.50	90.00	100.00	157.00	627.00	940.00
	86	19.00	7.10	8.20	.	60.00	85.00	375.00	560.00
MIN		19.00	6.20	8.00	2.00	60.00	38.00	375.00	560.00
MAX		30.00	11.40	8.90	232.00	116.60	160.00	627.00	940.00
MEAN		22.7500	7.9000	8.4091	82.5714	92.2455	83.1182	485.7143	697.5000
STDEV		3.3274	1.5547	.2773	82.6617	18.9206	40.9498	97.3648	134.5628
VALIDN		8	8	11	7	11	11	7	8

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
NOVEMBER	76	.	.	8.20	.	114.00	49.00	.	.
	77	.	.	8.20	.	118.50	67.00	.	.
	78	19.00	.	8.25	.	97.50	84.20	413.00	550.00
	79	18.00	9.90	8.70	64.00	108.00	77.80	.	710.00
	80	19.00	9.30	8.65	40.00	72.00	75.50	.	615.00
	81	17.00	7.60	8.00	65.00	62.00	90.00	300.00	400.00
	82	14.00	10.00	8.80	16.00	77.00	34.00	200.00	700.00
	83	20.00	6.30	8.60	0.00	90.00	270.00	475.00	700.00
	84	17.00	8.10	8.60	2.00	117.00	105.00	500.00	750.00
	85	16.00	13.40	8.40	18.00	93.00	152.00	543.00	815.00
	86	12.00	7.60	8.10	.	65.80	85.00	380.00	570.00
MIN		12.00	6.30	8.00	0.00	62.00	34.00	200.00	400.00
MAX		20.00	13.40	8.80	65.00	118.50	270.00	543.00	815.00
MEAN		16.8889	9.0250	8.4091	29.2857	92.2545	99.0455	401.5714	645.5556
STDEV		2.5712	2.1803	.2728	27.3905	20.7683	64.2905	120.1566	125.3855
VALIDN		9	8	11	7	11	11	7	9

MONTH	YEAR	TEMPERATURE DEGREES C	DISSOLVED OXYGEN MG/L	PH S.U.	FECAL COLIFORM #/100 ML	CHLORIDE MG/L	SULFATE MG/L	TOTAL DISSOLVED SOLIDS MG/L	SPECIFIC CONDUCTANCE UMHOS/CM @ 25C
DECEMBER	76	.	.	8.30	.	107.00	62.70	.	.
	77	.	.	8.20	.	120.50	65.50	.	.
	78	13.00	.	8.50	.	101.60	79.00	.	620.00
	79	12.00	10.20	8.60	22.00	116.00	.	.	790.00
	80	12.00	9.70	8.40	34.00	76.00	83.90	.	610.00
	81	8.00	10.10	8.30	53.00	52.00	73.00	340.00	425.00
	82	12.00	9.30	8.50	.	70.00	32.00	203.00	700.00
	83	11.00	7.70	8.40	0.00	90.00	120.00	435.00	700.00
	84	12.00	11.90	8.50	0.00	96.00	101.00	483.00	725.00
	85	13.00	10.70	8.40	28.00	95.00	130.00	576.00	850.00
	86	11.00	8.90	8.30	50.00	60.00	78.00	370.00	555.00
MIN		8.00	7.70	8.20	0.00	52.00	32.00	203.00	425.00
MAX		13.00	11.90	8.60	53.00	120.50	130.00	576.00	850.00
MEAN		11.5556	9.8125	8.4000	26.7143	89.4636	82.5100	401.1667	663.8889
STDEV		1.5092	1.2506	.1183	21.3597	22.4224	28.5983	128.3673	127.7883
VALIDN		9	8	11	7	11	10	6	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
JANUARY	76	.	.	0.00	0.00	0.00	0.00	0.00
	77	.20	.	0.00	0.00	0.00	0.00	0.00
	78	.37	.	0.00	0.00	0.00	0.00	.02
	79	.24	.	0.00	0.00	0.00	0.00	0.00
	80	.25	.80	0.00	0.00	0.00	.01	.03
	81	.37	4.00	.01	0.00	0.00	.01	.01
	82	.28	9.00	.	.	.	.	.
	83	.24	.73	0.00	.04	0.00	.04	.03
	84	.03	4.50	0.00	0.00	0.00	0.00	.01
	85	.34	5.20	0.00	0.00	0.00	0.00	0.00
	86	.24	4.80	.	.	.	.	.
	87	.28	6.60	.	.	.	.	.
MIN		.03	.73	0.00	0.00	0.00	0.00	0.00
MAX		.37	9.00	.01	.04	0.00	.04	.03
MEAN		.2582	4.4537	.0011	.0044	0.000	.0067	.0113
STDEV		.0944	2.7614	.0033	.0133	0.000	.0132	.0125
VALIDN		11	8	9	9	9	9	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
FEBRUARY	76	.20	*	0.00	.10	0.00	0.00	0.00
	77	.25	*	0.00	0.00	0.00	0.00	.00
	78	.33	*	0.00	0.00	0.00	0.00	0.00
	79	.27	*	0.00	0.00	0.00	0.00	0.00
	80	.33	.30	0.00	0.00	0.00	.01	0.00
	81	.30	3.70	0.00	0.00	0.00	.01	.02
	82	.20	6.50	*	*	*	*	*
	83	.62	6.14	0.00	.01	.01	.02	.03
	84	.21	8.00	0.00	0.00	0.00	0.00	.04
	85	.20	5.60	0.00	0.00	0.00	0.00	0.00
	86	.28	4.20	*	*	*	*	*
MIN		.20	.30	0.00	0.00	0.00	0.00	0.00
MAX		.62	8.00	0.00	.10	.01	.02	.04
MEAN		.2900	4.9200	0.000	.0122	.0011	.0044	.0102
STDEV		.1204	2.4928	0.000	.0331	.0033	.0073	.0155
VALIDN		11	7	9	9	9	9	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
MARCH	76	0.00	*	.03	.02	0.00	0.00	0.00
	77	.22	*	0.00	0.00	0.00	0.00	0.00
	78	*	*	*	*	*	*	*
	79	.23	*	0.00	0.00	0.00	0.00	0.00
	80	.28	.10	0.00	0.00	0.00	.02	.10
	81	.35	5.10	*	0.00	.01	.01	.02
	82	.24	6.00	*	*	*	*	*
	83	0.00	4.46	1.70	.20	0.00	0.00	0.00
	84	.26	7.20	0.00	0.00	0.00	0.00	.09
	85	.23	3.60	*	*	*	*	*
	86	.26	3.60	*	*	*	*	*
MIN		0.00	.10	0.00	0.00	0.00	0.00	0.00
MAX		.35	7.20	1.70	.20	.01	.02	.10
MEAN		.2070	4.2943	.2883	.0314	.0014	.0043	.0304
STDEV		.1152	2.2578	.6917	.0747	.0038	.0079	.0450
VALIDN		10	7	6	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
APRIL	76	.29	*	.02	.03	0.00	0.00	0.00
	77	.28	*	0.00	0.00	0.00	0.00	.30
	78	*	*	*	*	*	*	*
	79	0.00	*	0.00	0.00	0.00	0.00	0.00
	80	.31	1.90	0.00	0.00	0.00	.02	0.00
	81	.45	2.40	0.00	0.00	0.00	.01	0.00
	82	.23	4.90	*	*	*	*	*
	83	.32	3.60	0.00	0.00	0.00	0.00	0.00
	84	.33	7.40	0.00	0.00	0.00	0.00	.10
	85	.28	.80	*	*	*	*	*
	86	.30	.40	*	*	*	*	*
MIN		0.00	.40	0.00	0.00	0.00	0.00	0.00
MAX		.45	7.40	.02	.03	0.00	.02	.30
MEAN		.2790	3.0571	.0029	.0043	0.000	.0043	.0571
STDEV		.1132	2.4657	.0076	.0113	0.000	.0079	.1134
VALIDN		10	7	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
MAY	76	.26	*	.06	.02	0.00	0.00	0.00
	77	.24	*	0.00	0.00	0.00	0.00	0.00
	78	.35	*	0.00	0.00	0.00	0.00	0.00
	79	0.00	*	0.00	0.00	0.00	0.00	0.00
	80	.30	1.50	.01	0.00	0.00	.01	0.00
	81	.36	2.80	0.00	0.00	.01	0.00	.02
	82	.31	3.90	*	*	*	*	*
	83	.36	.50	0.00	0.00	0.00	0.00	0.00
	84	.26	.80	0.00	0.00	0.00	0.00	0.00
	85	.30	2.60	*	*	*	*	*
	86	.30	1.30	*	*	*	*	*
MIN		0.00	.50	0.00	0.00	0.00	0.00	0.00
MAX		.36	3.90	.06	.02	.01	.01	.02
MEAN		.2759	1.9143	.0087	.0025	.0013	.0013	.0025
STDEV		.1003	1.2240	.0210	.0071	.0035	.0035	.0071
VALIDN		11	7	8	8	8	8	8

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
JUNE	76	.29	*	0.00	0.00	.01	0.00	0.00
	77	.26	*	0.00	0.00	0.00	0.00	0.00
	78	.22	*	0.00	0.00	0.00	0.00	.20
	79	.20	*	0.00	0.00	0.00	0.00	0.00
	80	.28	2.20	0.00	0.00	0.00	0.00	0.00
	81	.40	4.40	*	*	*	*	*
	82	.50	.75	*	*	*	*	*
	83	.49	.79	0.00	0.00	.10	0.00	0.00
	84	.39	3.00	0.00	0.00	0.00	0.00	.10
	85	.25	5.60	*	*	*	*	*
	86	.30	5.00	*	*	*	*	*
MIN		.20	.75	0.00	0.00	0.00	0.00	0.00
MAX		.50	5.60	0.00	0.00	.10	0.00	.20
MEAN		.3256	3.1057	0.000	0.000	.0157	0.000	.0429
STDEV		.1038	1.9676	0.000	0.000	.0374	0.000	.0787
VALIDN		11	7	7	7	7	7	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
JULY	76	.20	*	0.00	.01	.01	0.00	.01
	77	.27	*	0.00	0.00	0.00	0.00	.26
	78	.38	*	0.00	0.00	0.00	0.00	0.00
	79	0.00	4.60	0.00	0.00	0.00	0.00	0.00
	80	.50	4.30	.01	0.00	0.00	0.00	.03
	81	.68	.40	*	*	*	*	*
	82	.30	.74	*	*	*	*	*
	83	.82	5.10	0.00	0.00	0.00	0.00	.50
	84	.45	4.80	0.00	0.00	0.00	0.00	.20
	85	.12	7.20	*	*	*	*	*
	86	.33	6.80	*	*	*	*	*
MIN		0.00	.40	0.00	0.00	0.00	0.00	0.00
MAX		.82	7.20	.01	.01	.01	0.00	.50
MEAN		.3685	4.2425	.0014	.0014	.0014	0.000	.1424
STDEV		.2381	2.4928	.0038	.0038	.0038	0.000	.1899
VALIDN		11	8	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
AUGUST	76	.27	*	0.00	.02	0.00	0.00	.03
	77	.76	*	0.00	0.00	0.00	0.00	1.62
	78	.28	*	0.00	0.00	0.00	0.00	0.00
	79	0.00	2.80	0.00	0.00	0.00	0.00	0.00
	80	.45	2.10	.02	0.00	.01	.02	.03
	81	.27	5.50	*	*	*	*	*
	82	.19	.84	*	*	*	*	*
	83	.11	7.80	0.00	0.00	0.00	0.00	0.00
	84	.38	5.20	0.00	0.00	0.00	0.00	0.00
	85	.20	7.00	*	*	*	*	*
	86	.36	6.80	*	*	*	*	*
MIN		0.00	.84	0.00	0.00	0.00	0.00	0.00
MAX		.76	7.80	.02	.02	.01	.02	1.62
MEAN		.2970	4.7550	.0029	.0029	.0014	.0029	.2396
STDEV		.1987	2.5480	.0076	.0076	.0038	.0076	.6089
VALIDN		11	8	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
SEPTEMBER	76	*	*	*	*	*	*	*
	77	.35	*	0.00	0.00	0.00	0.00	.24
	78	.25	*	0.00	0.00	0.00	0.00	0.00
	79	.31	2.10	0.00	0.00	0.00	.02	.04
	80	.53	.70	0.00	0.00	0.00	.01	0.00
	81	.35	4.00	*	*	*	*	*
	82	.29	.85	*	*	*	*	*
	83	.60	9.00	0.00	0.00	0.00	0.00	0.00
	84	.39	7.40	0.00	0.00	0.00	0.00	0.00
	85	.26	6.10	*	*	*	*	*
	86	.40	7.90	*	*	*	*	*
MIN		.25	.70	0.00	0.00	0.00	0.00	0.00
MAX		.60	9.00	0.00	0.00	0.00	.02	.24
MEAN		.3728	4.7563	0.000	0.000	0.000	.0050	.0473
STDEV		.1143	3.2956	0.000	0.000	0.000	.0084	.0968
VALIDN		10	8	6	6	6	6	6

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
OCTOBER	76	.24	*	0.00	0.00	0.00	0.00	0.00
	77	.38	*	0.00	0.00	0.00	0.00	.02
	78	.28	*	0.00	0.00	0.00	.05	.01
	79	.30	2.70	0.00	0.00	0.00	0.00	.06
	80	.29	4.20	.01	0.00	0.00	.01	*
	81	.22	3.40	*	*	*	*	*
	82	.15	.82	*	*	*	*	*
	83	.80	13.00	0.00	0.00	0.00	0.00	0.00
	84	.50	6.00	0.00	0.00	0.00	0.00	0.00
	85	.25	6.60	*	*	*	*	*
	86	.32	7.00	*	*	*	*	*
MIN		.15	.82	0.00	0.00	0.00	0.00	0.00
MAX		.80	13.00	.01	0.00	0.00	.05	.06
MEAN		.3388	5.4650	.0014	0.000	0.000	.0086	.0153
STDEV		.1774	3.6993	.0038	0.000	0.000	.0186	.0249
VALIDN		11	8	7	7	7	7	6

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
NOVEMBER	76	.26	*	0.00	0.00	0.00	0.00	0.00
	77	.36	*	0.00	0.00	0.00	0.00	.03
	78	.27	*	0.00	0.00	0.00	0.00	.02
	79	.38	2.60	0.00	0.00	0.00	0.00	.01
	80	.30	2.10	0.00	0.00	0.00	.01	0.00
	81	.32	1.76	*	*	*	*	*
	82	0.00	.87	*	*	*	*	*
	83	.14	12.70	0.00	0.00	0.00	0.00	.10
	84	.10	5.80	0.00	0.00	0.00	0.00	0.00
	85	.24	6.40	*	*	*	*	*
	86	.18	7.60	*	*	*	*	*
MIN		0.00	.87	0.00	0.00	0.00	0.00	0.00
MAX		.38	12.70	0.00	0.00	0.00	.01	.10
MEAN		.2314	4.9788	0.000	0.000	0.000	.0014	.0231
STDEV		.1162	3.9708	0.000	0.000	0.000	.0038	.0360
VALIDN		11	8	7	7	7	7	7

MONTH	YEAR	FLUORIDE MG/L AS	DISSOLVED SILICA MG/L AS SIO2	TOTAL CHROMIUM MG/L AS CR	TOTAL COPPER MG/L AS CU	TOTAL NICKEL MG/L AS NI	TOTAL LEAD MG/L AS PB	TOTAL ZINC MG/L AS ZN
DECEMBER	76	.22	.	0.00	.30	0.00	0.00	0.00
	77	.40	.	0.00	0.00	0.00	0.00	.01
	78	.25	.	0.00	0.00	0.00	0.00	.07
	79	.34	.	0.00	0.00	0.00	0.00	.05
	80	.32	3.00	0.00	0.00	.01	.01	0.00
	81	.02	6.70	.	.	.	.	.
	82	.26	.78	.	.	.	.	.
	83	.60	8.70	0.00	0.00	0.00	0.00	.09
	84	.29	6.00	0.00	.20	0.00	0.00	0.00
	85	.26	6.40	.	.	.	.	.
	86	.22	7.40	.	.	.	.	.
MIN		.02	.78	0.00	0.00	0.00	0.00	0.00
MAX		.60	8.70	0.00	.30	.01	.01	.09
MEAN		.2882	5.5686	0.000	.0714	.0014	.0014	.0320
STDEV		.1404	2.7339	0.000	.1254	.0038	.0038	.0380
VALIDN		11	7	7	7	7	7	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
JANUARY	76	.05	*	*	0.00	*	1634.00
	77	0.00	*	*	0.00	*	1633.00
	78	0.00	*	*	0.00	*	1627.00
	79	0.00	0.00	*	0.00	*	1626.00
	80	.01	0.00	*	0.00	*	1622.00
	81	.43	0.00	*	0.00	.74	1625.00
	82	*	*	*	*	.29	1635.00
	83	*	*	*	0.00	.60	1631.00
	84	.18	0.00	*	0.00	0.00	1625.00
	85	.60	0.00	*	0.00	*	1624.00
	86	*	*	*	*	.74	*
	87	*	*	*	*	.40	*
MIN		0.00	0.00	*	0.00	0.00	1622.00
MAX		.60	0.00	*	0.00	.74	1635.00
MEAN		.1588	0.000	*	0.000	.4617	1628.2000
STDEV		.2325	0.000	*	0.000	.2900	4.6380
VALIDN		8	5	0	9	6	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
JANUARY	76	.05	*	*	0.00	*	1634.00
	77	0.00	*	*	0.00	*	1633.00
	78	0.00	*	*	0.00	*	1627.00
	79	0.00	0.00	*	0.00	*	1626.00
	80	.01	0.00	*	0.00	*	1622.00
	81	.43	0.00	*	0.00	.74	1625.00
	82	*	*	*	*	.29	1635.00
	83	*	*	*	0.00	.60	1631.00
	84	.18	0.00	*	0.00	0.00	1625.00
	85	.60	0.00	*	0.00	*	1624.00
	86	*	*	*	*	.74	*
	87	*	*	*	*	.40	*
MIN		0.00	0.00	*	0.00	0.00	1622.00
MAX		.60	0.00	*	0.00	.74	1635.00
MEAN		.1588	0.000	*	0.000	.4617	1628.2000
STDEV		.2325	0.000	*	0.000	.2900	4.6380
VALIDN		8	5	0	9	6	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
FEBRUARY	76	.12	*	*	0.00	*	1633.00
	77	.10	*	*	0.00	*	1633.00
	78	.05	*	*	0.00	*	1626.00
	79	0.00	0.00	*	0.00	*	1626.00
	80	.01	0.00	*	0.00	*	1621.00
	81	.47	0.00	*	0.00	.13	1626.00
	82	*	*	*	*	.38	1634.00
	83	*	*	*	.02	.33	1631.00
	84	.13	0.00	*	0.00	*	1625.00
	85	.50	0.00	*	0.00	.08	1624.00
	86	*	*	*	*	.50	*
MIN		0.00	0.00	*	0.00	.08	1621.00
MAX		.50	0.00	*	.02	.50	1634.00
MEAN		.1725	0.000	*	.0022	.2840	1627.9000
STDEV		.1988	0.000	*	.0067	.1756	4.4833
VALIDN		8	5	0	9	6	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
MARCH	76	.16	*	*	0.00	*	1633.00
	77	.50	*	*	0.00	*	1632.00
	78	*	*	*	*	*	*
	79	0.00	0.00	*	0.00	*	1625.00
	80	.14	0.00	*	0.00	*	1620.00
	81	.97	0.00	*	0.00	.66	1626.00
	82	*	*	*	*	.36	1633.00
	83	0.00	*	*	0.00	.75	1631.00
	84	1.20	0.00	*	0.00	*	1625.00
	85	*	*	*	*	.45	1626.00
	86	*	*	*	*	.36	*
MIN		0.00	0.00	*	0.00	.36	1620.00
MAX		1.20	0.00	*	0.00	.75	1633.00
MEAN		.4243	0.000	*	0.000	.5160	1627.8889
STDEV		.4858	0.000	*	0.000	.1792	4.5399
VALIDN		7	4	0	7	5	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
APRIL	76	.14	*	*	0.00	*	1632.00
	77	0.00	*	*	0.00	*	1634.00
	78	.32	*	*	*	*	*
	79	0.00	0.00	*	0.00	*	1629.00
	80	0.00	0.00	*	0.00	1.01	1619.00
	81	.62	0.00	*	0.00	.45	1625.00
	82	*	*	*	*	.37	1632.00
	83	0.00	*	*	0.00	.60	1630.00
	84	.90	0.00	*	0.00	*	1624.00
	85	*	*	*	*	.07	1626.00
	86	*	*	*	*	.56	*
MIN		0.00	0.00	*	0.00	.07	1619.00
MAX		.90	0.00	*	0.00	1.01	1634.00
MEAN		.2475	0.000	*	0.000	.5100	1627.8889
STDEV		.3436	0.000	*	0.000	.3090	4.7813
VALIDN		8	4	0	7	6	9

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
MAY	76	.40	*	*	0.00	*	1632.00
	77	.40	*	*	0.00	*	1635.00
	78	0.00	*	*	0.00	*	1617.00
	79	0.00	0.00	*	0.00	*	1630.00
	80	.01	0.00	*	0.00	.99	1619.00
	81	.41	0.00	*	0.00	.59	1628.00
	82	*	*	*	*	.36	1635.00
	83	*	*	*	0.00	.78	1629.00
	84	0.00	0.00	*	0.00	*	1623.00
	85	*	*	*	*	.56	1627.00
	86	*	*	*	*	.35	*
MIN		0.00	0.00	*	0.00	.35	1617.00
MAX		.41	0.00	*	0.00	.99	1635.00
MEAN		.1743	0.000	*	0.000	.6050	1627.5000
STDEV		.2143	0.000	*	0.000	.2474	6.1869
VALIDN		7	4	0	8	8	10

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
JUNE	76	0.00	*	*	0.00	*	1631.00
	77	0.00	*	*	0.00	*	1633.00
	78	0.00	*	*	0.00	*	1622.00
	79	0.00	0.00	*	0.00	*	1629.00
	80	*	0.00	*	0.00	.68	1622.00
	81	*	*	*	*	.51	1630.00
	82	*	*	*	*	.61	1636.00
	83	0.00	*	*	0.00	.73	1629.00
	84	.80	0.00	*	0.00	.80	1620.00
	85	*	*	*	*	.76	1630.00
	86	*	*	*	*	0.00	*
MIN		0.00	0.00	*	0.00	0.00	1620.00
MAX		.80	0.00	*	0.00	.80	1636.00
MEAN		.1333	0.000	*	0.000	.5843	1628.2000
STDEV		.3266	0.000	*	0.000	.2755	5.2026
VALIDN		6	3	0	7	7	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
JULY	76	.63	*	*	0.00	*	1630.00
	77	0.00	*	*	0.00	*	1632.00
	78	.51	*	*	0.00	*	1620.00
	79	0.00	0.00	*	0.00	*	1629.00
	80	.50	0.00	*	0.00	1.08	1619.00
	81	*	*	*	*	.82	1632.00
	82	*	*	*	*	.30	1634.00
	83	*	*	*	0.00	1.47	1628.00
	84	.50	0.00	*	0.00	*	1619.00
	85	*	*	*	*	.60	1629.00
	86	*	*	*	*	.48	*
MIN		0.00	0.00	*	0.00	.30	1619.00
MAX		.63	0.00	*	0.00	1.47	1634.00
MEAN		.3567	0.000	*	0.000	.7917	1627.2000
STDEV		.2806	0.000	*	0.000	.4289	5.7116
VALIDN		6	3	0	7	6	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
AUGUST	76	.04	*	*	0.00	*	1630.00
	77	0.00	*	*	0.00	*	1631.00
	78	0.00	*	*	0.00	*	1629.00
	79	0.00	0.00	*	0.00	*	1626.00
	80	1.31	0.00	*	0.00	1.13	1617.00
	81	*	*	*	*	.77	1630.00
	82	*	*	*	*	.73	1635.00
	83	0.00	*	*	0.00	.60	1628.00
	84	0.00	0.00	*	0.00	*	1617.00
	85	*	*	*	*	.69	1629.00
	86	*	*	*	*	.38	*
MIN		0.00	0.00	*	0.00	.38	1617.00
MAX		1.31	0.00	*	0.00	1.13	1635.00
MEAN		.1929	0.000	*	0.000	.7167	1627.2000
STDEV		.4928	0.000	*	0.000	.2456	5.8462
VALIDN		7	3	0	7	6	10

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
SEPTEMBER	76	*	*	*	*	*	*
	77	.13	*	*	0.00	*	1630.00
	78	0.00	*	*	0.00	*	1628.00
	79	0.00	0.00	*	0.00	*	1623.00
	80	0.00	0.00	*	0.00	.91	1615.00
	81	*	*	*	*	.26	1627.00
	82	*	*	*	*	.35	1633.00
	83	.60	0.00	*	0.00	*	1626.00
	84	0.00	0.00	*	0.00	*	1616.00
	85	*	*	*	*	.40	1628.00
	86	*	*	*	*	.38	*
MIN		0.00	0.00	*	0.00	.26	1615.00
MAX		.60	0.00	*	0.00	.91	1633.00
MEAN		.1217	0.000	*	0.000	.4600	1625.1111
STDEV		.2400	0.000	*	0.000	.2572	6.0919
VALIDN		6	4	0	6	5	9

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
OCTOBER	76	.20	*	*	0.00	*	1631.00
	77	.16	*	*	0.00	*	1629.00
	78	.07	*	*	0.00	*	1628.00
	79	0.00	0.00	*	0.00	*	1623.00
	80	.46	0.00	*	0.00	.60	1625.00
	81	*	*	*	*	.56	1636.00
	82	*	*	*	*	.86	1632.00
	83	.10	0.00	*	0.00	*	1625.00
	84	0.00	0.00	*	0.00	*	1616.00
	85	*	*	*	*	.66	*
	86	*	*	*	*	.25	*
MIN		0.00	0.00	*	0.00	.25	1616.00
MAX		.46	0.00	*	0.00	.86	1636.00
MEAN		.1414	0.000	*	0.000	.5860	1627.2222
STDEV		.1592	0.000	*	0.000	.2204	5.8262
VALIDN		7	4	0	7	5	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
NOVEMBER	76	.80	*	*	0.00	*	1633.00
	77	0.00	*	*	0.00	*	1628.00
	78	.20	*	*	0.00	*	1627.00
	79	.06	0.00	*	0.00	*	1623.00
	80	.17	0.00	*	0.00	.53	1625.00
	81	*	*	*	*	.36	1637.00
	82	*	*	*	*	.77	1632.00
	83	.51	0.00	*	0.00	*	1626.00
	84	.60	0.00	*	0.00	*	1620.00
	85	*	*	*	*	*	*
	86	*	*	*	*	.16	*
MIN		0.00	0.00	*	0.00	.16	1620.00
MAX		.80	0.00	*	0.00	.77	1637.00
MEAN		.3343	0.000	*	0.000	.4550	1627.8889
STDEV		.3029	0.000	*	0.000	.2588	5.3020
VALIDN		7	4	0	7	4	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TOTAL IRON MG/L AS FE	TOTAL SILVER MG/L AS AG	TOTAL BARIUM MG/L AS BA	TOTAL CADMIUM MG/L AS CD	BROMIDE MG/L AS BR	LAKE ELEV ON SAMPLING DATE FMSL
DECEMBER	76	.20	*	*	0.00	*	1633.00
	77	.23	*	*	0.00	*	1627.00
	78	0.00	*	*	0.00	*	1627.00
	79	.02	0.00	*	0.00	*	1622.00
	80	.31	0.00	*	0.00	.61	1626.00
	81	*	*	*	*	.32	1634.00
	82	*	*	*	*	1.60	1632.00
	83	.74	0.00	*	0.00	*	1626.00
	84	.70	0.00	*	0.00	*	1620.00
	85	*	*	*	*	.44	*
	86	*	*	*	*	.23	*
MIN		0.00	0.00	*	0.00	.23	1620.00
MAX		.74	0.00	*	0.00	1.60	1634.00
MEAN		.3143	0.000	*	0.000	.6400	1627.4444
STDEV		.2988	0.000	*	0.000	.5552	4.7987
VALIDN		7	4	0	7	5	9

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
JANUARY	76	0.00	2.22	0.00	.40	7.50
	77	.09	.07	0.00	.24	7.20
	78	0.00	0.00	0.00	0.00	11.80
	79	0.00	0.00	0.00	0.00	8.20
	80	0.00	0.00	0.00	0.00	9.30
	81	0.00	0.00	0.00	.11	16.80
	82	.	.28	.03	.	.
	83	.	.75	0.00	.	.
	84	.40	.20	.01	.	.
	85	.07	.	.	.	7.40
	86	0.00	0.00	.	1.40	.
	87	0.00	0.00	.	0.00	.
MIN		0.00	0.00	0.00	0.00	7.20
MAX		.40	2.22	.03	1.40	16.80
MEAN		.0562	.3199	.0044	.2690	9.7429
STDEV		.1255	.6699	.0101	.4798	3.5023
VALIDN		10	11	9	8	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
FEBRUARY	76	0.00	.03	0.00	.20	11.00
	77	.09	.08	0.00	0.00	8.84
	78	0.00	.37	0.00	.70	8.48
	79	0.00	0.00	0.00	0.00	7.90
	80	0.00	0.00	0.00	0.00	7.80
	81	0.00	.45	0.00	0.00	9.30
	82	.	.30	.02	.	.
	83	.	0.00	0.00	.	.
	84	.40	.	.	.	.
	85	.23	0.00	.06	.	7.80
	86	0.00	0.00	.	.60	.
MIN		0.00	0.00	0.00	0.00	7.80
MAX		.40	.45	.06	.70	11.00
MEAN		.0802	.1224	.0089	.2143	8.7314
STDEV		.1429	.1783	.0203	.3078	1.1526
VALIDN		9	10	9	7	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
MARCH	76	.15	.28	0.00	.25	4.30
	77	0.00	.11	.03	.15	8.00
	78	.	.	.	.	.
	79	0.00	0.00	.05	0.00	7.40
	80	0.00	0.00	0.00	0.00	8.80
	81	0.00	0.00	0.00	.33	7.10
	82	.	.24	.03	.	.
	83	.	0.00	.01	.	.
	84	0.00	.	.	.	.
	85	.02	0.00	.08	.	.
	86	0.00	0.00	.	1.40	.
MIN		0.00	0.00	0.00	0.00	4.30
MAX		.15	.28	.08	1.40	8.80
MEAN		.0216	.0705	.0244	.3550	7.1200
STDEV		.0535	.1144	.0287	.5287	1.7050
VALIDN		8	9	8	6	5

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
APRIL	76	.15	.14	0.00	.51	12.00
	77	.06	.32	.04	.30	6.60
	78	0.00	0.00	.	.	.
	79	0.00	.23	0.00	0.00	6.90
	80	0.00	0.00	0.00	0.00	8.90
	81	0.00	0.00	0.00	.	7.70
	82	.	.38	0.00	.	.
	83	.	.20	.01	.	.
	84	.31	.	.	.	.
	85	.01	.10	.05	.	.
	86	0.00	0.00	.	1.60	.
MIN		0.00	0.00	0.00	0.00	6.60
MAX		.31	.38	.05	1.60	12.00
MEAN		.0593	.1374	.0129	.4822	8.4200
STDEV		.1070	.1426	.0211	.6611	2.1902
VALIDN		9	10	8	5	5

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
MAY	76	.25	.14	0.00	.10	8.60
	77	0.00	.29	.05	.39	7.95
	78	0.00	*	0.00	*	8.60
	79	0.00	0.00	0.00	.20	7.30
	80	0.00	0.00	0.00	0.00	9.70
	81	0.00	.20	.02	*	7.40
	82	*	.60	0.00	*	*
	83	0.00	0.00	0.00	*	0.00
	84	*	*	*	*	*
	85	.15	.15	.07	*	*
	86	0.00	0.00	*	.70	*
MIN		0.00	0.00	0.00	0.00	0.00
MAX		.25	.60	.07	.70	9.70
MEAN		.0439	.1533	.0159	.2768	7.0786
STDEV		.0903	.1985	.0270	.2766	3.2280
VALIDN		9	9	9	5	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
MAY	76	.25	.14	0.00	.10	8.60
	77	0.00	.29	.05	.39	7.95
	78	0.00	.	0.00	.	8.60
	79	0.00	0.00	0.00	.20	7.30
	80	0.00	0.00	0.00	0.00	9.70
	81	0.00	.20	.02	.	7.40
	82	.	.60	0.00	.	.
	83	0.00	0.00	0.00	.	0.00
	84	.	.	.	.	.
	85	.15	.15	.07	.	.
	86	0.00	0.00	.	.70	.
MIN		0.00	0.00	0.00	0.00	0.00
MAX		.25	.60	.07	.70	9.70
MEAN		.0439	.1533	.0159	.2768	7.0786
STDEV		.0903	.1985	.0270	.2766	3.2280
VALIDN		9	9	9	5	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
JUNE	76	.03	.11	.03	.08	24.00
	77	.03	.23	0.00	0.00	7.70
	78	*	*	*	*	10.40
	79	0.00	.29	.03	0.00	6.70
	80	0.00	0.00	0.00	0.00	8.80
	81	0.00	.53	0.00	*	*
	82	*	.70	.01	*	*
	83	.90	0.00	.02	*	.90
	84	0.00	0.00	.10	*	*
	85	0.00	.10	*	1.34	*
	86	0.00	0.00	*	1.10	*
MIN		0.00	0.00	0.00	0.00	.90
MAX		.90	.70	.10	1.34	24.00
MEAN		.1068	.1955	.0245	.4192	9.7500
STDEV		.2978	.2464	.0333	.6256	7.6969
VALIDN		9	10	8	6	6

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
JULY	76	.03	.10	.03	.07	26.00
	77	0.00	.07	0.00	0.00	9.18
	78	0.00	.34	0.00	.	10.90
	79	0.00	0.00	0.00	.22	7.40
	80	0.00	0.00	0.00	0.00	11.30
	81	0.00	.40	.05	.	.
	82	.	.22	0.00	.	.
	83	.20	.20	.01	.	.20
	84	.07	.	.	.	.
	85	.01	0.00	0.00	3.40	.
	86	0.00	0.00	.	.40	.
MIN		0.00	0.00	0.00	0.00	.20
MAX		.20	.40	.05	3.40	26.00
MEAN		.0310	.1326	.0100	.6822	10.8300
STDEV		.0635	.1500	.0180	1.3403	8.4598
VALIDN		10	10	9	6	6

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
AUGUST	76	.03	.12	.04	.07	9.00
	77	0.00	.58	.17	.36	8.65
	78	0.00	.15	.01	.92	10.60
	79	0.00	0.00	0.00	0.00	7.30
	80	0.00	0.00	0.00	.11	9.70
	81	*	.60	0.00	*	*
	82	*	0.00	.01	*	*
	83	.20	0.00	0.00	*	.20
	84	0.00	*	*	*	11.20
	85	0.00	0.00	0.00	*	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	.20
MAX		.20	.60	.17	.92	11.20
MEAN		.0257	.1456	.0257	.2433	8.0929
STDEV		.0662	.2410	.0556	.3571	3.7099
VALIDN		9	10	9	6	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
SEPTEMBER	76	*	*	*	*	*
	77	0.00	1.71	0.00	0.00	8.13
	78	0.00	.35	0.00	.19	7.40
	79	0.00	0.00	0.00	0.00	7.40
	80	0.00	0.00	0.00	0.00	9.80
	81	*	.37	.01	*	*
	82	*	0.00	0.00	*	*
	83	*	*	*	*	*
	84	0.00	*	*	*	10.70
	85	0.00	0.00	0.00	*	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	7.40
MAX		0.00	1.71	.01	.19	10.70
MEAN		0.000	.3034	.0014	.0380	8.6860
STDEV		0.000	.5894	.0038	.0850	1.4928
VALIDN		7	8	7	5	5

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
OCTOBER	76	0.00	.01	.03	0.00	9.20
	77	0.00	.10	0.00	1.28	8.27
	78	0.00	.19	0.00	.22	8.30
	79	0.00	0.00	0.00	0.00	8.50
	80	0.00	.32	.03	0.00	11.50
	81	*	.61	0.00	*	*
	82	*	.20	.01	*	*
	83	*	*	*	*	*
	84	.08	*	*	*	8.00
	85	0.00	0.00	0.00	*	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	8.00
MAX		.08	.61	.03	1.28	11.50
MEAN		.0100	.1590	.0091	.2500	8.9617
STDEV		.0283	.2044	.0143	.5122	1.3080
VALIDN		8	9	8	6	6

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
NOVEMBER	76	.18	.34	.04	.41	5.60
	77	.01	*	0.00	.12	9.55
	78	0.00	.75	0.00	.40	8.70
	79	0.00	0.00	0.00	0.00	8.40
	80	0.00	0.00	0.00	0.00	10.50
	81	*	.51	0.00	*	*
	82	*	.78	.01	*	*
	83	.65	*	*	*	*
	84	.11	*	*	*	5.20
	85	.10	0.00	*	.60	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	5.20
MAX		.65	.78	.04	.60	10.50
MEAN		.1171	.2980	.0071	.2186	7.9917
STDEV		.2107	.3462	.0150	.2477	2.1402
VALIDN		9	8	7	7	6

MONTH	YEAR	DISSOLVED ORTHO-P MG/L AS P	NITRATE NITROGEN MG/L AS N	NITRITE NITROGEN MG/L AS N	AMMONIA NITROGEN MG/L AS N	POTASSIUM MG/L AS K
DECEMBER	76	0.00	.29	.06	.17	5.96
	77	0.00	.53	0.00	0.00	8.55
	78	0.00	0.00	0.00	0.00	8.80
	79	*	*	*	*	7.70
	80	0.00	0.00	0.00	0.00	10.50
	81	*	.37	.04	*	*
	82	*	0.00	.02	*	*
	83	.10	*	*	*	6.80
	84	.36	*	*	*	8.00
	85	0.00	0.00	*	.70	*
	86	0.00	0.00	*	0.00	*
MIN		0.00	0.00	0.00	0.00	5.96
MAX		.36	.53	.06	.70	10.50
MEAN		.0575	.1489	.0205	.1447	8.0443
STDEV		.1271	.2155	.0266	.2802	1.4646
VALIDN		8	8	6	6	7

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
JANUARY	76	.	152.00	240.00	52.00	22.30	48.50	0.00
	77	.	124.00	228.00	37.00	43.00	54.20	0.00
	78	.	163.00	270.00	51.80	34.60	88.70	0.00
	79	.	150.00	212.00	62.00	14.00	75.00	0.00
	80	30.00	153.00	226.00	55.00	21.00	94.00	0.00
	81	120.00	141.00	220.00	54.00	21.00	67.00	.01
	82	17.00	141.00	190.00	62.00	9.00	48.00	.
	83	6.80	195.00	214.00	53.70	13.00	43.70	.
	84	4.00	92.00	159.00	43.00	13.00	64.20	.
	85	19.00	90.00	212.00	.	.	57.00	.
	86	4.90	125.00	270.00	67.40	24.80	.	.
	87	10.00	124.00	200.00	.	.	.	.
MIN		4.00	90.00	159.00	37.00	9.00	43.70	0.00
MAX		120.00	195.00	270.00	67.40	43.00	94.00	.01
MEAN		26.4625	137.5000	220.0833	53.7900	21.5700	64.0300	.0017
STDEV		38.7927	29.2870	31.1666	8.9879	10.5559	17.2996	.0041
VALIDN		8	12	12	10	10	10	6

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
FEBRUARY	76	*	145.00	245.00	77.00	24.00	61.50	0.00
	77	*	135.00	210.00	58.00	20.00	56.00	0.00
	78	*	167.00	270.00	50.30	31.60	79.70	*
	79	*	143.00	210.00	52.00	19.00	60.00	0.00
	80	40.50	166.00	244.00	60.00	23.00	63.00	0.00
	81	26.00	142.00	226.00	56.00	21.00	50.00	.01
	82	28.00	130.00	168.00	60.00	4.00	*	*
	83	5.60	195.00	232.00	65.00	17.00	50.60	*
	84	11.00	147.00	238.00	63.40	19.40	48.60	*
	85	16.00	120.00	236.00	57.70	22.40	59.00	*
	86	13.00	130.00	272.00	65.00	27.00	*	*
MIN		5.60	120.00	168.00	50.30	4.00	48.60	0.00
MAX		40.50	195.00	272.00	77.00	31.60	79.70	.01
MEAN		20.0143	147.2727	231.9091	60.4000	20.7636	58.7111	.0020
STDEV		12.0665	21.3546	29.1700	7.2951	6.8939	9.4849	.0045
VALIDN		7	11	11	11	11	9	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
MARCH	76	*	168.00	210.00	48.00	24.00	45.00	0.00
	77	*	133.00	220.00	42.00	26.00	60.00	0.00
	78	*	*	*	*	*	*	*
	79	*	159.00	218.00	66.00	12.00	67.00	0.00
	80	57.00	176.00	224.00	58.00	19.00	77.00	0.00
	81	105.00	150.00	268.00	74.00	24.00	57.00	.09
	82	47.00	130.00	180.00	56.00	10.00	34.00	*
	83	9.40	184.10	218.00	51.30	21.90	102.10	*
	84	34.00	153.00	238.00	52.10	26.20	123.90	*
	85	35.00	120.00	232.00	58.00	21.00	*	*
	86	35.00	134.00	274.00	86.00	15.00	*	*
MIN		9.40	120.00	180.00	42.00	10.00	34.00	0.00
MAX		105.00	184.10	274.00	86.00	26.20	123.90	.09
MEAN		46.0571	150.7100	228.2000	59.1400	19.9100	70.7500	.0180
STDEV		29.8008	21.3249	27.3650	13.0414	5.7828	29.7108	.0402
VALIDN		7	10	10	10	10	8	5

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
APRIL	76	.	180.00	240.00	50.00	30.60	56.00	0.00
	77	.	145.00	235.00	36.00	22.00	57.00	0.00
	78	.	171.00	266.00	52.00	33.00	85.00	.
	79	.	135.00	200.00	46.00	20.00	53.00	0.00
	80	74.00	204.00	260.00	85.00	12.00	64.00	0.00
	81	18.00	76.00	232.00	54.00	24.00	50.00	.01
	82	39.00	137.00	184.00	45.00	17.00	.	.
	83	64.00	154.00	218.00	59.30	14.60	57.50	.
	84	29.00	152.00	242.00	72.20	15.10	120.00	.
	85	13.00	112.00	230.00	152.00	78.00	.	.
	86	27.00	134.00	270.00	88.20	12.20	.	.
MIN		13.00	76.00	184.00	36.00	12.00	50.00	0.00
MAX		74.00	204.00	270.00	152.00	78.00	120.00	.01
MEAN		37.7143	145.4545	234.2727	67.2455	25.3182	67.8125	.0020
STDEV		23.0919	34.1244	26.5107	32.6391	18.8182	23.7034	.0045
VALIDN		7	11	11	11	11	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
MAY	76	*	152.00	248.00	46.00	28.00	58.00	0.00
	77	*	130.00	224.00	35.90	22.70	95.00	0.00
	78	*	180.00	270.00	59.20	33.20	86.10	0.00
	79	*	136.00	192.00	48.00	17.00	49.00	0.00
	80	*	182.00	256.00	65.00	23.00	72.00	0.00
	81	13.00	140.00	290.00	90.00	16.00	45.00	.02
	82	27.00	132.00	200.00	53.00	16.00	32.00	*
	83	36.00	162.00	224.00	65.80	14.60	92.00	*
	84	18.00	150.00	250.00	51.30	29.60	90.00	*
	85	28.00	126.00	264.00	66.00	24.00	*	*
	86	26.00	138.00	298.00	87.00	19.00	*	*
MIN		13.00	126.00	192.00	35.90	14.60	32.00	0.00
MAX		36.00	182.00	298.00	90.00	33.20	95.00	.02
MEAN		24.6667	148.0000	246.9091	60.6545	22.1000	68.7889	.0033
STDEV		8.0911	19.4113	34.1334	16.6285	6.2076	23.4867	.0082
VALIDN		6	11	11	11	11	9	6

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
JUNE	76	*	164.00	256.00	53.00	41.50	80.00	0.00
	77	*	152.00	184.00	55.00	23.60	45.40	0.00
	78	*	171.00	254.00	48.00	32.40	94.80	0.00
	79	*	153.00	210.00	59.00	15.00	52.00	0.00
	80	59.00	167.00	232.00	63.00	18.00	51.00	.03
	81	27.00	158.00	236.00	67.00	16.00	*	*
	82	42.00	131.00	194.00	43.00	21.00	30.00	*
	83	140.00	156.00	232.00	172.00	60.00	152.00	*
	84	10.00	164.00	296.00	80.20	23.30	80.20	*
	85	32.00	116.00	272.00	72.00	22.00	*	*
	86	63.00	128.00	240.00	68.00	17.00	*	*
MIN		10.00	116.00	184.00	43.00	15.00	30.00	0.00
MAX		140.00	171.00	296.00	172.00	60.00	152.00	.03
MEAN		53.2857	150.9091	236.9091	70.9273	26.3455	73.1750	.0060
STDEV		42.4096	17.9636	32.8678	35.2315	13.6233	38.4570	.0134
VALIDN		7	11	11	11	11	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
JULY	76	.	151.00	252.00	61.00	30.70	65.00	0.00
	77	.	158.00	241.00	46.80	27.00	71.10	.
	78	.	162.00	264.00	45.20	37.00	106.40	.05
	79	170.00	150.00	214.00	50.00	20.00	58.00	0.00
	80	57.00	190.00	246.00	58.00	24.00	61.00	.02
	81	40.00	140.00	246.00	68.00	18.00	.	.
	82	14.00	131.00	186.00	52.00	14.00	48.00	.
	83	17.00	153.00	230.00	61.80	18.50	45.00	.
	84	12.00	155.00	270.00	80.00	20.00	68.00	.
	85	13.00	124.00	270.00	72.00	22.00	.	.
	86	26.00	122.00	240.00	69.00	17.00	.	.
MIN		12.00	122.00	186.00	45.20	14.00	45.00	0.00
MAX		170.00	190.00	270.00	80.00	37.00	106.40	.05
MEAN		43.6250	148.7273	241.7273	60.3455	22.5636	65.3125	.0175
STDEV		53.4494	19.3551	25.0044	11.1947	6.7190	18.9488	.0236
VALIDN		8	11	11	11	11	8	4

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
AUGUST	76	*	142.00	240.00	53.00	35.00	71.00	0.00
	77	*	149.00	220.00	33.70	31.60	73.20	0.00
	78	*	121.00	174.00	31.00	28.00	78.20	0.00
	79	130.00	143.00	200.00	49.00	19.00	59.00	0.00
	80	120.00	170.00	246.00	58.00	24.00	63.00	.11
	81	25.00	137.00	278.00	76.00	21.00	*	*
	82	15.00	137.00	216.00	69.00	10.00	26.00	*
	83	13.00	135.00	214.00	53.70	19.40	47.00	*
	84	18.00	144.00	252.00	66.00	21.00	66.00	*
	85	14.00	136.00	274.00	70.00	24.00	*	*
	86	36.00	138.00	234.00	70.00	*	*	*
MIN		13.00	121.00	174.00	31.00	10.00	26.00	0.00
MAX		130.00	170.00	278.00	76.00	35.00	78.20	.11
MEAN		46.3750	141.0909	231.6364	57.2182	23.3000	60.4250	.0220
STDEV		49.1788	11.9202	31.0718	14.9474	7.0712	16.8863	.0492
VALIDN		8	11	11	11	10	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
SEPTEMBER	76	.	.	.	.	.	.	.
	77	.	125.00	250.00	39.50	20.10	47.30	0.00
	78	.	130.00	202.00	33.20	17.30	49.20	0.00
	79	110.00	150.00	208.00	45.00	23.00	62.00	0.00
	80	35.00	167.00	252.00	61.00	24.00	66.00	0.00
	81	150.00	137.00	250.00	66.00	21.00	.	.
	82	18.00	140.00	200.00	70.00	12.00	28.00	.
	83	21.00	137.00	210.00	57.50	16.00	53.00	.
	84	34.00	140.00	260.00	75.00	17.70	67.00	.
	85	16.00	117.00	272.00	78.00	19.00	.	.
	86	28.00	126.00	232.00	.	.	.	.
MIN		16.00	117.00	200.00	33.20	12.00	28.00	0.00
MAX		150.00	167.00	272.00	78.00	24.00	67.00	0.00
MEAN		51.5000	136.9000	233.6000	58.3556	18.9000	53.2143	0.000
STDEV		50.0970	14.1457	26.6467	15.9350	3.6861	13.6480	0.000
VALIDN		8	10	10	9	9	7	4

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
OCTOBER	76	*	126.00	224.00	55.00	32.00	68.00	0.00
	77	*	148.00	266.00	36.90	25.60	74.20	0.00
	78	*	120.00	186.00	38.40	19.30	45.20	0.00
	79	*	149.00	222.00	66.00	14.00	65.00	0.00
	80	18.00	131.00	224.00	61.00	18.00	43.00	.01
	81	53.00	167.00	258.00	68.00	21.00	*	*
	82	9.00	160.00	200.00	52.00	17.00	45.00	*
	83	27.00	150.00	226.00	70.60	12.20	49.00	*
	84	18.00	134.00	248.00	56.10	26.20	90.00	*
	85	26.00	138.00	276.00	66.00	27.00	*	*
	86	19.00	110.00	194.00	*	*	*	*
MIN		9.00	110.00	186.00	36.90	12.20	43.00	0.00
MAX		53.00	167.00	276.00	70.60	32.00	90.00	.01
MEAN		24.2857	139.3636	229.4545	57.0000	21.2300	59.9250	.0020
STDEV		13.9966	17.2816	29.6660	11.8497	6.3158	17.0907	.0045
VALIDN		7	11	11	10	10	8	5

FORT PHANTOM HILL RESERVOIR QUALITY

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
NOVEMBER	76	*	125.00	220.00	33.00	23.70	60.00	0.00
	77	*	139.00	254.00	67.80	26.60	99.80	0.00
	78	*	140.00	190.00	44.80	18.90	131.20	.03
	79	26.00	160.00	226.00	57.00	20.00	66.00	0.00
	80	27.00	138.00	276.00	70.00	26.00	47.00	0.00
	81	54.00	112.00	174.00	62.00	5.00	*	*
	82	36.00	156.00	222.00	64.00	15.00	56.00	*
	83	100.00	148.00	244.00	65.00	19.90	53.00	*
	84	22.00	132.00	216.00	52.90	20.40	52.00	*
	85	11.00	122.00	254.00	62.00	24.00	*	*
	86	20.20	108.00	190.00	*	*	*	*
MIN		11.00	108.00	174.00	33.00	5.00	47.00	0.00
MAX		100.00	160.00	276.00	70.00	26.60	131.20	.03
MEAN		37.0250	134.5455	224.1818	57.8500	19.9500	70.6250	.0060
STDEV		28.4435	16.7891	31.3108	11.4652	6.3299	29.4821	.0134
VALIDN		8	11	11	10	10	8	5

MONTH	YEAR	TURBIDITY FORMAZIN T. UNITS	TOTAL ALKALINITY MG/L AS CACO3	HARDNESS MG/L AS CACO3	CALCIUM MG/L	MAGNESIUM MG/L	SODIUM MG/L	MANGANESE MG/L
DECEMBER	76	*	127.00	228.00	30.30	25.20	73.00	0.00
	77	*	138.00	276.00	50.70	28.50	88.40	0.00
	78	*	142.00	194.00	52.00	15.60	57.80	.30
	79	19.00	160.00	236.00	56.00	23.00	62.00	0.00
	80	32.00	130.00	220.00	56.00	19.00	66.00	.03
	81	23.00	136.00	172.00	56.00	8.00	53.00	*
	82	23.00	156.00	212.00	138.00	74.00	32.00	*
	83	125.00	140.00	237.30	63.00	19.50	60.00	*
	84	21.00	122.00	224.00	*	*	54.00	*
	85	17.00	126.00	268.00	64.00	26.00	*	*
	86	17.00	114.00	206.00	*	*	*	*
MIN		17.00	114.00	172.00	30.30	8.00	32.00	0.00
MAX		125.00	160.00	276.00	138.00	74.00	88.40	.30
MEAN		34.6250	135.5455	224.8455	62.8889	26.5333	60.6889	.0660
STDEV		36.8314	13.8807	30.0949	29.8213	18.8439	15.3506	.1315
VALIDN		8	11	11	9	9	9	5

APPENDIX E

BAYLOR
COLLEGE OF
MEDICINE

Texas Medical Center
Houston, Texas 77030

Department of Virology
and Epidemiology
(713) 799-4444

Joseph L. Melnick, Ph.D.
Distinguished Service Professor
and Chairman

November 18, 1987

Mr. Dwayne Hargesheimer
Director of Water Utilities
P. O. Box 60
Abilene, Texas 79604

Dear Mr. Hargesheimer:

Enclosed please find our final report of the work done under contract with the City of Abilene, dated March 13, 1987. As you will note, because of the importance of the study we conducted many more tests than originally requested in the contract.

Sincerely yours,

Joseph L. Melnick

enclosure

cc: Mr. John H. Cook
Freese and Nichols, Inc.
811 Lamar Street
Fort Worth, Texas 76102

TECHNICAL REPORT

Abilene Water Reclamation

Attention: Mr. Dwayne Hargesheimer
Director of Water Utilities
City of Abilene

Study objective: Establishment of baseline data of viral occurrence in wastewater, Fort Phantom Hill Reservoir and creeks feeding the reservoir.

Study design and sampling sites:

The sampling regime, as dictated by financial considerations and distance from the laboratory, was as follows. Raw and treated wastewater, two reservoir sites and two creeks flowing into the reservoir were sampled in April (spring) and August (high summer) 1987. Details of volume and water conditions are given in Table 1. All samples were collected and concentrated to a volume of approximately 2 liters in the field before transfer to the laboratory on wet ice for further concentration and assay. Raw wastewater was collected as a composite sample (3.8 liters collected hourly over 5-hour period) to ensure a more representative virus sample. Wastewater was collected upon discharge from the plant following treatment that included conventional activated sludge process after primary clarification, aeration with the addition of polymer to enhance flocculation, and final clarification by settling. Reservoir samples were taken from intakes supplying the electricity generating plant and potable water treatment plant. Duplicate samples were collected of reservoir and treated wastewater on each occasion.

occasion. The two creeks included in the study flowed through residential areas and received city storm water before emptying into the reservoir.

Table 1. Collection sites and water conditions

Collection site	April pH	April temp. (°C)	April volume (liters)	August pH	August temp. (°C)	August volume (liters)
Wastewater[1]						
raw	7.22	NT[3]	18.9	7.29	ND	18.9
treated	7.05	17.2	473	7.02	29	378
Reservoir[2]						
utility intake	8.8	12.8	473	8.25	31	378
potable water intake	8.06	11.7	378	8.36	28	378
Elm Creek	8.53	13.3	378	8.56	31	378
Cedar Creek	8.22	13.4	378	8.29	31	378

1 Raw sewage sample was a composite of 5 x 3.8 liter samples collected at hourly intervals over the period of maximum flow.

2 Duplicate samples were collected at each reservoir site and of wastewater effluent.

3 Not tested.

Field and laboratory sampling, concentration, virus assay and identification

Field:

Collect sample (378 - 470 liters) in a large tank; adjust pH to 3.5, and add $AlCl_3$ to 0.5 mM final concentration; pass through 3.0 + 0.45 µm porosity filterite cartridge filters (25.6 cm long); elute each filter with 1 liter of elution media (10% tryptose phosphate broth, 3% beef extract, 0.05 M glycine, pH 9.5) for 5 minutes with shaking and back flush under positive pressure; separate virus from solids by filtration of eluate at pH 9.5, through 0.45 and 3.0 µm, 47 or 90 mm flat filters; adjust pH to 7.5; transport to laboratory on wet ice.

Laboratory:

Reconcentrate: Add polyethylene glycol 6000 to 8% final concentration. Stir 1.5 hour to overnight at 5°C. Centrifuge 10,000 x g, resuspend pellet in 10 ml, 0.15 M Na_2HPO_4 final pH 9.0, Shake 30 minutes at 300 RPM, centrifuge 10,000 x g 30 minutes, adjust pH to 7.5.

Decontaminate: Pass through 0.22 µm low protein binding, serum treated filter or add antibiotics.

Assay:

Hepatitis A virus (HAV): Dot blot hybridization using ssRNA probes.

Rotavirus (RV): Immunofluorescence using combination of monoclonal (human strains) and polyclonal (human and non-human strains) antibodies.

Enteroviruses: Plaque assay in BGM cells; cytopathic effects (CPE) assay in BGM cells in liquid culture. Identification by serum neutralization tests.

Other human enteric viruses: CPE assay in primary monkey kidney cell line (African green). Identified by electron microscopy and serum neutralization.

Table 2. Virus detection

	Hepatitis A virus	Human Rotavirus (IU[1]/100 ml)	Enteroviruses (BGM cells)			Other enteric viruses	
			Plaque assay (PFU[2]/100 ml)	Liquid culture	Identity[3]	CPE[4] on (AGMK)	Identity
April							
Wastewater raw	--[5]	4500	880	+[6]	P1,P2,P3 CB5,E7	+	Reovirus 2
Treated A	--	9	8	+	P1,P3,CB4 CB5	+	Reovirus 2
B	--	4	6	+	CB5	+	Reovirus 2
Reservoir							
Site 1A	--	--	--	--		--	
B	--	--	--	--		+	Reovirus 2
Site 2A	--	--	--	--		--	
B	--	--	--	--		--	
Creek 1	--	--	--	--		--	
Creek 2	--	--	--	--		+	Reovirus 2
August							
Wastewater Raw	--	--	7250	+		+	Reovirus 2
Treated A	--	--	not determined	+		+	Reovirus 2
B	--	--	50	+		+	Reovirus 2
Reservoir Site 1A	--	--	--	--		--	
B	--	--	--	--		--	
Site 2A	--	--	--	--		--	
B	--	--	--	+		--	
Creek 1	--	--	--	--		+	Reovirus 2
2	--	--	--	+		+	Reovirus 2

1 IU = Infectious units
2 PFU = Plaque forming units
3 P1, P2, P3 = poliovirus type 1, 2 and 3.
CB4, CB5 = coxsackievirus B, type 4 and 5.
E7 = echovirus, type 7
4 Cytopathic effect
5 Not detected
6 Virus positive

Results

The results of all viral studies are shown in Table 2. No HAV was detected in any sample. RV was only found in the April wastewater samples consistent with the recognized occurrence of rotavirus in winter and spring. A variety of enteroviruses were present in wastewater with significantly greater numbers detected in summer than in the spring. The only viruses detected in samples other than raw and treated wastewater were reovirus type 2, which occurred in both creeks and at one reservoir site as well as wastewater. The general occurrence of this virus type and the known presence of this virus in both human and animal populations make it difficult to ascertain its origin, particularly as the municipal wastewater includes abattoir wastes. Virus reduction was quite significant following the treatment regimen (greater than 99.99% for RV and enteroviruses). Reovirus concentrations were not quantified.

Parasitlogy Study

City of Abilene Water Department

Performed and Submitted by Terry L. Foster, Ph. D.

October 14, 1987

Objective: To evaluate water sources in the city of Abilene for the purpose of identifying the presence and concentration of protozoan parasites identified by the State of Texas as worthy of establishing baseline data.

Specific Organisms to be Included:

Giardia lamblia
Cryptosporidium sp.
Entamoeba hartmanni
Entamoeba coli
Endolimax nana
Nagleria sp.
Hartmanella sp.
Acanthomeba sp.

Summary of Characteristics of Microorganisms:

A. *G. lamblia*

Intestinal parasite (flagellate) acquired by injestion of cysts.
Incubation period averages 9 days.
Nausea, upper intestinal cramping, malaise, diarrhea.
Diagnosed by finding cysts or trophozoites in feces.
10-20 microns length

B. *Cryptosporidium* sp.

Coccidia, 3-6 microns, no cysts, identified by acid-fast stain.
Normal disease course is diarrhea, cramping, nausea, anorexia and usually lasts 10-15 days.
Immunocompromised patients have similar symptoms but disease is prolonged from weeks to years.
No treatment.
Prevalent in AIDS patients

C. *Entamoeba hartmanni*, *E. coli*, and *Endolimax nana*

Amoeba, produce cysts which are hardy, may live in the cecum and colon. Non pathogenic, but must be differentiated from their pathogenic cousin, *E. histolytica*.

D. Nagleria, Hartmanella, Acanthomeba

Free living amoeba found in soil, fresh water, and sewage. Nagleria and Acanthomeba may cause a fatal disease of the central nervous system in humans.
Nagleria - Usually enters through nasal passage, invades brain and causes an acute and fulminating primary amebic meningoencephalitis which generally produces death in 5-7 days after symptoms develop. May respond to therapy with amphotericin B if administered early.

Acanthomeba cause a chronic granulomatous encephalitis which last for weeks or months before causing death. It has recently been recognized as causing eye infections which may lead to loss of an eye. It has been isolated from the ear, lungs, nasopharynx, and intestine. Portal of entire for encephalitis is usually inhalation of cysts from freshly turned soil. Infection may respond to treatment with sulfadiazine and selected antibiotics.

Water Samples to Be Assayed:

Wastewater Treatment Plant
Intake
Effluent

Water Treatment Plant
Intake
Effluent

One sampling to be taken during warm season and one in cold season.

Method of Processing:

Sample Acqisition
Sample Concentration - 0.22 micron, cross-flow filters
Special Processing - Flotation, sedimentation
Microscopic Identification -
Wet Mount-stained and unstained
Permanent Mount-stained

Identification - Life cycle stage
Size, shape
Staining reactions
Motility
Number of nuclei
Presence of cellular inclusions
Chromatin material

Enumeration - Volumetric sampling
Microscopic counts
Calculation of concentration factor

Table 1. Parasitology Study

City of Abilene Water Department

October 14, 1987

Sample Site	Sample Volume	Date Collected	Concentrate Volume	Centrifuged Volume
Water Treatment Plant-Effluent (Holding Tank)	44.3 gal (167.6 liters)	9/18/87	1.0 liter	10ml
Ft. Phantom Lake Water Intake	46.3 gal (175.1 liters)	9/18/87	1.0 liter	10ml
Raw Sewage Primary LF_2	40 gal (151 liters)	9/25/87	2.5 liter	25ml
Wastewater Effluent	50.2 gal (190 liters)	9/23/87	1.0 liter	10ml

Fairleigh Dickinson Laboratories, Inc.
Abilene, Texas

Table 2: Parasitology Study

City of Abilene Water Department

October 14, 1987

Microscopic Analysis of Stained and Unstained Wet Mounts and Stained Permanent Mounts

Sample Site	Concentrate Volume Assayed	Concentration Factor	Organisms Detected	Number Detected
Water Treatment Effluent	0.4ml	167X	None	None
Ft. Phantom	0.4ml	175X	Entamoeba hartmanni	14 per liter 54 per gallon
Wastewater Effluent	0.4ml	190X	Entamoeba Coli	66 per liter 250 per gallon
			Entamoeba hartmanni	130 per liter 500 per gallon
Raw Sewage	0.1ml	70X	Entamoeba coli	286 per liter 1080 per gallon
			Entamoeba hartmanni	860 per liter 3240 per gallon
			Endolimax nana	143 per liter 540 per gallon
			Acanthomeba sp.	3 per liter 11 per gallon

Fairleigh Dickinson Laboratories, Inc.
Abilene, Texas

PARASITOLOGY STUDY - FINAL REPORT
CITY OF ABILENE WATER DEPARTMENT

Performed by Fairleigh Dickinson Laboratories, Inc.
Terry L. Foster, Ph. D.

Indentifications Performed by Clark Beasley, Ph. D.

Submitted January 13, 1988

Objective:	To evaluate water sources in the City of Abilene for the purpose of identifying the presence and concentration of protozoan parasites identified by the State of Texas as worthy of establishing baseline data.
Protocol:	Sampling and assay procedures were described in FDL reports dated October 14 and November 23, 1987. This report includes final results of the cold water samples.
Results Overview:	Numbers are generally increased and rationale is given. Acid fast stain yielded what appears to be Crytosporidium sp. in high concentration. Inordinately high levels are explained as incorrect identification. This observation re-emphasizes the need for more specific diagnostic assays.

Samples:

Ft. Phantom Lake	Jan. 4, 1987	187 liters to 1 liter
Treated Effluent	Jan. 4, 1987	188 liters to 1.4 liters
Wastewater	Jan. 5, 1987	80 liters to 40 liters
Treated Wastewater	Jan. 5, 1987	105 liters to 2.0 liters

Parasitology Study

City of Abilene Water Department

January 5-6, 1988

Microscopic Analysis of Stained and Unstained Wet Mounts

Sample Site	Concentrate Volume Assayed	Organisms Detected	Number Detected
Water Treat. Plant Raw Water	0.1 ml	*Entamoeba hartmanni*	241 / liter
		Acanthamoeba sp.	4 / liter
Water Treat. Plant Finished Water	0.1 ml	None	None
Sewage Treat. Plant Raw Sewage	0.1 ml	*Entamoeba hartmanni*	60,000 / liter
		Entamoeba coli	25,000 / liter
		Endolimax nana	5,000 / liter
		Acantamoeba sp.	3,200 / liter
Sewage Treat. Plant Plant Effluent	0.1 ml	*Entamoeba hartmanni*	2,377 / liter
		Entamoeba coli	679 / liter
		Endolimax nana	340 / liter

Parasitology Study

City of Abilene Water Department

January 5-6, 1988

Microscopic Analysis of Acid-Fast Stain for *Cryptosporidium* sp.

Sample Site	Concentrate Volume Assayed	Organisms Detected	Number Detected
Water Treat. Plant Raw Water	0.1 ml	*Cryptosporidium* sp.	None
Water Treat. Plant Finished Water	0.1 ml	None	None
Sewage Treat. Plant Raw Sewage	0.1 ml	None	None
Sewage Treat. Plant Plant Effluent	0.1 ml	None	None

Comments relating to

Parasitology Study
City of Abilene Water Department
January 5-6, 1988

The organisms dealt with are parasitic, and so adapted to survival in the host (in this case mammals, usually the human). In *Entamoeba histolytica*, according to Chandler (1930), "After the stools have been passed the amebae begin to become abnormal and to die almost immediately ... ". This is no doubt true of all the parasitic amoebae, since their existence is tied to the internal environment of the host. Therefore we probably should not expect to find the trophozoite (amoeba form) in the water samples.

The cyst, on the other hand, is the stage that is utilized for transfer from one host to another. They, therefore, are the stages which can survive outside the host and would be found in the water samples. According to Schmidt and Roberts (1981) "Cysts of *E. histolytica* can remain viable and infective in a moist, cool environment for at least 12 days, and in water they can live up to 30 days. They are rapidly killed by putrefaction, desiccation, and temperatures below -5 C and above 40 C." From this we might expect to find higher numbers of cysts in the winter samples than in the summer samples.

Schmidt and Roberts (1981) state that *E. coli* has a superior ability over *E. histolytica* to survive putrefaction. It is assumed, therefore, that it has a greater chance of passing through a sewage treatment plant. According to the same reference the *Endolimax nana* cyst "is more susceptible to purefaction and desiccation than is that of *E. coli*."

A technique to be checked which may be of value is noted by Chandler: "The criterion which has been extensively employed to determine the viability of cysts is the fact that dead cysts usually stain with eosin whereas living cysts do not, but this test is not infallible."

MacKinnon and Hawes (1961) states "*E. invadens*, from snakes and other reptiles, is morphologoically indistinguishable from *E. histolytica* at every stage in its life history ... ". Also, they state "A considerable number of amoebae described under various names so closely resemble *E. histolytica* as to be morphologically indistinguishable from it at any of the known stages of their life-cycles. They are widely distributed and, with the exception of *E. moshkovskii*, which occurs in sewage and has not yet been connected with any host (Neal, 1953), they are entozoic." Therefore, a test such as monoclonal antibody assay would be essential when dealing with lake water or sewage treated in open ponds.

Chandler, Asa C. 1930. Introduction to Human Parasitology. John Wiley & Sons, London.

Mackinnon, Doris L., and R. S. J. Hawes. 1961. An Introduction to the Study of Protozoa. Oxford Univ. Press, London.

Neal, R. A. 1953. Studies on the morphology and biology of Entamoeba moshkovskii Tshalaia. Parasitology 43:253.

Schmidt, Gerald D., and Larry S. Roberts. 1981. Foundations of Parasitology. C. V. Mosby Co., St. Louis.

ACID-FAST STAIN FOR *Cryptosporidium*

1. Spread sample on slide, and allow to dry.

2. Fix the dried film in absolute methanol for 1 min., and air dry the slide.

3. Flood the slide with Kinyon carbol-fuchsin, and stain the smear for 5 min.

4. Wash the slide with 50% ethyl alcohol in water, and immediately rinse it with water.

5. Destain the smear with 1% sulfuric acid for 2 min. or until no color runs from the slide.

6. Wash the slide with water.

7. Counterstain the smear with Loeffler methylene blue for 1 min.

8. Rinse the slide with water, dry it, and examine the smear with oil immersion.

The results are that *Cryptosporidium* oocysts stain bright red, and background materials stain blue or pale red.

KINYOUN CARBOL-FUCHSIN STAIN

Basic fuchsin	4 g
Alcohol, 95%	20 g
Phenol crystals	8 g
Distilled water	100 ml

LOEFFLER METHYLENE BLUE

1. Solution A

Methylene blue	0.3 g
95% ethanol	30.0 ml

2. Solution B

0.01% potassium hydroxide	100 ml

Dissolve the methylene blue in alcohol, and add the potassium hydroxide solution.

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 5

LAKE FORT PHANTOM HILL - WATER QUALITY STUDIES

Principal Author: Ken Iceman, P.E.

INTRODUCTION

The previous water quality studies and models developed for Lake Fort Phantom Hill (LFPH) were used to determine, to the extent possible, if the U.S. Army Corps of Engineers Reservoir Water Quality Model (WQRRS) is a reasonable candidate for the impact analysis of advanced wastewater treatment (AWT) effluent discharge into LFPH a water supply reservoir for the City of Abilene, Texas. The model was then used to examine the resultant impact of effluent discharges on LFPH during a 2-year drought period. The basic chemical and biological processes of the water quality model are shown in the flowchart of Figure 1.

The first step in the evaluation procedure was to take available (historic) data on the reservoir and surrounding basin, apply it to the water quality model, and evaluate whether the model was able to estimate the historic water quality in the reservoir in an acceptable manner.

This calibration process included the development of numerous kinds of input data for the reservoir, tributaries, diversions, weather, water management, water consumption, and related water quality.

Historic reservoir water quality in LFPH was used to compare the model results with the field sampling information. The time consistency of each model input with the field sampling data is critical in establishing criteria for appropriate model performance. The manner in which the model re-

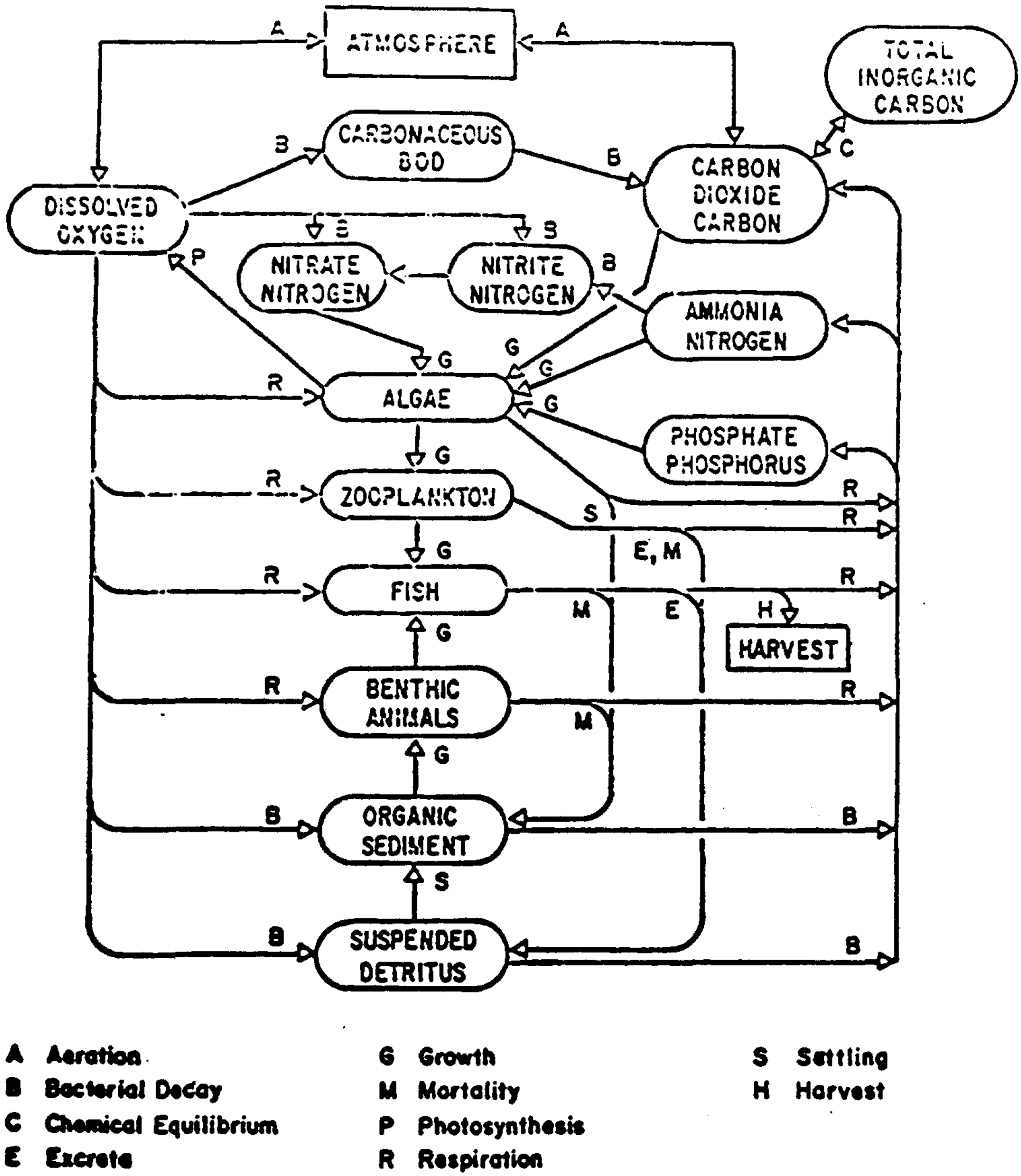


Figure 1
Quality and Ecologic Relationships

sults are examined is directly dependent upon the data base used as input and the data used to compare against.

The model strengths and limitations can be properly evaluated through a realistic set of objectives/goals for the analysis approach recognizing data deficiencies and inconsistencies, model limitations, expected performance of the model related to field knowledge and experience, and a working understanding of the model framework.

Once the calibration process is completed, it is customary to examine the model performance using an independent (time) set of field data to confirm the validity of the model coefficients and data. The data sampling program conducted from March 1987 to October 1987 would be a reasonable candidate for this verification. The data sampling period base would be sufficiently long to observe the biological productivity cycles, the spring and fall runoff periods, and the warming and cooling cycles in the reservoir from early spring through late fall.

Upon completion of the verification analysis, using the same calibrated coefficients, the evaluation of the model could be completed and final judgment made on the accuracy of the model for in-lake water quality impact analysis.

At this point, based on initial acceptance of the model's calibration, a variety of what-if studies have been performed on levels of wastewater treatment, AWT flow augmentation, and water management. The alternative analyses show the effect of various AWT treatment levels on algal production in LFPH.

The results of these studies can also be correlated to the impacts of water quality constituents which are not direct model results. In the case of LFPH, the historic data show a positive correlation between TDS and Cl,

SO_4, and conductivity. The model results for TDS can therefore be used to estimate changes to Cl, SO_4, and conductivity through application of the empirical equations for each alternative.

APPROACH

The model has been developed from the perspective of critical drought conditions in the basin. These conditions prevailed between 1979 and 1982 within the historic data base which extends for 11 years from 1976 to 1986. Since specific water-quality data for this shorter period were even more limited than over the 11-year period, it was decided to calibrate the model for the mean conditions over the entire 11-year period.

Because the model was to be used for comparison of several AWT discharge levels into LFPH, particularly during dry years, an estimate of both normal and dry year diversion levels from the Clear Fork of the Brazos River and Deadman Creek were incorporated into the analysis. Although the amount of these diversions into LFPH varied greatly, it was assumed the lesser quantities coupled with lower direct rainfall and larger raw water intake quantities would approximate the hydrology of a drought-type condition.

A 12-month period was used for calibration in an effort to include a complete seasonal cycle of variations in the weather, inflows, and diversions. Although 12-hour time steps were used in the model, the results were evaluated on a monthly basis. There were insufficient monthly water quality and quantity data of the LFPH system to be more time-specific in the calibration. As an example, in the 11 years of City of Abilene data (132 months), there were fewer than 20 values of chlorophyll-a and suspended solids, and no orthophosphate data between 1979 and 1982. Other measures of nutrients in both the lake and the tributaries were severely lacking for certain months.

These kinds of data restrictions were considered in the evaluation of the model's performance. Similarly, the known model limitations such as no anaerobic chemistry and biological processes, no shoreline erosion/washoff capacity, and one-dimensional analysis (i.e., vertical layers with no horizontal variations) were also considered with respect to the presently understood processes of LFPH.

CRITICAL CONSIDERATIONS

The LFPH reservoir has at least three unique environmental characteristics that must be represented by the model. These conditions are:

1. Well mixed, nonstratified water in the reservoir throughout most of the year

2. High turbidity levels

3. Light- and phosphorus-limited algae productivity

These conditions are not always common in reservoirs due to seasonal weather changes and inflows which typically permit stratification, water clarity improvements, and algal growths resulting from higher levels of nutrients (usually well above normal half-saturation levels).

In order to achieve Condition 1 in LFPH, the WQRRS model vertical diffusion coefficients were adjusted to increase the transfer of mass throughout the water column as a function of wind speed and density gradient. The empirical relations used in the model permit modification of coefficients to increase or decrease vertical mixing to achieve well-mixed conditions or stratified conditions.

The second condition was developed in the model by reducing the settling velocities for inorganic suspended solids to a level which maintained a relatively constant concentration in the reservoir throughout the year. The suspended solids data indicated about 10 to 12 mg/l was a reasonable level at all times. Inflow concentrations of suspended solids for the diversions or tributaries (Elm Creek) were not available. The shoreline washing of material from wind and wave action was thought to contribute substantially to the low water clarity and high turbidity suspended solids relationships. The most straightforward way the model could be adjusted to account for this expected physical condition was to limit the settling of the material.

A light-limited and phosphorus-limited algal productivity (Condition 3) was achieved in the model at elevated nutrient levels by including self-shading characteristics of suspended material in the determination of the composite light extinction coefficient and by increasing the phosphorus half-saturation constant. This procedure was available in the model but needed to be activated through the specification of different light attenuation constants for suspended particulate material and algae. These attenuation constants and the base secchi depth (without suspended material) were adjusted in the calibration to provide a composite light extinct coefficient approximately equivalent to a 24-inch secchi depth.

The following field data and model data show the similarity of light penetration characteristics used for the LFPH calibration:

SECCHI DISC DEPTH
(inches)

	Field Data	Model[1]
Range:	15 to 49	24 to 27
Average:	25	26

[1] Effective secchi disc depth due to composite effects of pure water, algae, and suspended solids.

As a result of the various adjustments to the model, the three LFPH critical conditions were approximated in the calibration procedure. Additional data on suspended solids of the inflows, light penetration data, and nutrients/algal growth would further assist in developing the appropriate balance between settling of the suspended material, light penetration, and algal productivity. Ultimately, some measure of algal productivity under varying conditions of nutrient concentrations and available light may need to be considered in sampling program.

DATA BASE

The historical data base and model coefficient information used throughout the preliminary calibration were derived from the following sources:

- City of Abilene--Water quality records compiled by Freese and Nichols

- Texas Water Commission--Water quality data compiled by Freese and Nichols

- U. S. Geological Survey--Mapping and surface-water records

- Freese and Nichols--Draft Water Quality Assessment Lake Fort Phantom Hill, 1987

- Freese and Nichols--Chloride Control Program Report, 1984

- Tetra Tech--Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling, Second Edition, 1985

- U. S. Army Corps of Engineers--Water Quality for Rivers-Reservoir Model Documentation, HEC, 1978 (Revised 1984)

- U. S. Army Corps of Engineers--Water Quality Study of the Trinity River, Fort Worth District, 1974

- NOAA--National Weather Service Data, Abilene, Texas, 1971-1980

- Freese and Nichols--Study of Coordinated Operation of Existing Raw Water Supply Sources, Abilene and West Central Texas Municipal Water District, 1980

- West Texas Utilities Company 1986 Operations Data

Several computer graphs of the 11-year monthly means of LFPH water quality data base have been presented in the Draft Water Quality Assessment Report by Freese and Nichols. The mean values of the following water quality parameters were used in calibrating the WQRRS model:

- Temperature
- Dissolved Oxygen (DO)
- Ammonia (NH_3)

- Nitrate (NO_3)
- Ortho-Phosphate ($O-PO_4$)
- Fecal Coliform
- Total Suspended Solids (TSS)
- pH
- Total Alkalinity
- Total Dissolved Solids (TDS)
- Chlorophyll-a

The estimated quantities of water diverted to LFPH from Clear Fork and Deadman Creek during drought conditions were taken directly from Table C-5 of Freese and Nichols' "Study of Coordinated Operation of Existing Raw Water Supply Sources" report (1980) and Clear Fork diversion data supplied by Freese and Nichols. These data covered the period of record from 1941 through 1977 and 1976 through 1985, respectively. In addition, the natural inflow quantities from local drainage and Elm Creek were taken from Table C-3 in the same report.

The water quality data for these inflows (Clear Fork, Deadman Creek, Elm Creek) were estimated from several sources-the Chloride Control Program Report; the Corps of Engineers, Fort Worth District, Trinity River Report; ongoing project sampling study; and previous 1973 sampling data from Freese and Nichols. The Chloride Control Program Report indicated that the Clear Fork waters were typically of poorer quality most of the year except during the higher runoff periods, May through June and September through October. For those months, the alkalinity, TDS, and pH data were generally much lower, similar to Deadman Creek. The Trinity River Basin lies south of the study area by some distance. These data may not be representative of the LFPH drainage basin, but the information appears reasonable for use until better data are made available through the sampling program. March 1987 and May 1987 tributary sampling data and earlier 1973 data provided the most legitimate data base for establishing runoff water quality.

Due to the sparsity of site-specific data for each tributary or diversion, the water quality of each inflow was assumed to be approximately the same. This was deemed permissible for the Clear Fork because the flows diverted to LFPH were assumed to occur during periods of higher runoff when the water quality was typically better and thus similar to Deadman and Elm Creeks.

Table 1 shows the water quality data assumed for the Clear Fork diversions (May, June, September, and October), Deadman Creek (May and October) and Elm Creek (all year).

The initial conditions of the LFPH reservoir were determined from the computer graphs of the 11-year mean water quality data. An estimated initial condition value for each water quality constituent was made using the December and January data. The calibration period was from January through December. Table 2 shows the initial reservoir conditions assumed for the calibration of the model.

The physical reservoir data for the model were composed of area-capacity curves; length of the reservoir; bottom elevation; intake tower gate elevations; the location, size, and elevation of the raw water intake; West Texas Utilities (WTU) intake/discharge; and the proposed siting of the AWT plant outfall.

The effects of the WTU intake/discharge were considered in calibrating the model The effects of the DO diffuser were not directly included in either the calibration or the analysis of alternatives. The AWT plant discharge was included by first simulating 1 year without the discharge to develop the monthly water quality profiles in the lake. These results were

Table 1

TRIBUTARY/DIVERSIONS WATER QUALITY

Constituent	Value
Temperature:	Variable with month (8°C to 28°C range)
Dissolved Oxygen:	80 percent of saturation at given temperature
Ammonia:	0.25 mg/l
Nitrate-Nitrite:	0.10 to 0.50 mg/l
Ortho-Phosphate:	0.05 mg/l
TDS:	350 to 400 mg/l
Chlorophyll-a:	3 to 20 mg/l
pH:	7.8 to 7.9 units
Alkalinity:	90 to 120 mg/l
Suspended Solids:	11 mg/l
Fecal Coliforms:	8,000 MPN/100 ml (except May and October--18,000 to 20,000 MPN/100 ml)
BOD_5:	4 mg/l

Table 2

LFPH INITIAL WATER QUALITY CONDITIONS
(December Period)

Constituent	Value
Ammonia	0.19 mg/l
Nitrate + Nitrite	0.31 mg/l
Ortho-Phosphate	0.06 mg/l
TDS	475 mg/l
Chlorophyll-a	2 mg/l
pH	8.7 units
Alkalinity	153 mg/l
Suspended Solids	11 mg/l
Fecal Coliforms	6 MPN/100 ml

then used to define the inflow water quality conditions of the circulated cooling water and included the temperature increment of 5°C above the lake temperature. The resultant rise in lake temperatures was found to be less than one degree Celcius for all the months. This change in temperature was felt to have no impact on the reservoir water quality, and the WTU was therefore dropped from further analysis in the alternatives.

Meteorological information for air temperatures, cloud cover, wind speed, and precipitation were taken directly from the NOAA National Weather Service station in Abilene. Daily data were compiled for each month from 1971 to 1980 and monthly average were calculated. The weather data shown in Table 3 were used in the model calibration process. These data were not changed during the alternative analysis of drought conditions.

MODEL CALIBRATION

The LFPH calibration process was based on the philosophy that for purposes of examining model performance during the annual cycle, the reservoir pool elevations should remain approximately the same at the end of the year as at the beginning. This would reduce the need to consider a fluctuating water volume in the lake in interpreting the model. In addition, the mixing processes, algal productivity, nutrient uptake, evaporation, and water budget should be similar to that found in the 11-year mean monthly data developed for LFPH.

In evaluating the water budgets, the hydrologic data and model results were found to be in approximate agreement once direct precipitation on the reservoir surface was included. The difference in beginning and ending reservoir volumes was less than 7 percent. The consumption of the WTU-circulated cooling water made up the majority of the reservoir net losses in one

Table 3

AVERAGE MONTHLY WEATHER DATA FOR ABILENE, TEXAS

Month	Air Temperature (°F)	Dew Point (°F)	Cloud Cover (%)	Air Pressure (in. Hg)	Wind Speed (mph)
Jan	40.3	26.9	59	28.2	1.9
Feb	47.3	31.0	53	28.2	3.1
Mar	57.0	36.7	50	28.2	4.2
Apr	64.7	46.1	50	28.2	6.1
May	71.9	56.2	52	28.2	6.5
Jun	80.5	61.2	41	28.2	8.9
Jul	83.3	62.6	43	28.2	8.2
Aug	81.9	62.8	46	28.2	8.3
Sep	75.1	59.6	53	28.2	4.4
Oct	65.3	48.9	41	28.2	4.8
Nov	52.2	38.9	47	28.2	2.9
Dec	46.0	29.8	51	28.2	3.4

year. The total evaporation data (net evaporation plus rainfall) showed an approximate depth of 69 inches per year, where the model estimated the total annual evaporation to be 67 inches.

The diversions into the reservoir, natural inflows, and depletions during the calibration period are shown in Table 4.

Through the annual water balance, the reservoir fluctuations in the model were between 1.0 and 2.0 feet, which is similar to the mean monthly variations found in the data base.

The water quality calibration was developed through the adjustments of suspended sediment settling, inclusion of self-shading light attenuation constants on suspended solids, nitrification rates, algae maximum-specific growth rates and half-saturation constants, and temperature dependent adjustments to chemical and biological rate coefficients. The other coefficients in the model were left at their default values, which have been determined from several years of research, empirical studies, and field experience along with engineering applications in diverse environmental conditions. The results of the model calibration are shown in Figures 2 through 12. The TSS and chlorophyll-a graphs show only approximate historical monthly means due to lack of data.

The model calibration results indicate a definite relationship between the water column DO and the water temperature. This result is consistent with field knowledge since the reservoir is well mixed , experiences average wind velocities of 3 to 8 mph throughout the year, and has low levels of algal productivity. In addition, the profile data suggest limited chemical stratification and DO depletions due to bacteriological decay.

The general nutrient-photosynthesis interaction in the model appears to be consistent with the mean historical values of NH_3, NO_3, and $O\text{-}PO_4$.

Table 4

LFPH CALIBRATION WATER BALANCE

Component	Volume (acre-feet)
Clear Fork Diversion (+ve)	6,000
Deadman Creek Diversion (+ve)	22,000
Elm Creek Inflow (+ve)	22,500
Direct Rainfall (+ve)	5,900
Direct Evaporation (-ve)	15,100
Raw Water Intake (-ve)	21,600
Consumptive Use by WTU (-ve)	2,200
NET	-2,500[2]

[2] Less than 7 percent of total initial volume of 39,000 acre-feet.

Figure 2

FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY TEMPERATURE

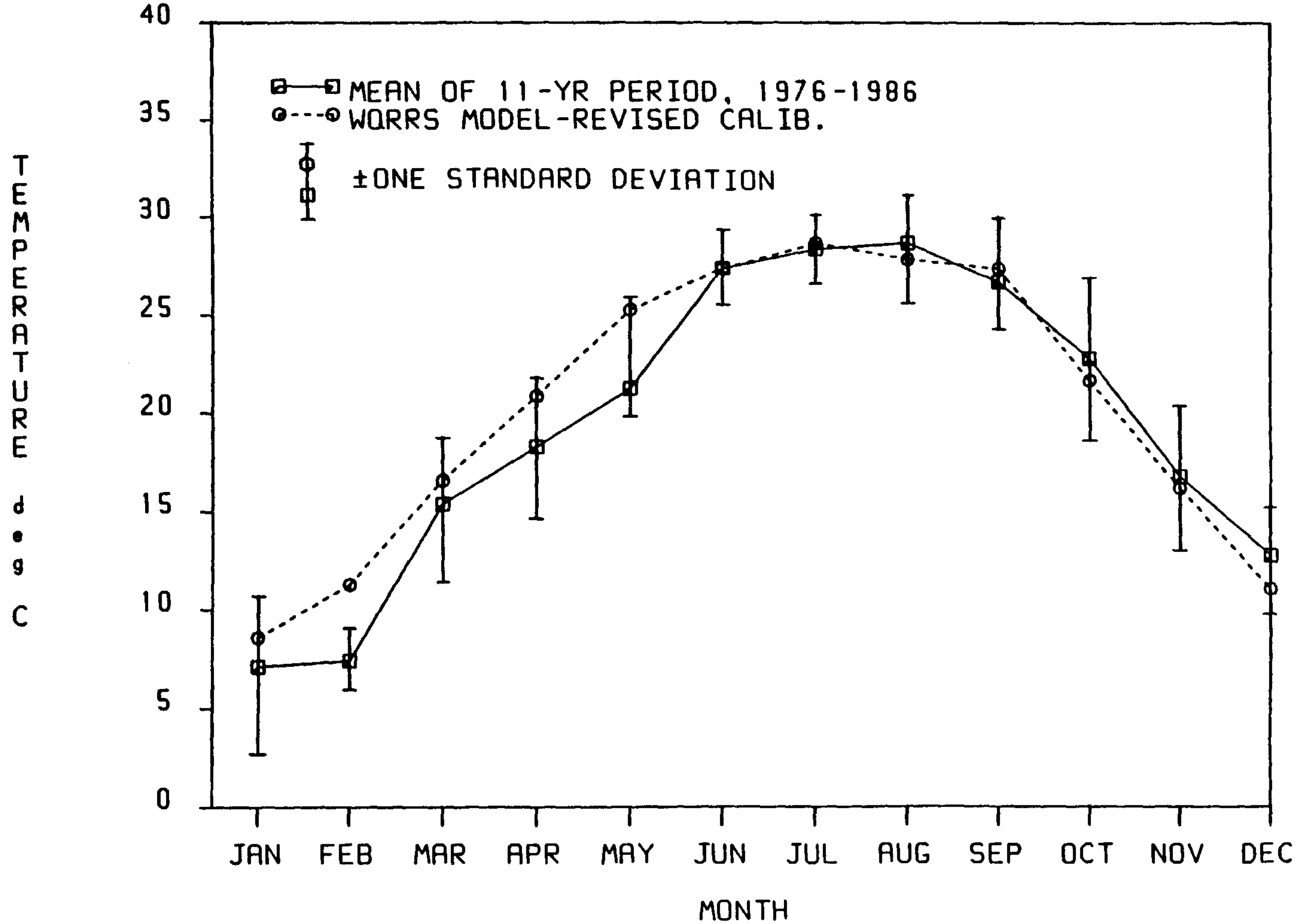


Figure 3

FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY DISSOLVED OXYGEN

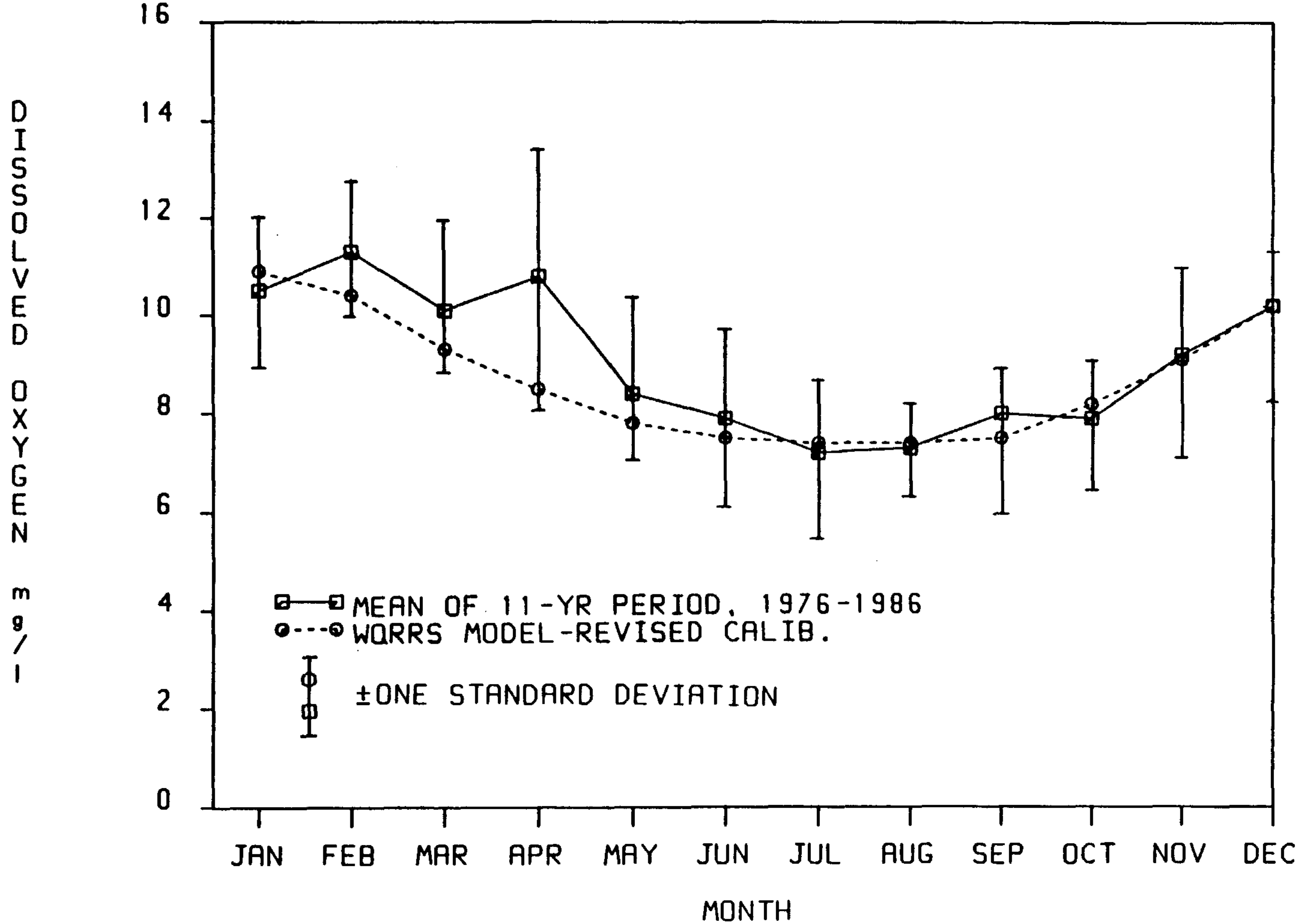
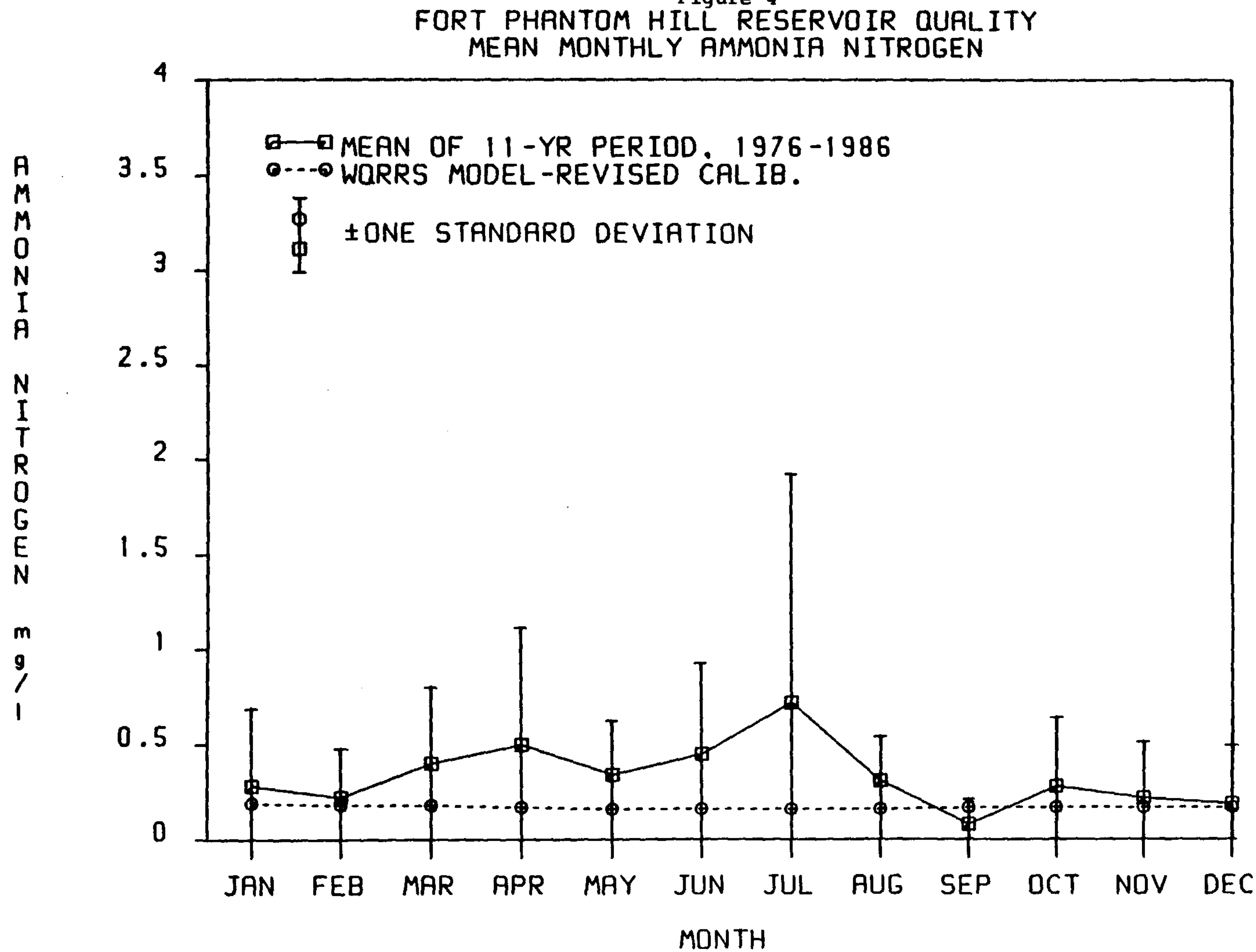
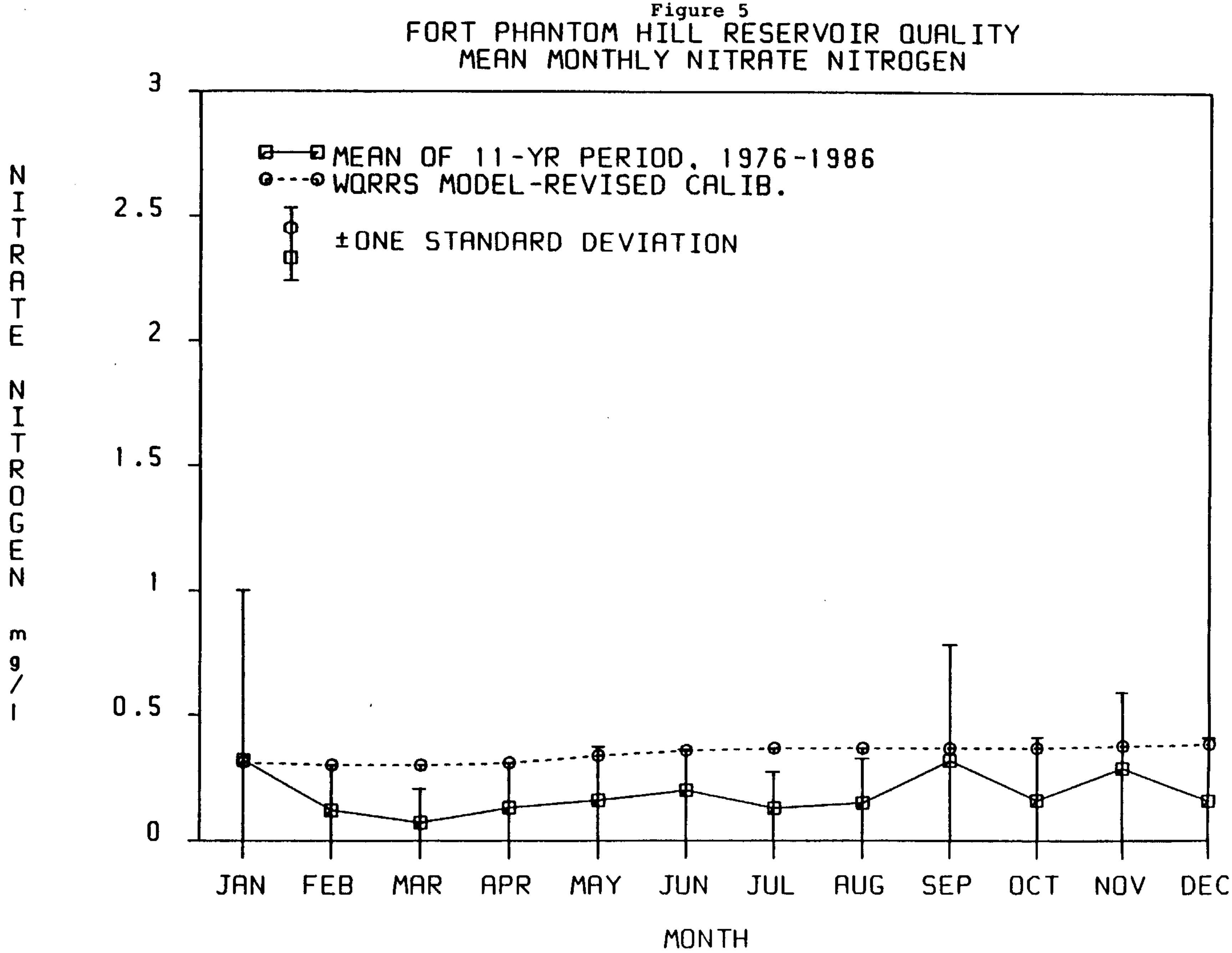


Figure 4



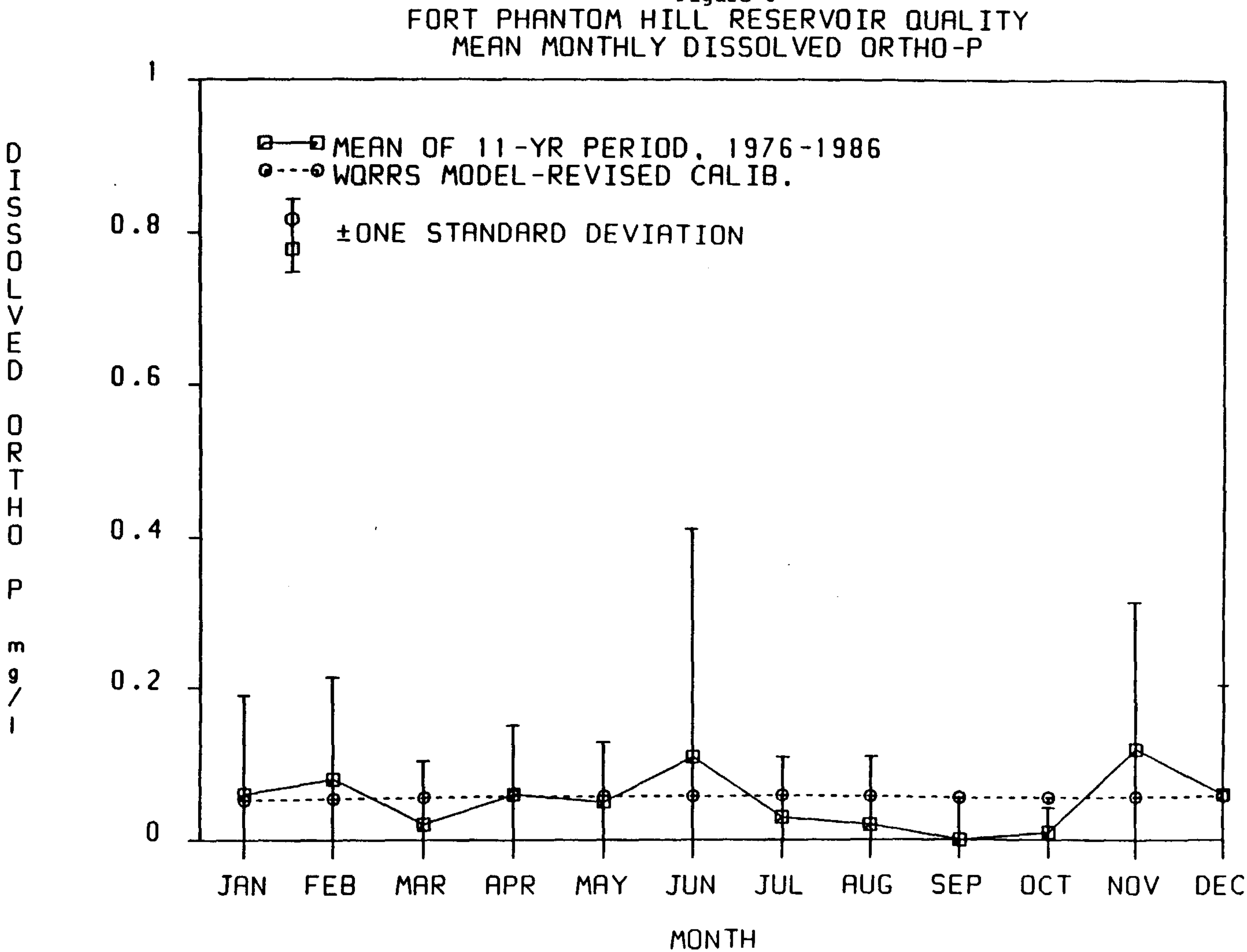
FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY AMMONIA NITROGEN
MEAN OF 11-YR PERIOD, 1976-1986
WQRRS MODEL-REVISED CALIB.
±ONE STANDARD DEVIATION
AMMONIA NITROGEN mg/l
4
3.5
3
2.5
2
1.5
1
0.5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 5



FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY NITRATE NITROGEN
MEAN OF 11-YR PERIOD, 1976-1986
WQRRS MODEL-REVISED CALIB.
±ONE STANDARD DEVIATION
NITRATE NITROGEN mg/l
3
2.5
2
1.5
1
0.5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 6



FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY DISSOLVED ORTHO-P
MEAN OF 11-YR PERIOD, 1976-1986
WQRRS MODEL-REVISED CALIB.
±ONE STANDARD DEVIATION
DISSOLVED ORTHO P mg/l
1
0.8
0.6
0.4
0.2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 7

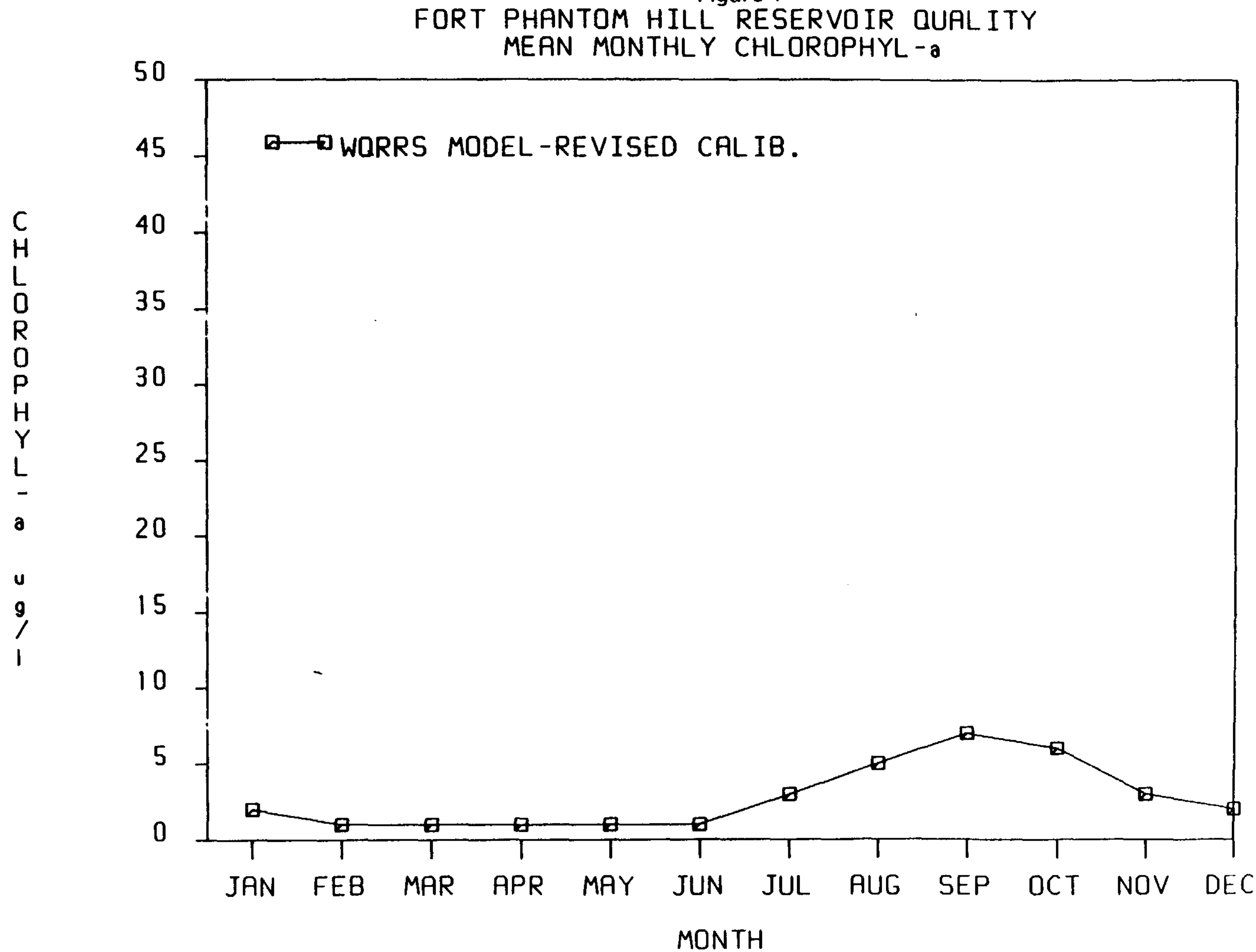

FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY CHLOROPHYL-a
WQRRS MODEL-REVISED CALIB.
CHLOROPHYL-a ug/l
50
45
40
35
30
25
20
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 8

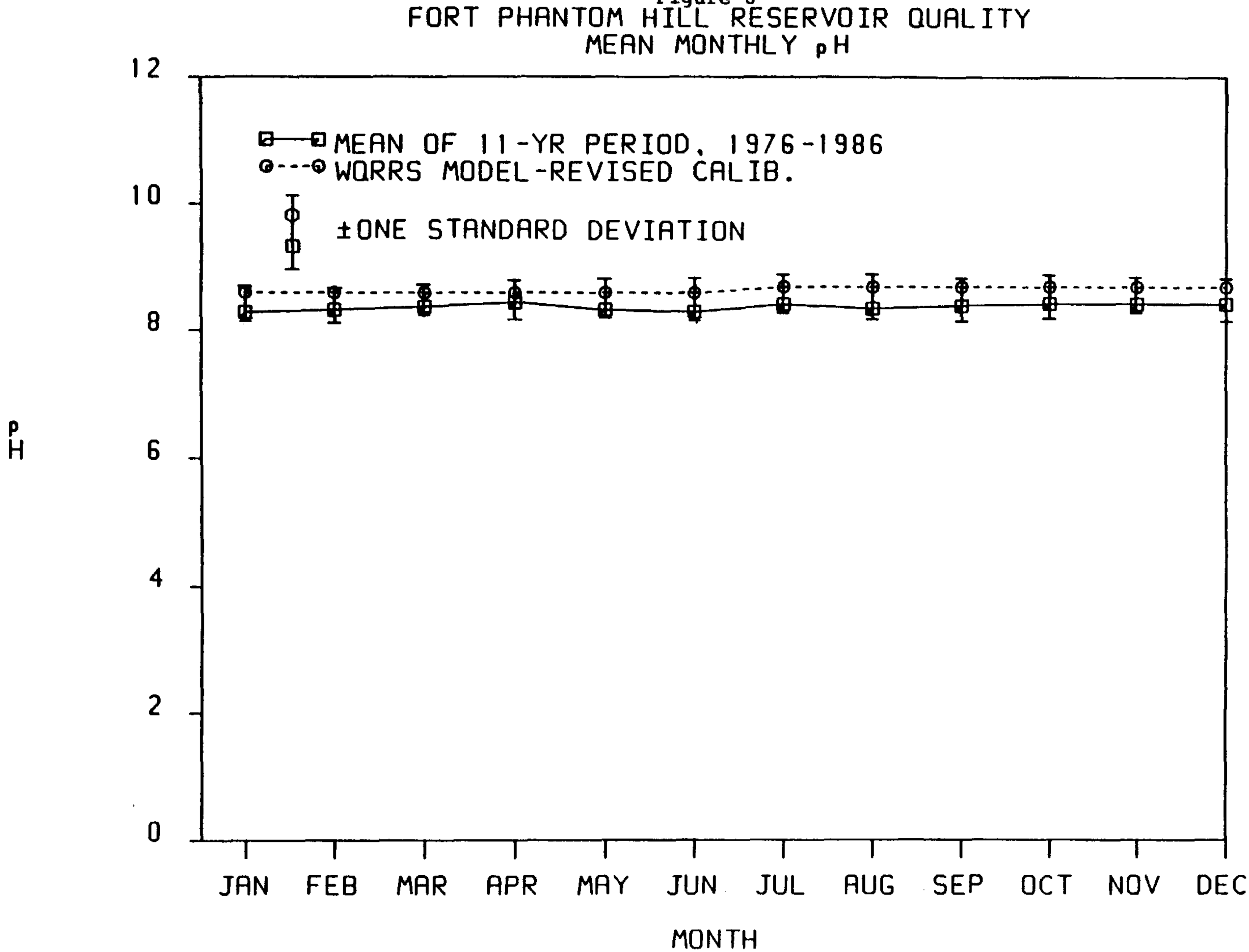

FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY pH
MEAN OF 11-YR PERIOD, 1976-1986
WQRRS MODEL-REVISED CALIB.
±ONE STANDARD DEVIATION
pH
12
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 9

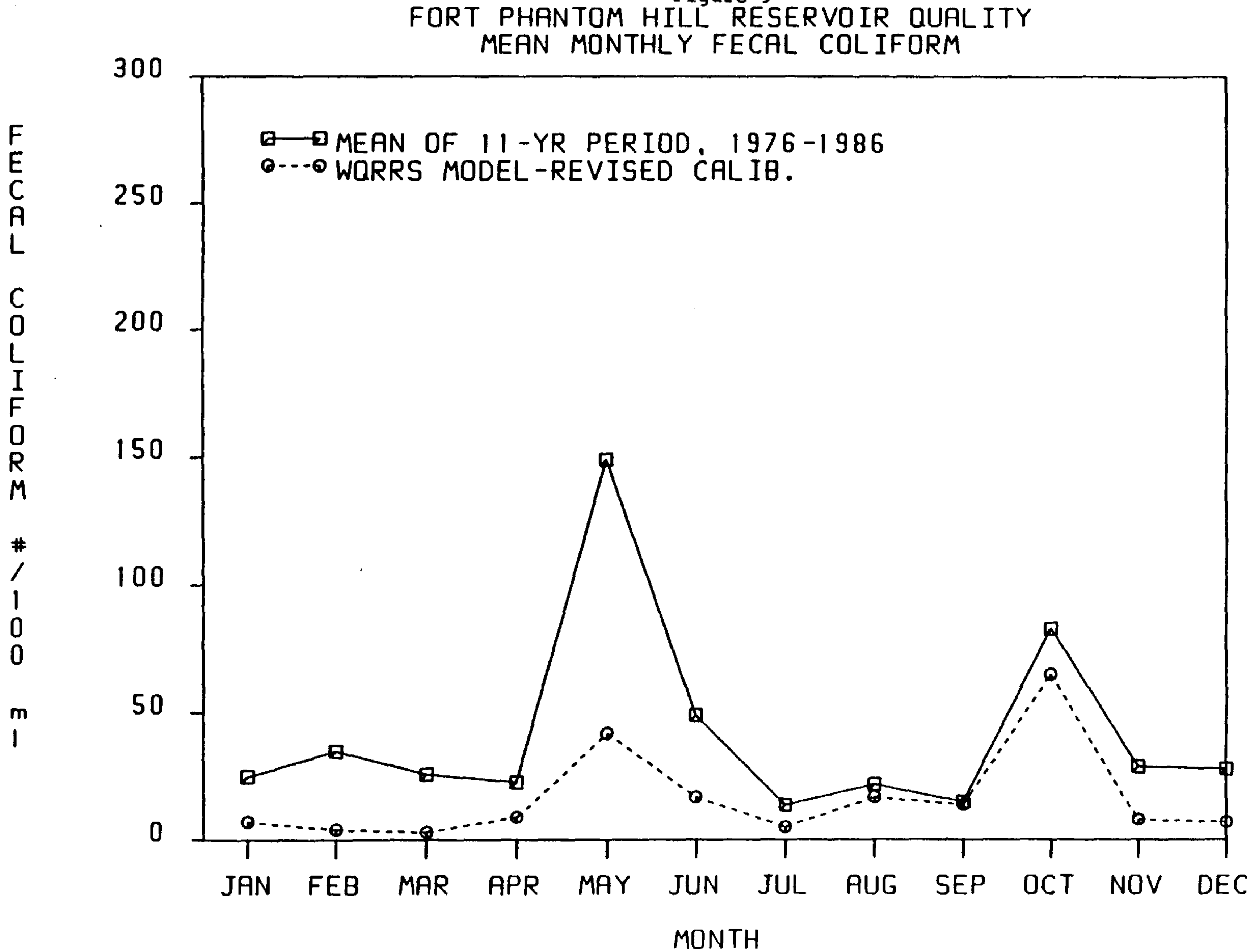

FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY FECAL COLIFORM
MEAN OF 11-YR PERIOD, 1976-1986
WQRRS MODEL-REVISED CALIB.
FECAL COLIFORM #/100 ml
300
250
200
150
100
50
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 10

FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY TOTAL DISSOLVED SOLIDS

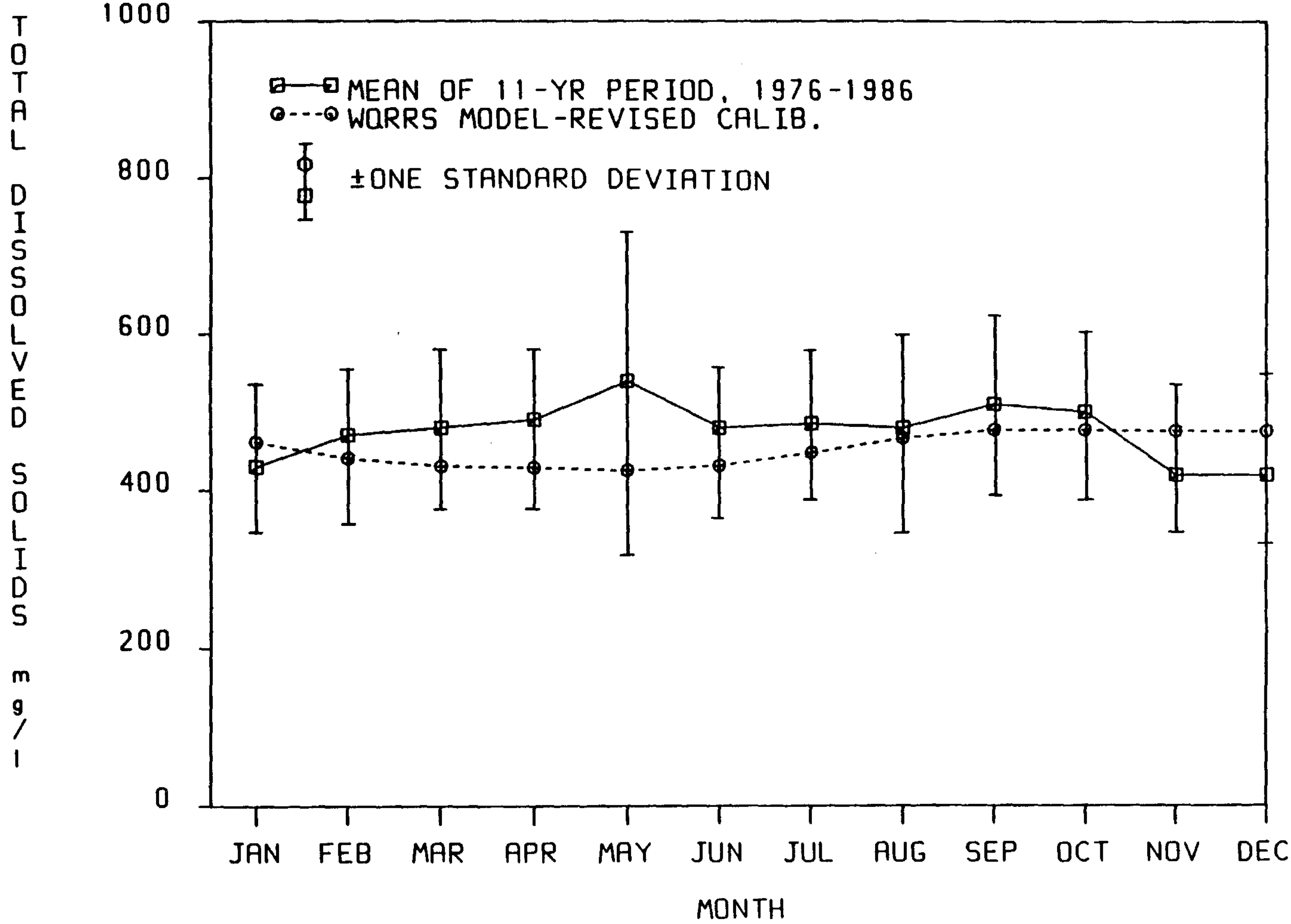
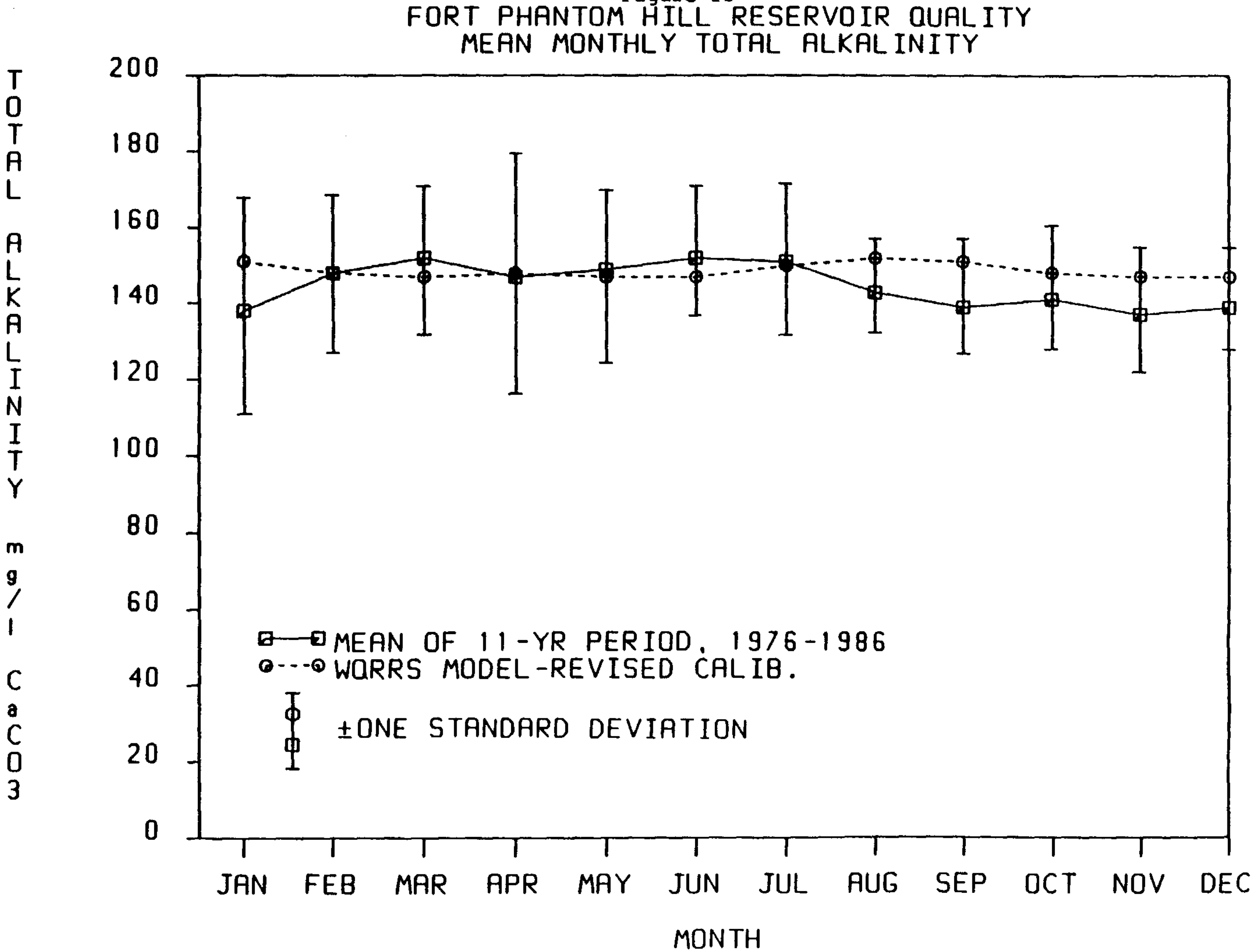
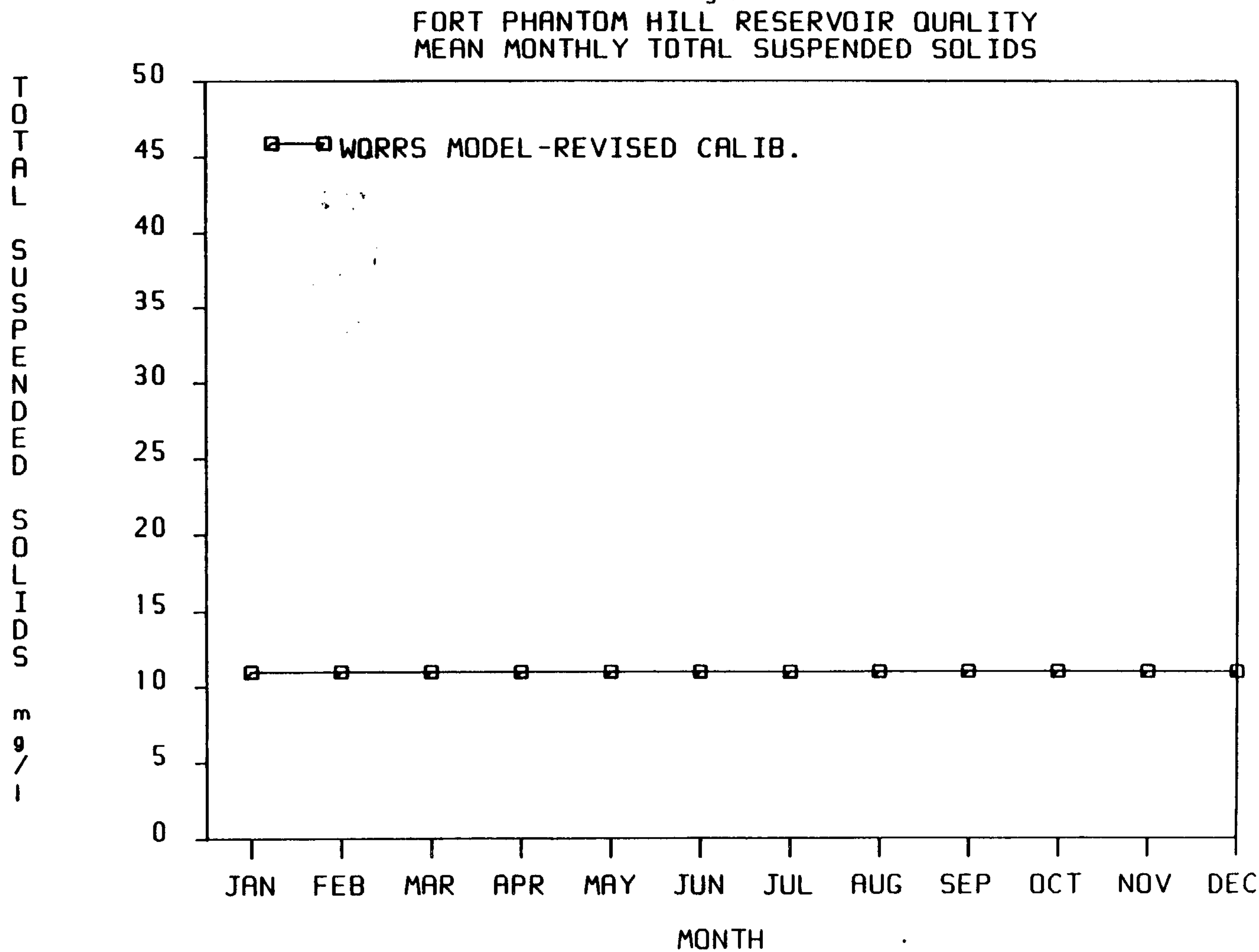


Figure 11



FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY TOTAL ALKALINITY
TOTAL ALKALINITY mg/l CaCO3
200
180
160
140
120
100
80
60
40
20
0
MEAN OF 11-YR PERIOD, 1976-1986
WQRRS MODEL-REVISED CALIB.
±ONE STANDARD DEVIATION
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 12



FORT PHANTOM HILL RESERVOIR QUALITY
MEAN MONTHLY TOTAL SUSPENDED SOLIDS
TOTAL SUSPENDED SOLIDS mg/l
50
45
40
35
30
25
20
15
10
5
0
WQRRS MODEL-REVISED CALIB.
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

The model has not been able to entirely capture the monthly fluctuations of NH_3 and NO_3 or O-PO_4 via nitrification and biological activity. The overall magnitudes of the nutrients on an annual basis are reasonable. The model may require better tributary loading information to appropriately account for the monthly changes shown in the field data. The timing and location of sampling may also have biased the actual mean reservoir concentrations shown in the comparison graphs.

The dips and rises in the historic NH_3 and O-PO_4 are probably related to algal productivity, but the September rise in observed NO_3 suggests the model may also have some imbalance in the NH_3 loading, since the model NO_3 actually decreases rather than increases in September. Careful review of the historical data has shown that several monthly means of the nutrients were established from only a very few data values over the 11-year period. This tends to severely bias the historical means and must be acknowledged in the interpretation of the model results.

The vertical profiles of water quality in the model indicate less than a 1°C temperature variation from the reservoir surface to the bottom throughout the year. Average monthly water column levels of DO are above 7.0 mg/l, which is sufficient to maintain aerobic conditions and support fish and other aquatic life.

Surface concentrations of algae vary throughout the annual cycle with low levels during winter and spring periods, increasing throughout the summer with peaks in August and September. The model ratio of chlorophyll-a (ug) to algae biomass (mg) was assumed at 30. This ratio provided chlorophyll-a concentrations in the range of the observed field data between 2 and 40 ug/l. The maximum chlorophyll-a concentrations were estimated by the model during calibration at 8 to 10 ug/l, assuming complete mixing. Should the model algae concentrations have been limited to the surface layers, the resultant values would be three to four times greater or about 24 to 40 ug/l of chlorophyll-a. Therefore, the completely mixed levels of 8 to 10 ug/l were felt to be appropriate in calibrating the model for a generally well mixed system.

The concentration of fecal coliform in the water column varied seasonally with the assumed runoff effects (inferred in the data) and the density of the inflows. The vertical coliform distribution showed where the equilibrium level density occurred and whether the inflows to the reservoir tended to stay near the surface of the reservoir or the bottom. This phenomenon may be critical to the AWT discharge and raw water intake. Fecal coliform concentrations tend to exaggerate the effects of vertical water movement from month to month because of the significant differences (three times) of the inflow values assumed during the higher runoff periods. The other values of water quality are less variable, and changes due to various ecologic processes become masked.

The TDS and alkalinity model results are generally similar to the historical data. The monthly variations depicted by the field data are thought to be more a result of variations in the tributary inflows since the model uses relatively constant values of TDS and alkalinity for the runoff.

The pH-alkalinity-algal productivity relationships may not be properly captured in the field data. The pH-CO_2 equilibrium routines in the model indicate the pH-CO_2 balance with alkalinities of this range are virtually unaffected by biological activity. A sensitivity analysis with the model demonstrated no more than 0.2 pH unit variance due to algae. It is apparent the model finds a pH-CO_2 equilibrium different from that found in the field. A chemical imbalance may be suggested in the field data between the CO_2 gas transfer mechanisms, the alkalinity and pH of the tributary inflows or diversions and the reservoir. The reservoir pH adjusts itself by 0.2 unit in the first month to a pH of 8.5 and oscillates between 8.6 and

8.8 for the balance of the year. The field data suggest a pH of no more than 8.3 or 8.4 is the range to be expected.

Some discussion has been offered about the legitimacy of the model's pH-CO_2 equilibrium mechanics in light of current research on acid rain. It is conceivable that new technology may be available for modeling the acid-pH chemistry of surface waters. At this point, however, better quantification of pH and alkalinity date for the diversion and inflow water may be a more practical approach to consider, if necessary.

The fecal coliform results are only as good as the estimated data for the monthly tributary /diversion loadings. No data were available; therefore, estimates of loads were made based on the principle that high runoff periods often carry high washoff loads of coliforms not typically found during other times of the year. This phenomenon is dependent on the surrounding land use patterns and the location of potential sources such as feed lots, dairies, and similar facilities which could produce peaks of fecal coliforms during high runoff periods.

MODEL CALIBRATION COMMENTS

The WQRRS model calibration on LFPH shows substantial promise for developing a representation of the lake system consistent with the field data and observations. Parameters which may require changes and/or updates in the future are:

- pH-CO_2-alkalinity balance
- Nutrient-algal relationships to the tributary loadings
- General tributary/diversions water quality data base

As the inconsistencies in these parameters are either resolved through more data collection or model modifications, or are determined to be of minor consequence, the WQRRS model should become a more useful tool to examine the relative impacts of AWT discharge levels in LFPH.

The objectives of this study and the ultimate goals of the analysis have been discussed with Noel Williams/SAC. Should one of the planning goals be to track an effluent plume through the lake (assuming one would exist), then another model may need to be considered since the one-dimensional WQRRS model assumes uniform concentration in each horizontal layer and therefore cannot show transport of material horizontally. For the purpose of tracking an AWT plume which might contain a pathogenic substance, a two-dimensional model of the lake would be needed to follow the material from the discharge location throughout the lake as it is affected by wind shear, inflows and withdrawal velocity fields. This sort of approach would assume complete vertical mixing at the point of maximum rise height of the plume. The ultimate concern of mixing AWT water with the raw water supply will probably be the issue of dilution and potential contamination levels in the lake, locally and far afield.

In addition to the current modeling objectives, the issue of toxic concentrations of un-ionized ammonia in the LFPH waters will be a concern to the fishery. The temperatures and pH of the waters are adequate to generate percentages of un-ionized ammonia in the range of 10 to 20 percent of total ammonia. Since the total ammonia concentrations in LFPH are currently of the 0.2± mg/l magnitude, the existing un-ionized fraction could approach or exceed the 0.02 to 0.04 mg/l level during drought conditions. The EPA standard for un-ionized ammonia will also become stricter. This issue will be discussed in the alternatives analysis section.

AWT DISCHARGE -- ALTERNATIVES ANALYSIS

The proposed AWT discharges to LFPH were determined to be 3, 7, 12, and 17 mgd for Type A, Type B, and Type C effluent quality. Type A quality would be defined as the best quality effluent with lower BOD_5 $O\text{-}PO_4$, NH_3, NO_3, TDS, and suspended solids. Table 5 shows the water quality parameters defined for the AWT effluent types.

These data were used in the analysis of alternatives using Type A, Type B, and Type C discharge water quality for each of the two plant flowrates (3 mgd and 7 mgd) and Type A only at the 12 mgd and 17 mgd flowrates for comparison.

These alternatives were considered for a 2-year drought-type hydrologic condition following operation under normal hydrologic conditions. The drought condition comparisons show the impacts of the AWT plant on LFPH water quality during severely low water supply conditions.

The inflow water quality from the natural runoff and from the sions is likely to be of poorer quality during the drought conditions. No data were available to assess the degree of degradation in the natural runoff except as reflected in the LFPH data in 1977, which was considered a drought year. The LFPH data indicated a significant increase in nitrates and TDS during dry years with phosphates remaining near their normal levels.

Due to lack of specific data, the water quality of the natural runoff and diversions into LFPH were kept the same for drought conditions as for the normal runoff conditions used during model calibrations. These water quality concentrations are shown in Table 5.

Table 5

AWT DISCHARGE WATER QUALITY

Parameter	Type A	Type B	Type C
DO	85% Saturation	Same	Same
BOD_5	5.0 mg/l	5.0 mg/l	10.0 mg/l
NH_3	2.0 mg/l	2.0 mg/l	3.0 mg/l
NO_3	10.0 mg/l	10.0 mg/l	25.0 mg/l
P_T	0.2 mg/l	2.0 mg/l	10.0 mg/l
TDS	800 mg/l	800 mg/l	1,100 mg/l
pH	7.0 units	Same	Same
Fecal Coliform	2.0 MPN/100 ml	Same	Same
Alkalinity	100 mg/l	Same	Same

The hydrology of the drought condition analysis was adjusted according to data in Table C-3 of Study of Coordinated Operation of Existing Raw Water Supply Sciences, Abilene and West Central Texas Municipal Water District, (Freese and Nichols, 1980) and assumptions based on project team discussions.

Table 6 shows the hydrologic data used in the analysis for both the normal year (calibration) and the drought year (alternatives). The reduction of natural waters directed into LFPH during drought conditions is about 73 percent from the normal-year condition.

The drought-condition base case was used to compare each of the AWT discharge alternatives with how the systems would operate without AWT discharge during drought years but having been preceded by 3 mgd discharge under normal years for some time. An initial storage pool of 65,000 acre-feet was assumed using the Table 6 inflows and diversions. Included into the base case analysis was the "drought year" water demand for the year 1990 of 17 mgd, or approximately 19,200 acre-feet annually. The water balance during 2 years of the drought conditions would show a maximum decrease in the storage pool of about 46,000 acre-feet at the 3 mgd discharge level for the AWT plant. Figure 13 shows the other changes in LFPH storage for the different discharge alternatives.

The alternative analysis process incorporates and separately analyzes the impacts on LFPH from an increase to the available water supply due to AWT discharges from 3 mgd to 17 mgd (3,350 acre-feet/year to 19,000 acre-feet/year). These AWT inflow accretions to LFPH would serve to attenuate the 2-year storage losses from a possible 50,000 acre-feet with AWT inflows to between 22,000 acre-feet and 46,000 acre-feet. The minimum ending balance of LFPH water storage would be about 19,000 acre-feet under the 3 mgd discharge alternatives.

Table 6

HYDROLOGIC CONDITIONS OF LFPH INFLOWS
(acre-feet)

NORMAL HYDROLOGIC CONDITIONS (CALIBRATION)

Reservoir Accretions

Natural Inflow	22,500
Direct Rainfall	5,900
Deadman Creek Diversion	2,000
Clear Fork-Brazos Diversion	6,000
	36,400

Reservoir Withdrawals

Raw Water Intake	21,600
Lake Evaporation (Model Result)	15,100
Consumptive Use by WTU	2,200
	38,900

2-YEAR DROUGHT HYDROLOGIC CONDITIONS (ALTERNATIVES)

Reservoir Acretions

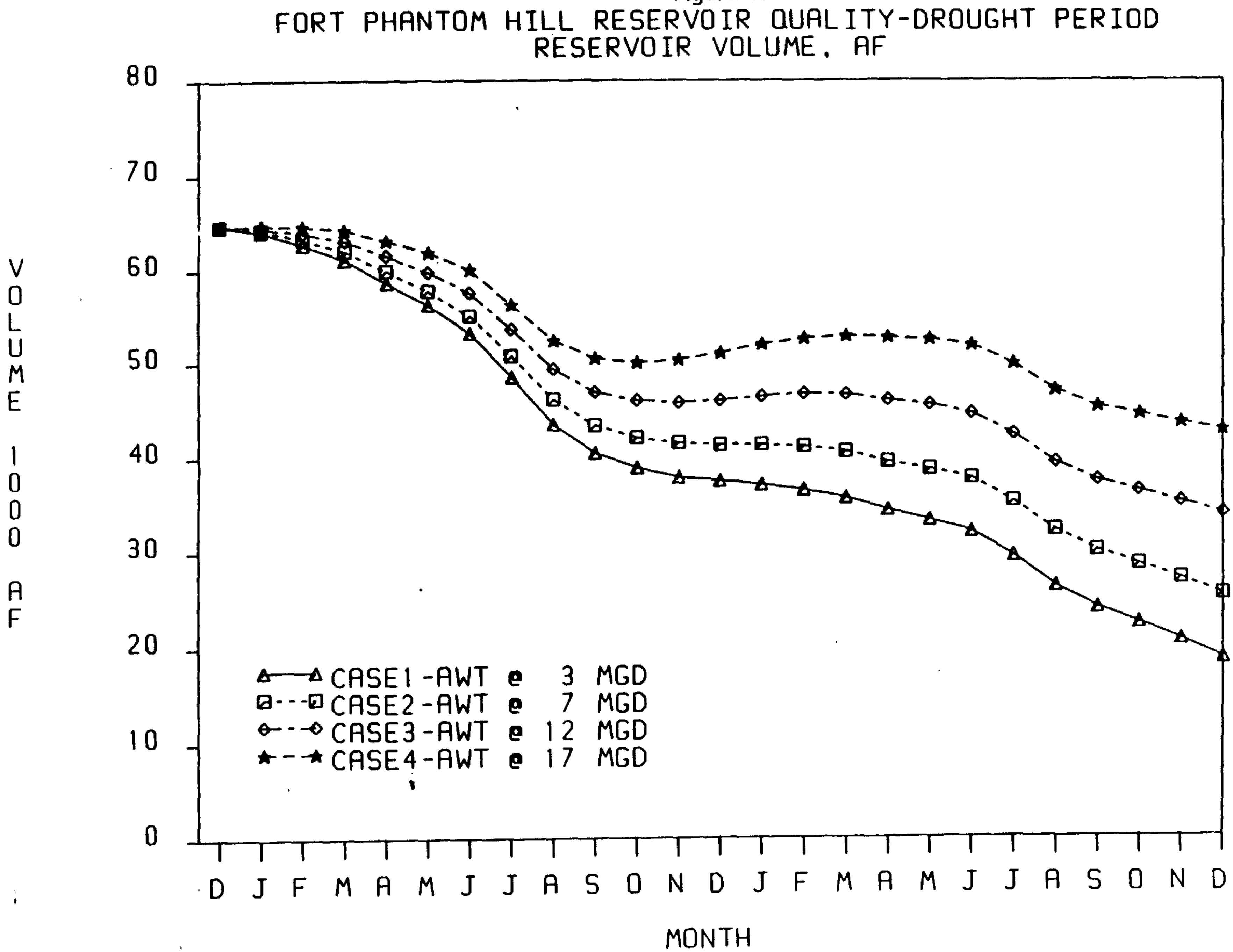
Natural Inflow	5,500
Direct Rainfall	2,300
Deadman Creek Diversion	0
Clear Fork-Brazos Diversion	2,140
	9,940

Reservoir Withdrawals

Raw Water Intake (1990 projected demand)	19,200
Lake Evaporation (Estimated)	16,000[1]
	35,200

[1]WTU evaporative losses are included within this total. WTU has reported water rights of 2,500 ac.ft. per year and no drought contingency plan.

Figure 13


FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
RESERVOIR VOLUME, AF
80
70
60
50
40
30
20
10
0
VOLUME 1000 AF
CASE1-AWT @ 3 MGD
CASE2-AWT @ 7 MGD
CASE3-AWT @ 12 MGD
CASE4-AWT @ 17 MGD
D J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

The water quality impacts resulting from discharging 3 mgd AWT effluent into the LFPH system over a 2-year drought period following a period of AWT discharge during normal water years at a 3 mgd level using Type A effluent water quality are shown in Figures 14 through 18. These figures describe the changes due to the AWT discharge to LFPH at a 3 mgd level only. Additional insight into the affects of the three treatment levels at the proposed AWT are also shown. Figures 19 through 23 and Figures 24 through 28 show the similar effects of the three effluent water quality types a the 7 mgd and the Type A effects at 12/17 mgd levels. The alternatives were each analyzed using an estimate initial condition in the LFPH reservoir. This initial condition reflects the impact of 3 mgd effluent discharging into the lake using Type A water quality for a period of 2-5 years. The estimated initial conditions of the LFPH water quality are shown in Table 7.

HYDROLOGIC IMPACTS

The drought condition alternatives experience about a 23,000 to 46,000 acre-foot water storage deficit in LFPH over the 2-year cycle using the design year 1990 water demand estimates. The results of this demand are to lower the initial storage of LFPH from 65,000 acre-feet to between 37,000 and 50,000 acre-feet by the end of the first year, and to between 19,000 and 42,000 acre-feet by the end of the second year.

By continuing to add varying amounts of AWT discharges to LFPH, the resulting water balances of the system at the end of 2 years are shown in Table 8.

At the full 17 mgd AWT discharge level, the LFPH water storage in the system was kept to approximately 65 percent of the initial storage volume at the end of the drought.

Figure 14

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
TOTAL DISSOLVED SOLIDS (INITIAL VOLUME= 65000 AF)

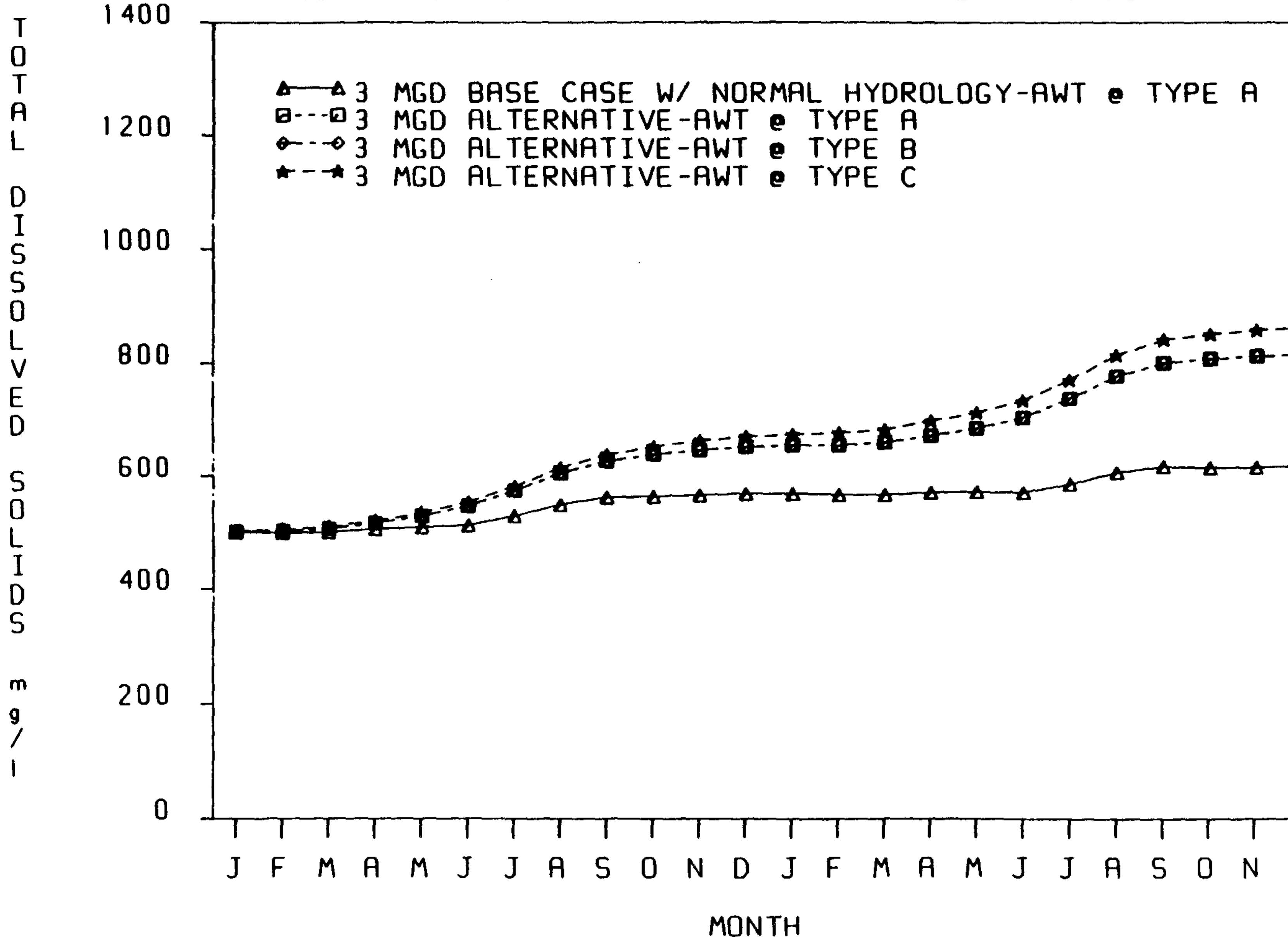
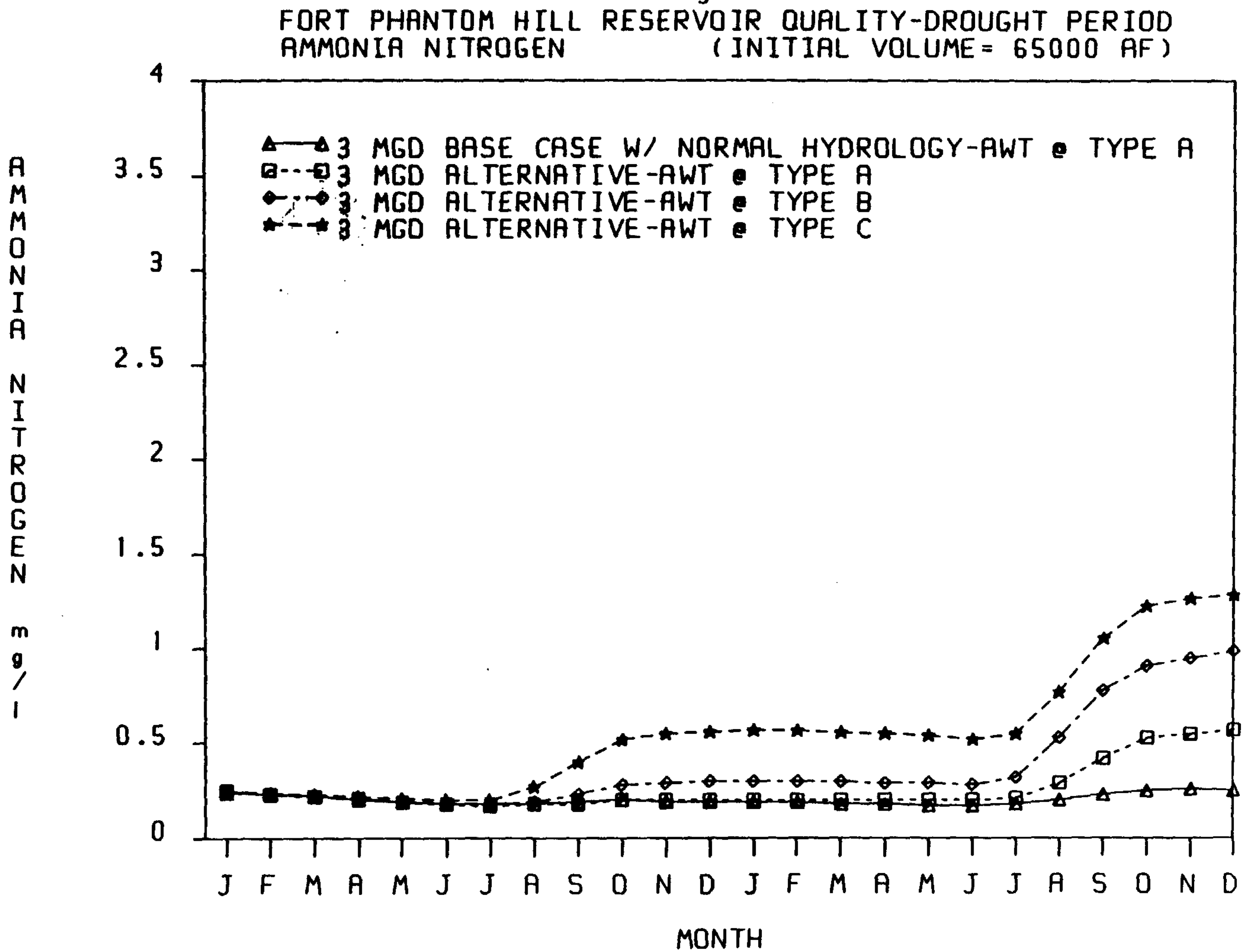


Figure 15



FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
AMMONIA NITROGEN (INITIAL VOLUME= 65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE B
3 MGD ALTERNATIVE-AWT @ TYPE C
AMMONIA NITROGEN mg/l
0
0.5
1
1.5
2
2.5
3
3.5
4
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 16

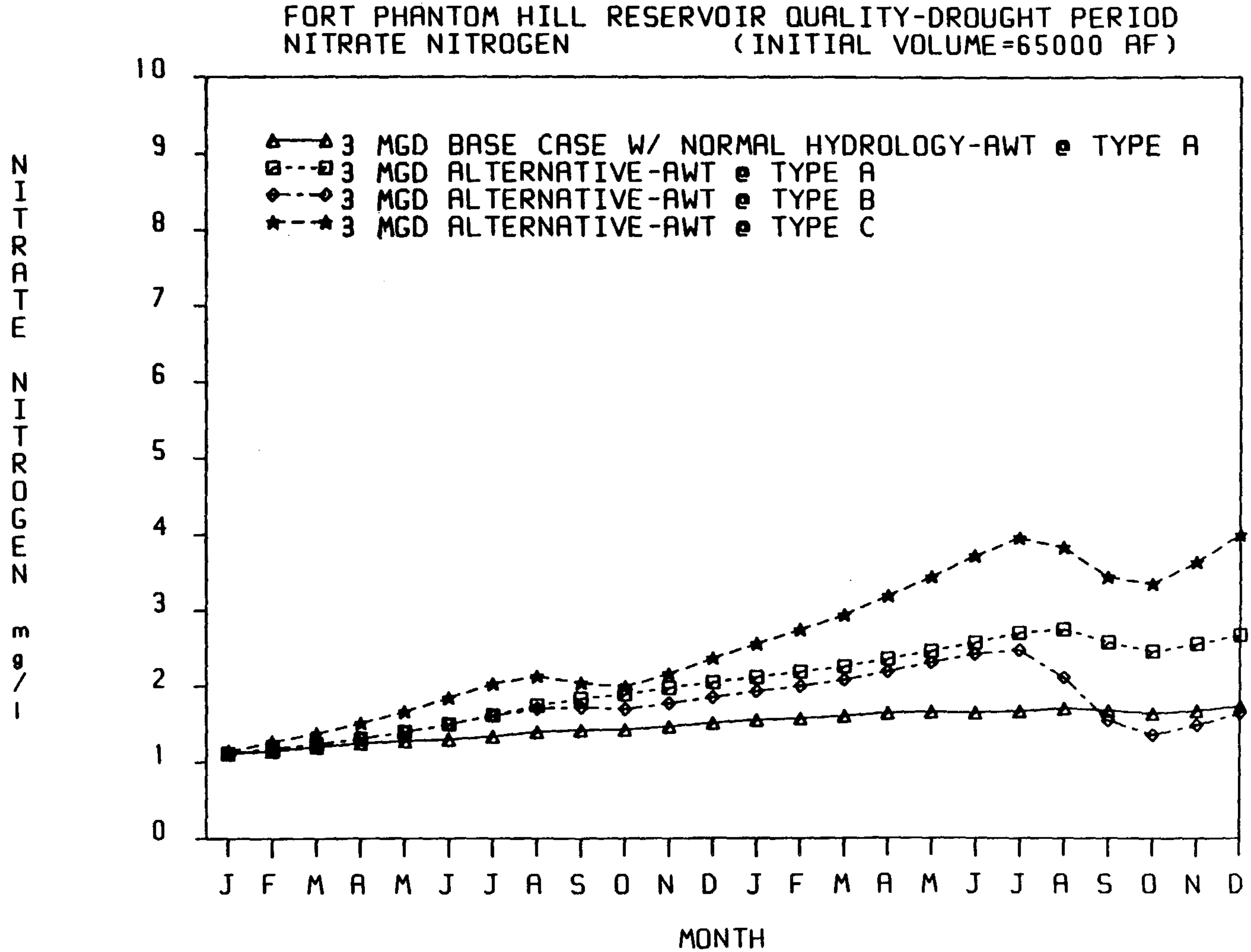

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
NITRATE NITROGEN (INITIAL VOLUME=65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE B
3 MGD ALTERNATIVE-AWT @ TYPE C
NITRATE NITROGEN mg/l
0
1
2
3
4
5
6
7
8
9
10
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 17

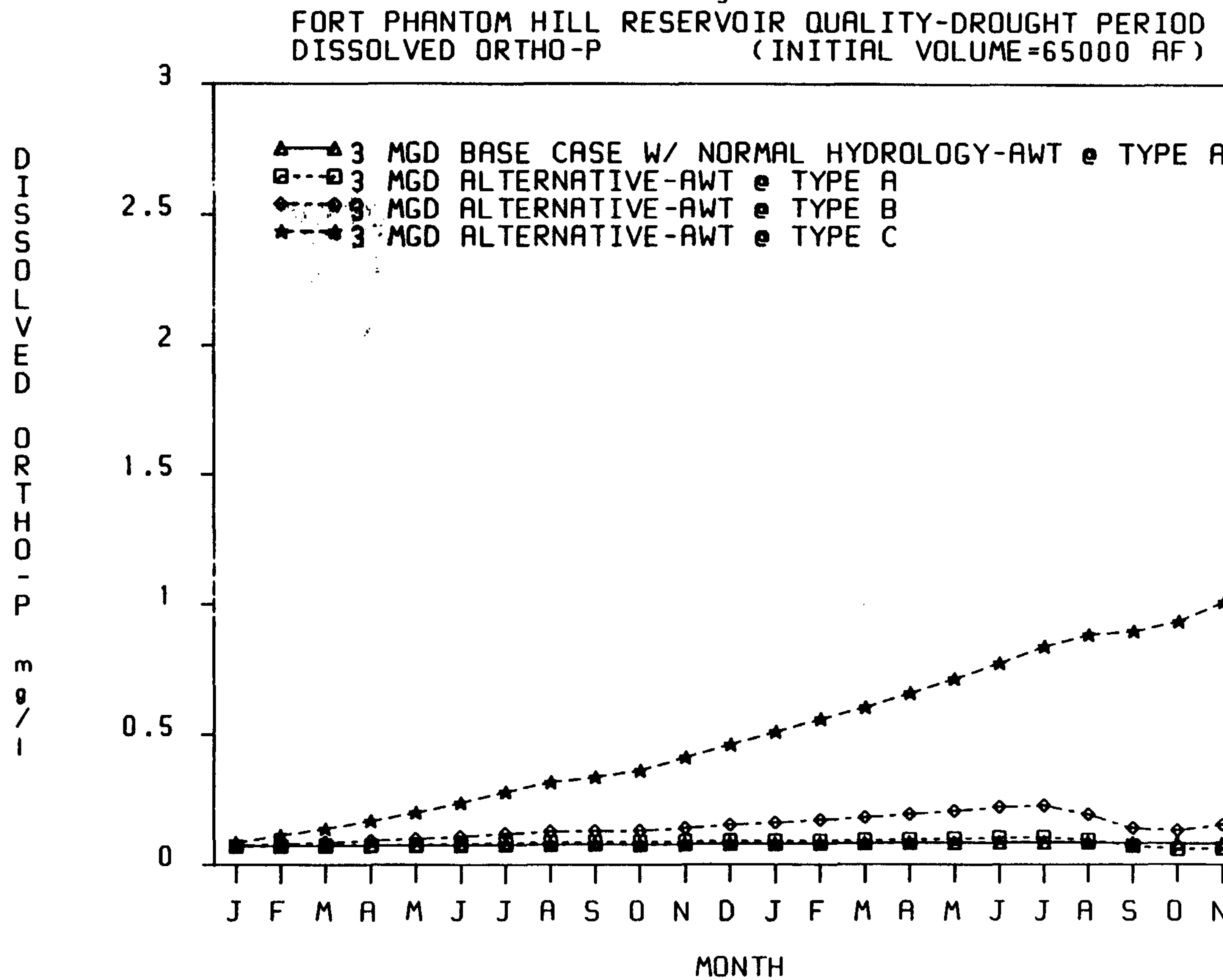

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
DISSOLVED ORTHO-P (INITIAL VOLUME=65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE B
3 MGD ALTERNATIVE-AWT @ TYPE C
DISSOLVED ORTHO-P mg/l
0
0.5
1
1.5
2
2.5
3
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 18

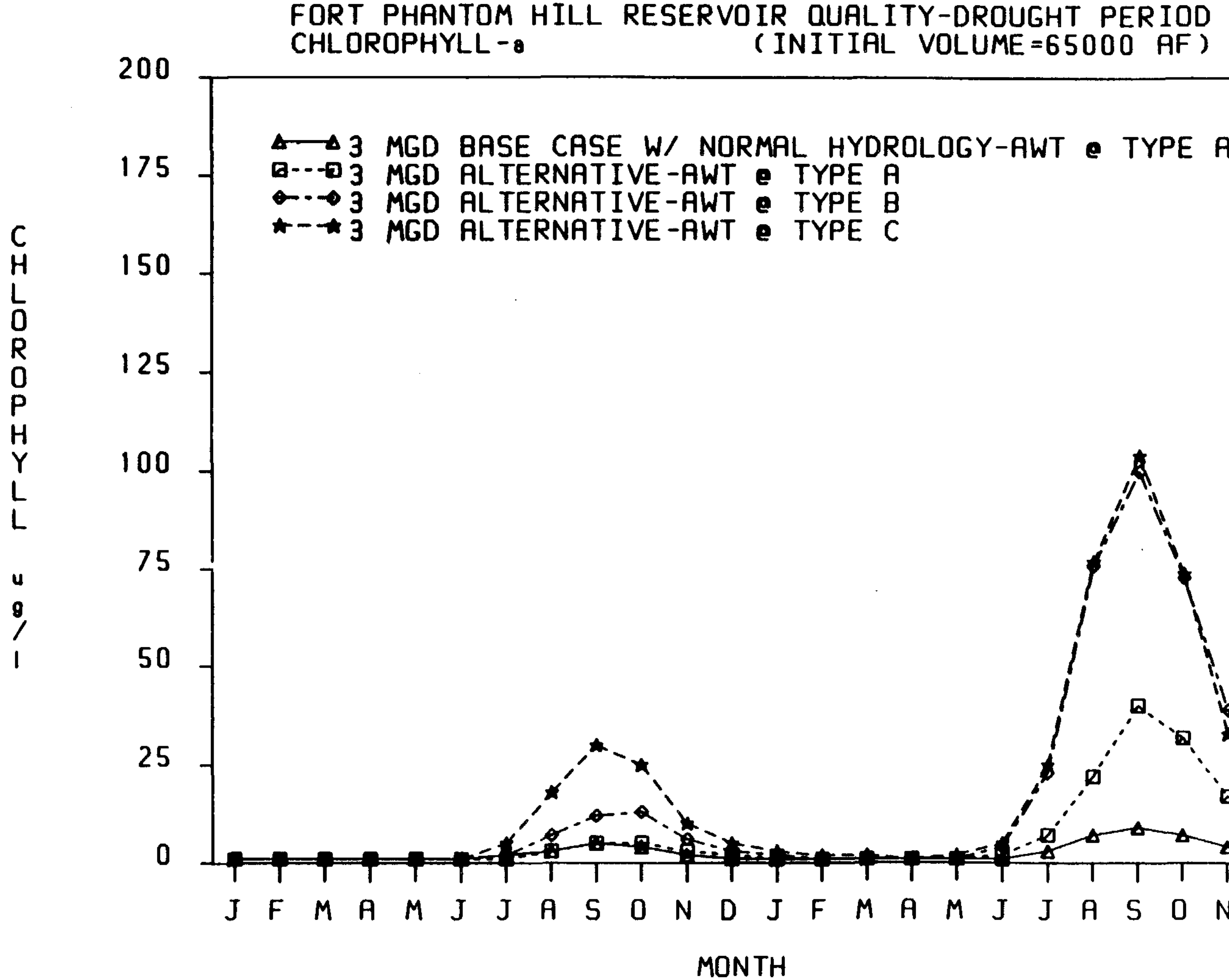

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
CHLOROPHYLL-a (INITIAL VOLUME=65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE A
3 MGD ALTERNATIVE-AWT @ TYPE B
3 MGD ALTERNATIVE-AWT @ TYPE C
CHLOROPHYLL ug/l
200
175
150
125
100
75
50
25
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 19

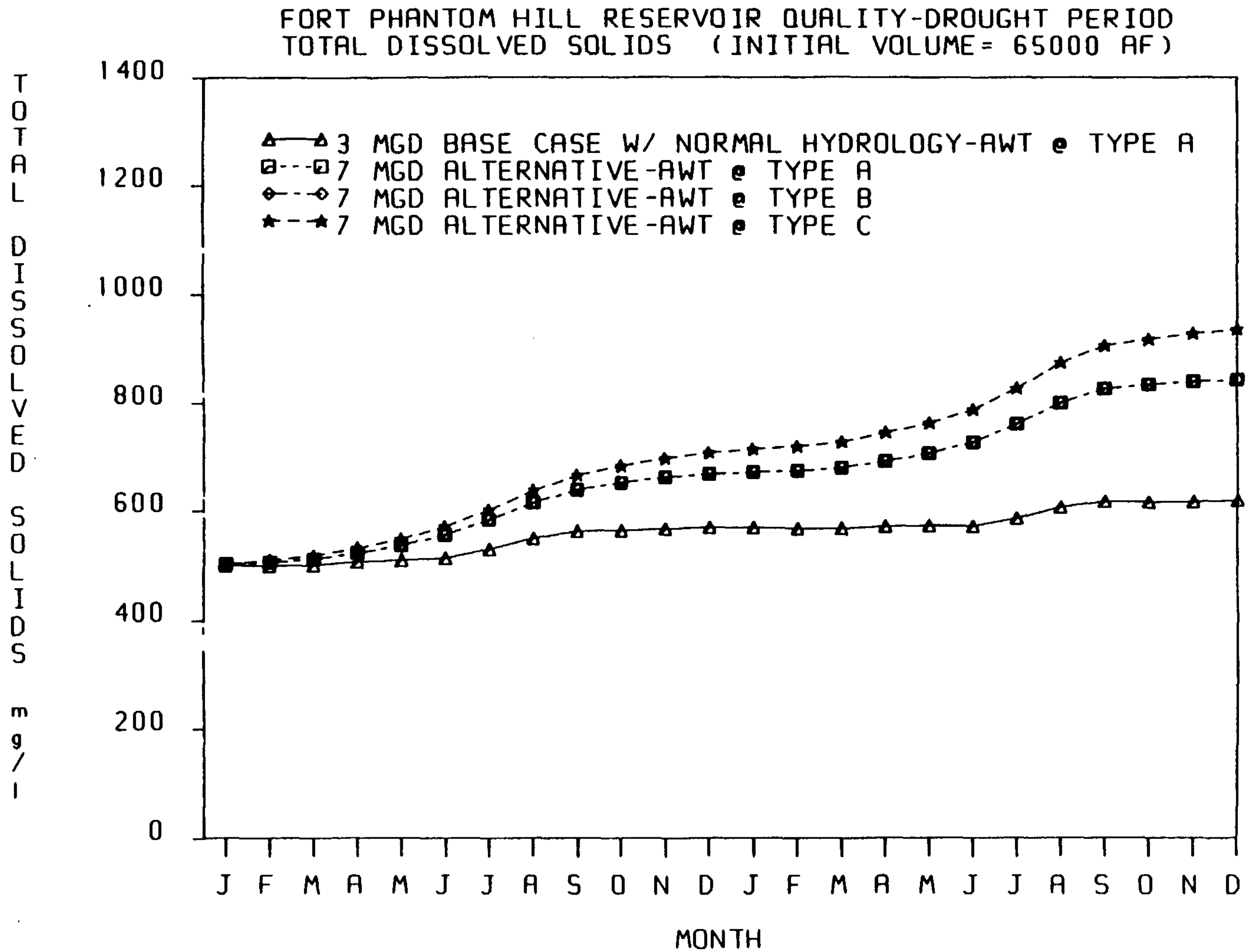

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
TOTAL DISSOLVED SOLIDS (INITIAL VOLUME= 65000 AF)
TOTAL DISSOLVED SOLIDS mg/l
1400
1200
1000
800
600
400
200
0
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE B
7 MGD ALTERNATIVE-AWT @ TYPE C
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 20

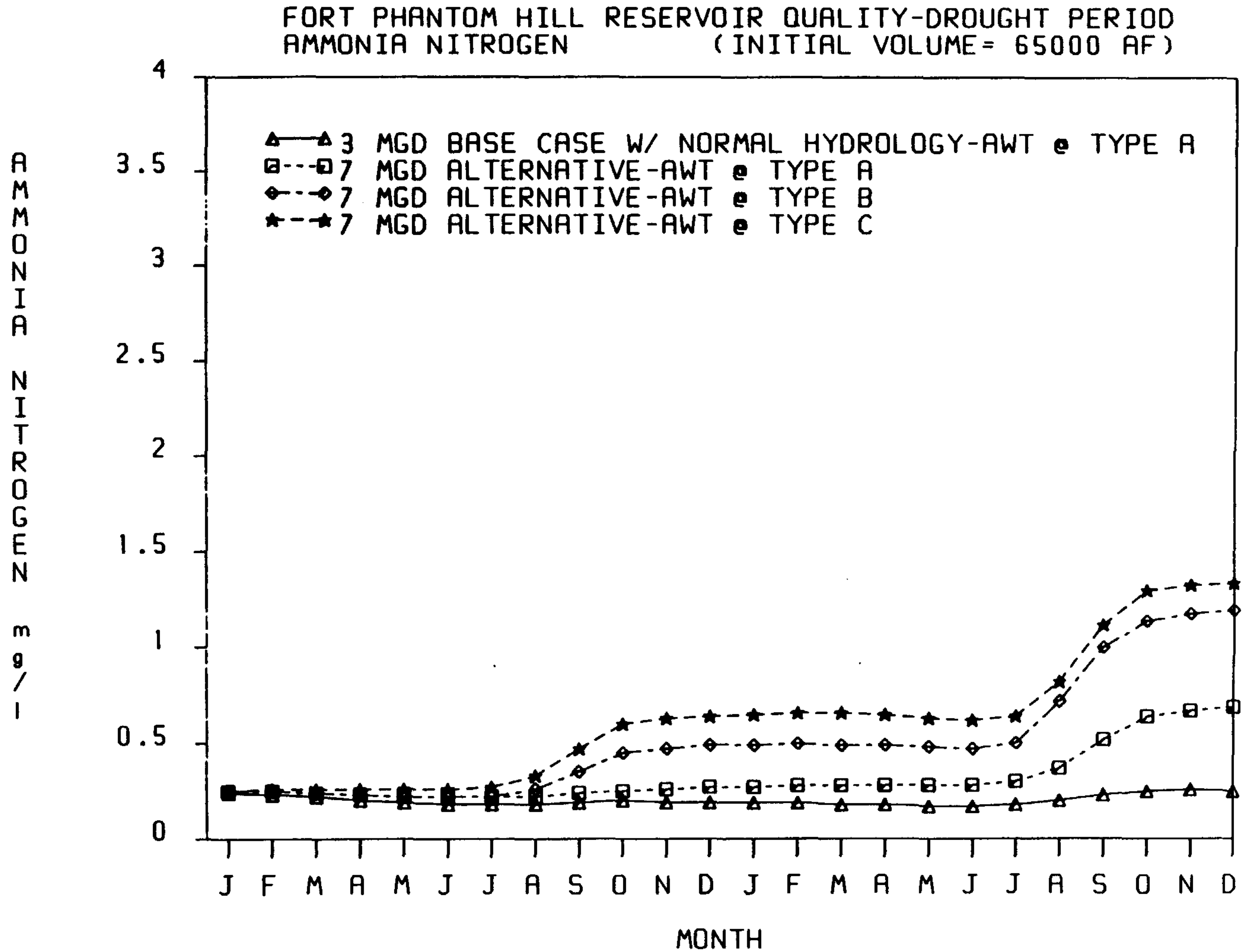

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
AMMONIA NITROGEN (INITIAL VOLUME= 65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE B
7 MGD ALTERNATIVE-AWT @ TYPE C
AMMONIA NITROGEN mg/l
4
3.5
3
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 21

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
NITRATE NITROGEN (INITIAL VOLUME=65000 AF)

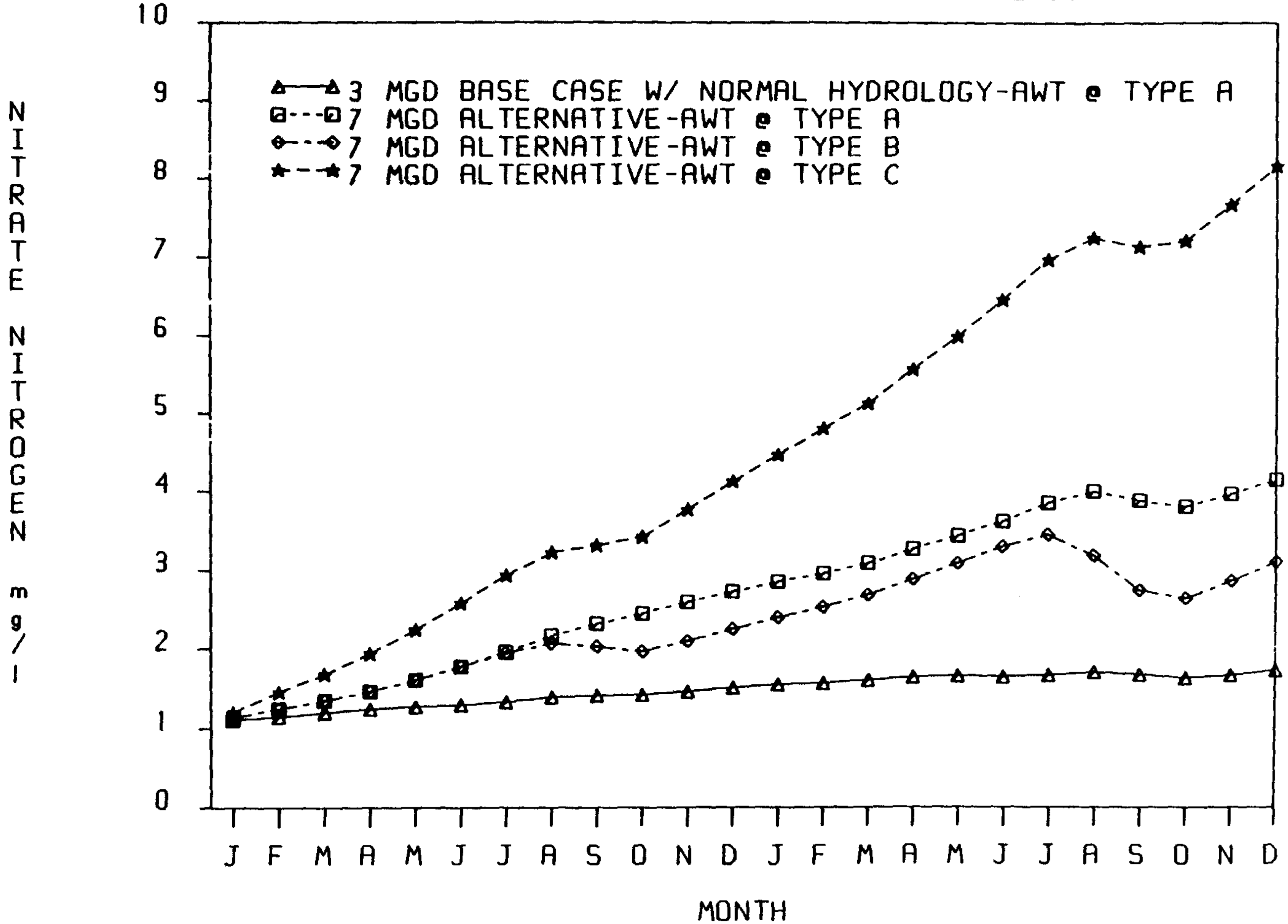
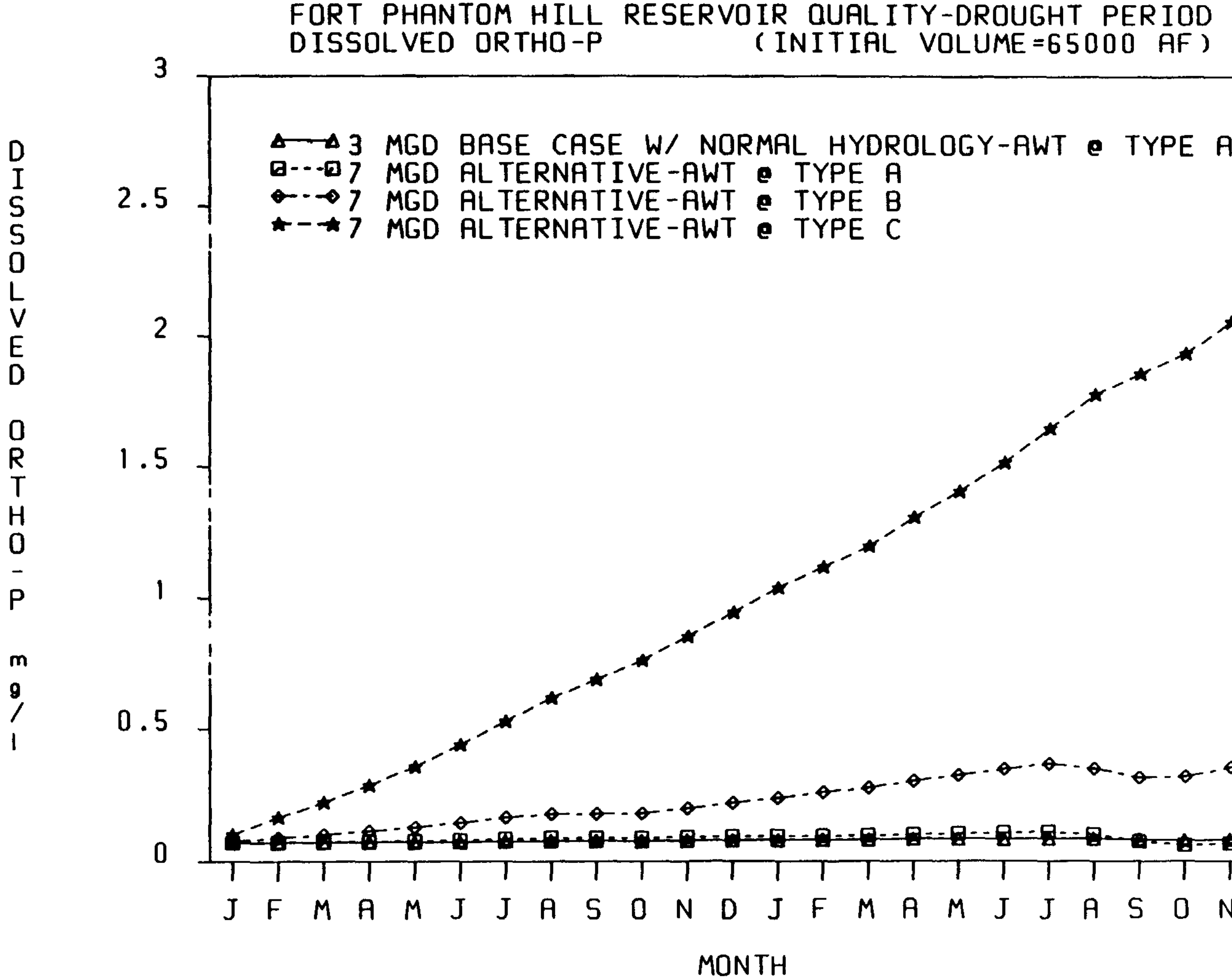


Figure 22



FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
DISSOLVED ORTHO-P (INITIAL VOLUME=65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE B
7 MGD ALTERNATIVE-AWT @ TYPE C
DISSOLVED ORTHO-P mg/l
3
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 23

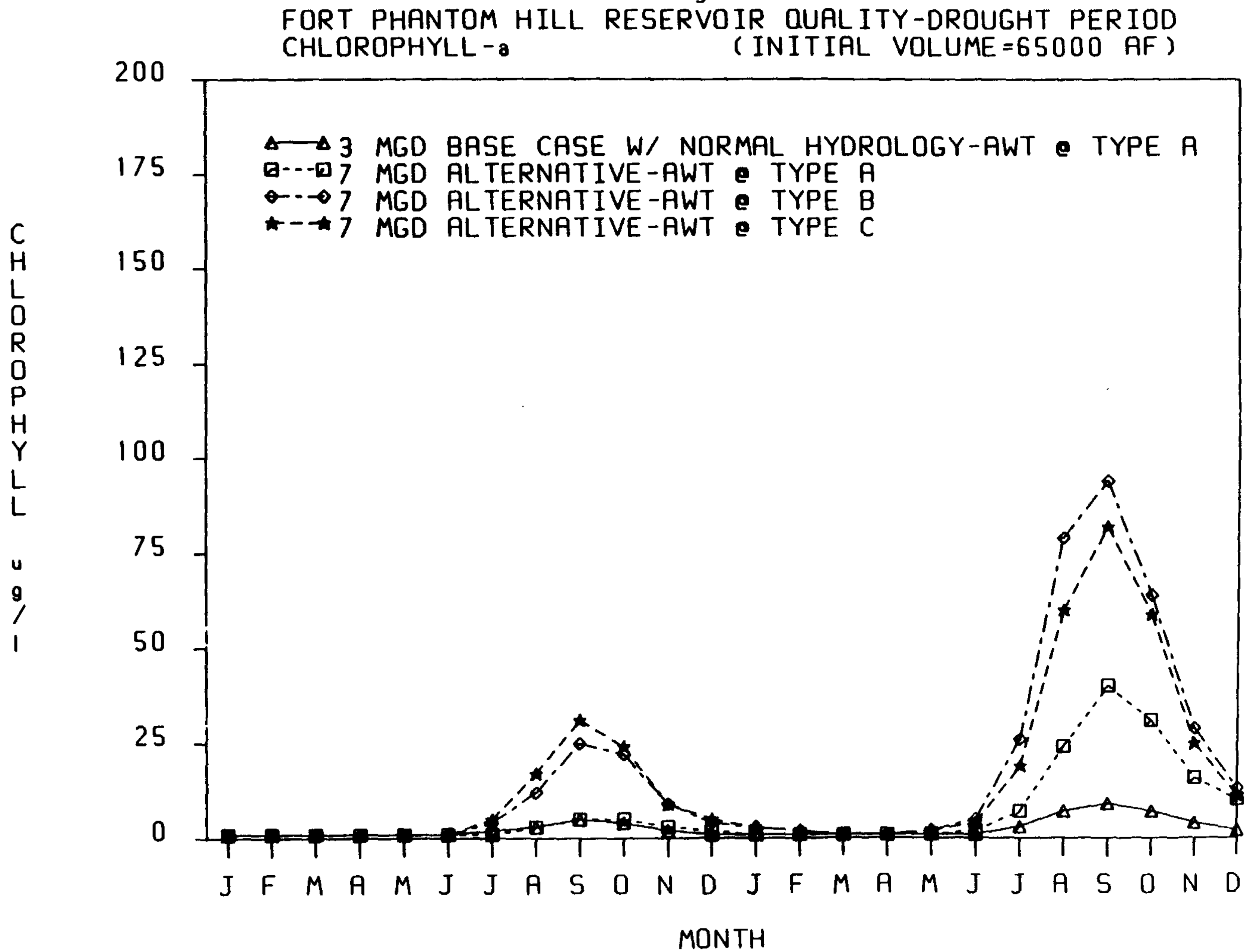
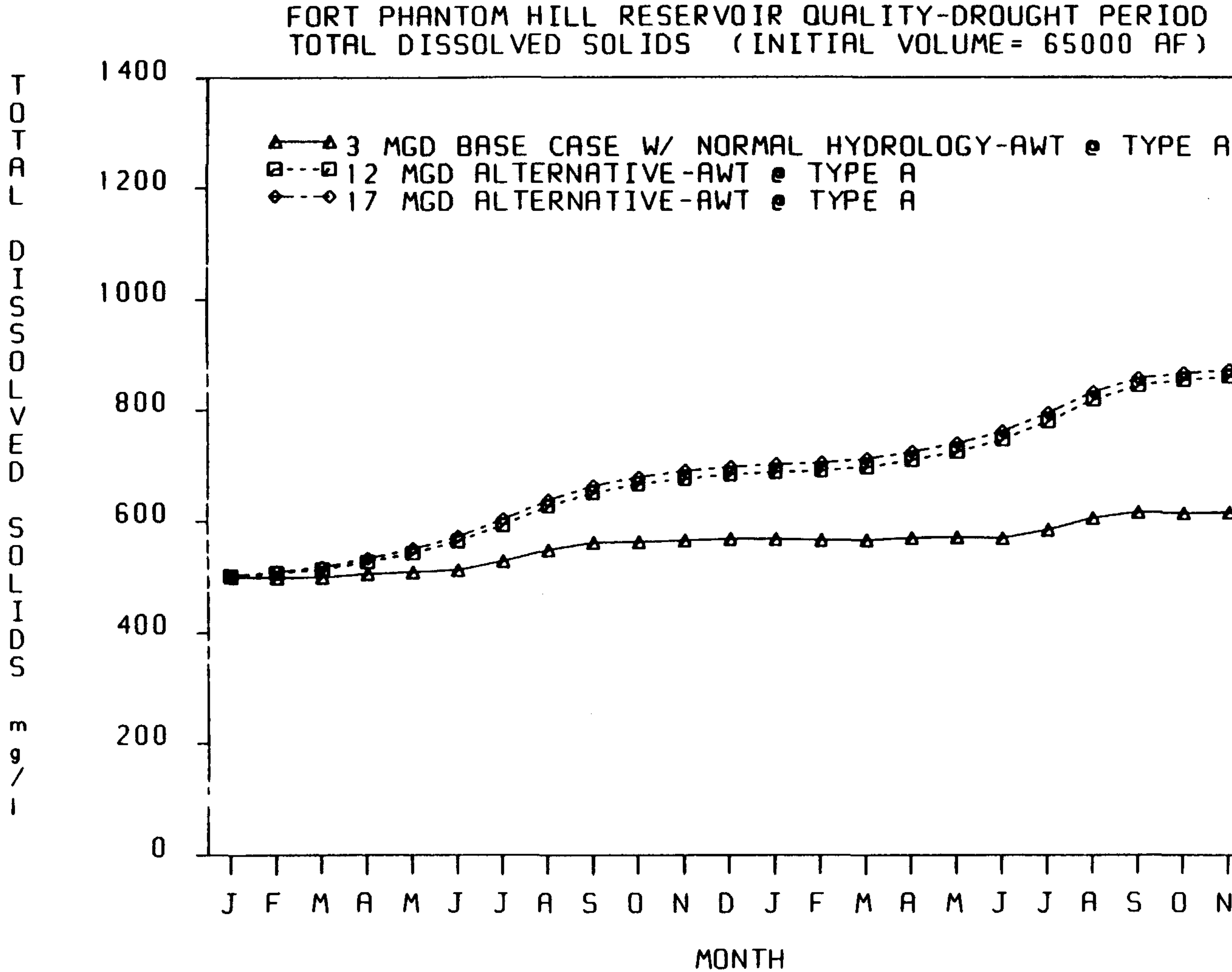
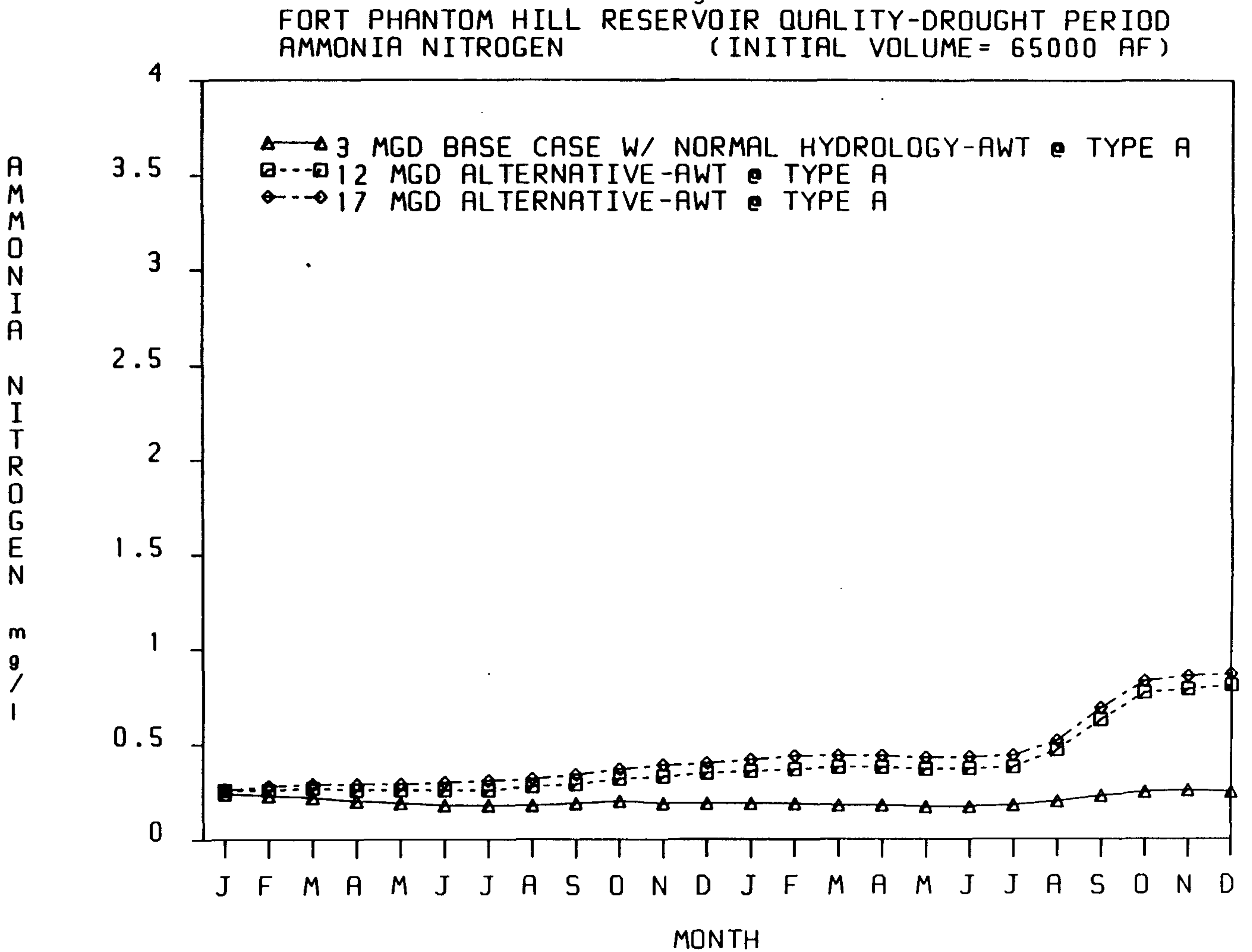

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
CHLOROPHYLL-a (INITIAL VOLUME=65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE A
7 MGD ALTERNATIVE-AWT @ TYPE B
7 MGD ALTERNATIVE-AWT @ TYPE C
CHLOROPHYLL ug/l
200
175
150
125
100
75
50
25
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 24



FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
TOTAL DISSOLVED SOLIDS (INITIAL VOLUME= 65000 AF)
TOTAL DISSOLVED SOLIDS mg/l
1400
1200
1000
800
600
400
200
0
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
12 MGD ALTERNATIVE-AWT @ TYPE A
17 MGD ALTERNATIVE-AWT @ TYPE A
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 25



FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
AMMONIA NITROGEN (INITIAL VOLUME= 65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
12 MGD ALTERNATIVE-AWT @ TYPE A
17 MGD ALTERNATIVE-AWT @ TYPE A
AMMONIA NITROGEN mg/l
4
3.5
3
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 26

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
NITRATE NITROGEN (INITIAL VOLUME=65000 AF)

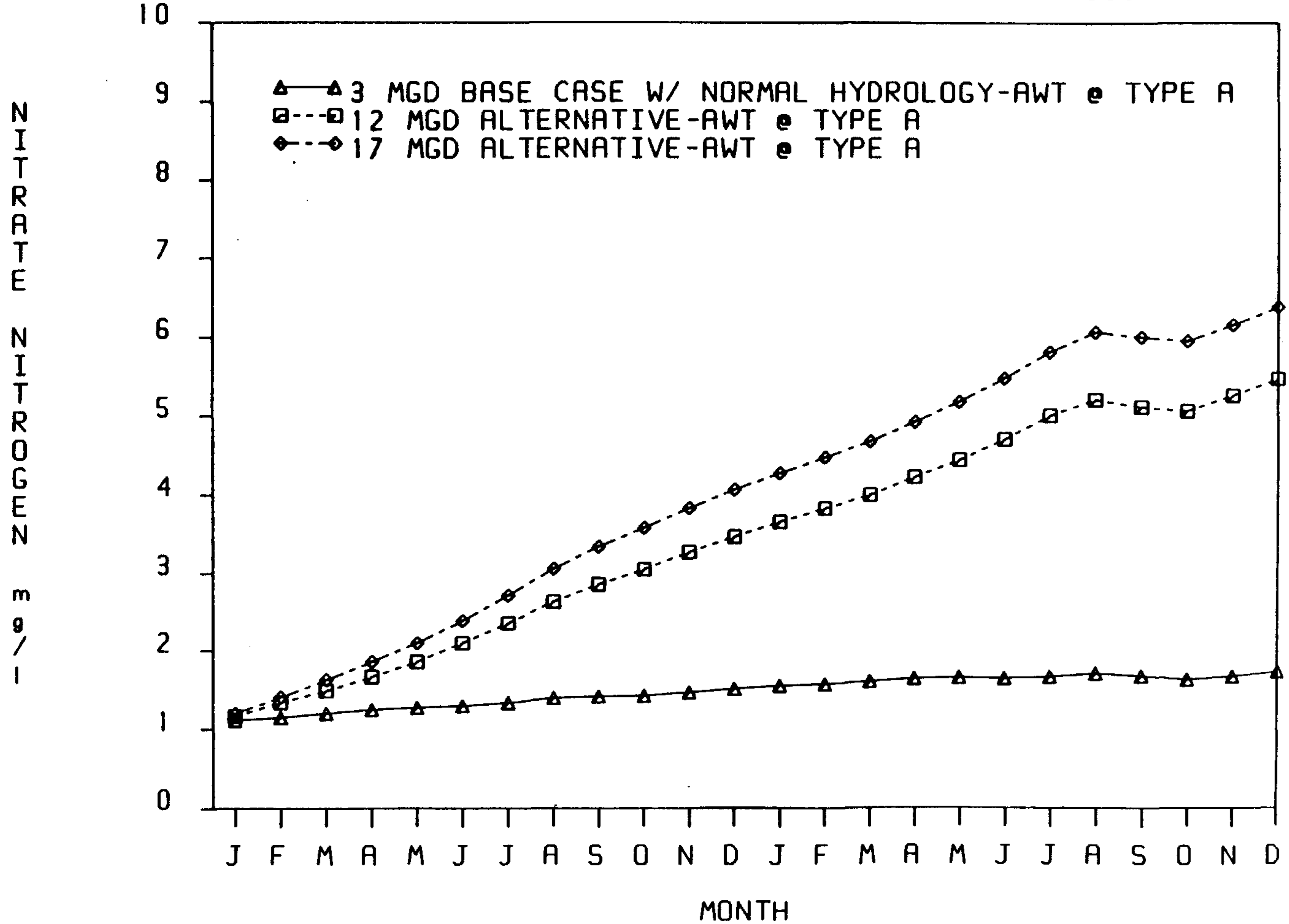


Figure 27

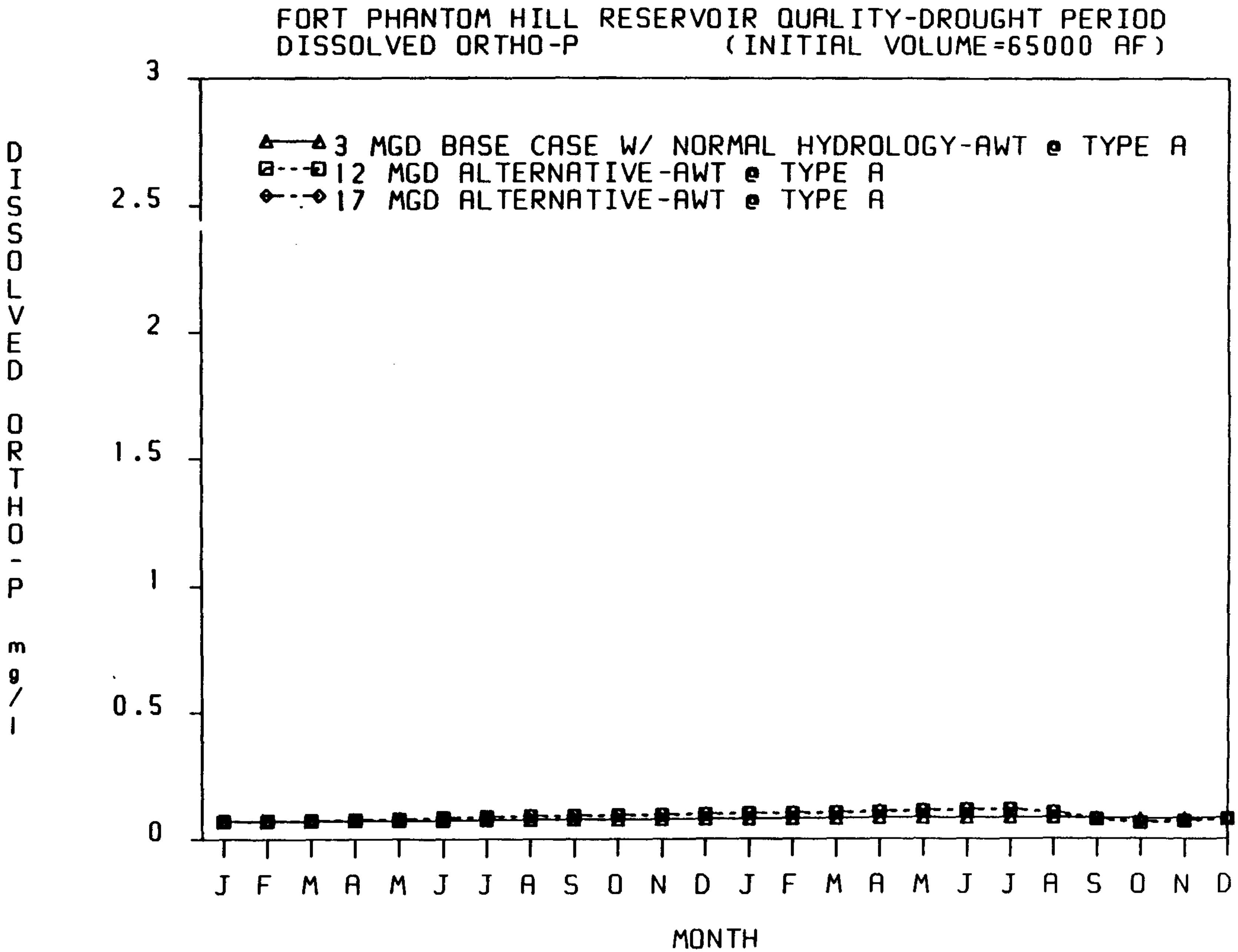

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
DISSOLVED ORTHO-P (INITIAL VOLUME=65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
12 MGD ALTERNATIVE-AWT @ TYPE A
17 MGD ALTERNATIVE-AWT @ TYPE A
DISSOLVED ORTHO-P mg/l
3
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Figure 28

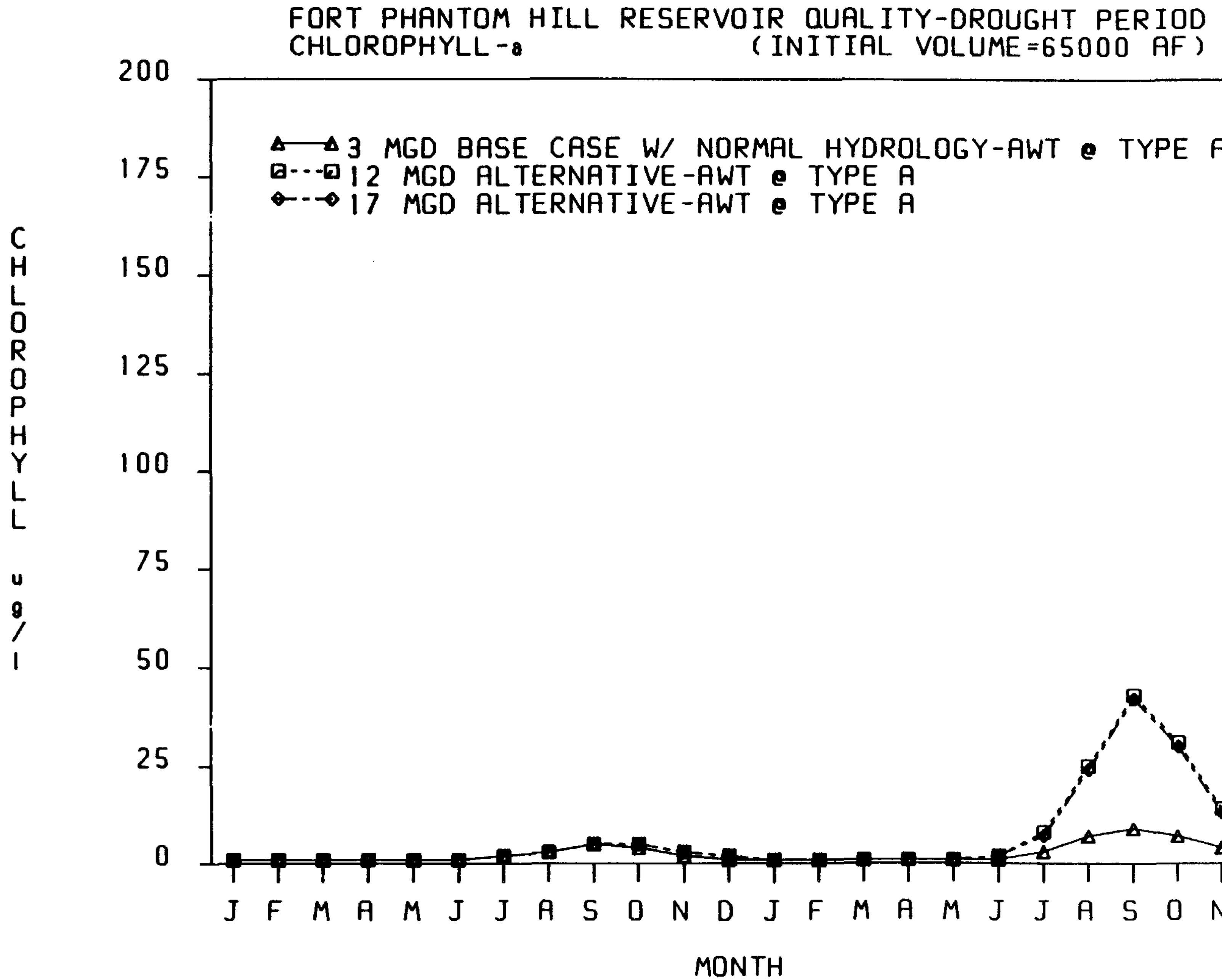

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
CHLOROPHYLL-a
(INITIAL VOLUME=65000 AF)
3 MGD BASE CASE W/ NORMAL HYDROLOGY-AWT @ TYPE A
12 MGD ALTERNATIVE-AWT @ TYPE A
17 MGD ALTERNATIVE-AWT @ TYPE A
CHLOROPHYLL ug/l
200
175
150
125
100
75
50
25
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

Table 7

INITIAL CONDITIONS FOR THE 2-YEAR DROUGHT PERIOD
(December Period)

Ammonia	0.25 mg/l
Nitrate	1.10 mg/l
Ortho-phosphate	0.07 mg/l
TDS	500 mg/l
Chlorophyll-a	2 ug/l
pH	8.3 units
Alkalinity	145 mg/l
Suspended Solids	11 mg/l
Fecal Coliforms	30 MPN/100 ml

Table 8

LFPH WATER BALANCE WITH AWT INFLOWS
(After 2 Years)

Amount of AWT Inflow (mgd)	LFPH Initial Storage (acre-feet)	LFPH Ending Storage (acre-feet)
3.0	65,000	19,000
7.0	65,000	26,000
12.0	65,000	34,000
17.0	65,000	42,000

WATER QUALITY IMPACTS

The water quality impacts of the various AWT effluent treatment levels are gradual increases in most of the nutrient concentrations and algal production along with increases in TDS. The water temperature and DO in the lake remained relatively constant between the calibration and the drought base case. The DO varies throughout the year as a function of temperature and algal productivity similar to the calibration. A tabulation of water quality at various lake levels are presented in Table 9.

The Type B and Type C AWT treatment alternatives appear to increase the biological productivity by approximately a factor of 2.5 for the Type A at both the 3 mgd and 7 mgd discharge rates. The Type A drought cases showed a peak chlorophyll-a level of 40 ug/l, while the Type B and Type C cases resulted in a peak of 100 ug/l. This additional productivity was probably the major contributor to a 0.2 mg/l increase in surface DO levels. The 12 mgd and 17 mgd effluent discharge levels using Type A water quality produced about the same levels of chlorophyll-a as the other Type A cases. This suggests that the controlling factor for the LFPH water quality from a biological viewpoint is the effluent quality more than the quantity.

Substantially greater levels of nutrients are present in LFPH under the Type B and Type C effluent alternatives. In addition, the increased discharge rate at the same level of AWT treatment tends to elevate lake concentrations of nutrients but to a lesser degree than by varying the levels of treatment. Table 10 shows the changes in LFPH nutrient concentrations subject to the changes in discharge rate for the same treatment level, Type A. The concentration of nitrogen compounds shows about a twofold increase due to the increased AWT discharge, whereas the change from Type A to Type C treatment at the same discharge rate caused an increase in nitrogen compounds of about three times (see Figures 14 through 18). Because of the apparent light- and phosphorous-limited environment,

Table 9

Tabulation of Water Quality at Various Lake Levels[a]

	Selected Water Quality Parameters	Lake Level (ac-ft)[b]		
		65,000	45,000	30,000
1.	TDS mg/l	500	600	700
2.	Ammonia mg/l[c]	0.25	0.20	0.25
3.	Nitrate mg/l[c]	1.1	1.6	2.2
4.	Ortho-P mg/l[c]	0.05	0.05	0.06
5.	Chlorophyll-a ug/l[c]	<2	<5	<10

[a]Water quality varies both in time of year and with lake levels. The flows selected represent a near-full lake, 65,000 ac-ft; low water condition, 45,000 ac-ft; and extreme drought condition, 30,000 ac-ft. Values shown are based on Type A treatment levels.

[b]The water quality of most parameters are not independent of historic trends or time of year; i.e, the past levels of the lake influence present water quality. The 65,000 ac-ft level shown is a January date and the 45,000 ac-ft is a July date in the first year of drought condition, and the 30,000 ac-ft is a June date in the second year of drought condition for this table.

[c]Ortho-P, chlorophyll-a, ammonia and nitrate will vary from values presented depending on time of year; i.e., nitrate values projected for 30,000 ac-ft in September-October is 1.3 mg/l versus 2.2 mg/l shown for June, due to euthrophication.

Table 10

LFPH NUTRIENT CONCENTRATION VERSUS AWT DISCHARGE

AWT Discharge (mgd)	Near-Surface Nutrient Concentrations (mg/l)		
	Ammonia	Nitrate	Ortho-Phosphate
3	0.57	2.67	0.067
7	0.70	4.09	0.072
12	0.83	5.39	0.075
27	0.89	6.29	0.078

the differences in chlorophyll-a caused by changes in discharge rate are insignificant for the same treatment level. The algal uptake of phosphorous has probably attenuated the increases of this nutrient in the lake during the rapid growing period (August through September) due to changes in flowrate. However, during the spring season before the algae begin to bloom, the levels of O-PO_4 have increased by 16 percent in the 3 mgd alternative.

The concluding overview of the Type A effluent discharge into LFPH appears to be an elevation of nutrients with little change in biological activity as the quantity of AWT inflow increases. Although the amount of nitrogen in the lake increases more than the ortho-phosphate, the growth in algae appears to more closely follow the phosphorus changes. This supports the concept of phosphorus limitation developed in the model.

It is also felt that these levels of nutrients in the lake could normally produce much higher levels of algae in a less turbid environment (NTU = 50). Because of the turbidity levels in LFPH, the algal productivity is expected to be light-limited as well. This may develop into a problem should the AWT effluent be of substantially better clarity, especially at the higher discharge rates. The improvement of overall lake clarity would likely encourage more algal production due to the greater penetration of light into the water column.

The model has suggested a phosphorous-limiting environment, but this phenomenon has not been absolutely confirmed by bioassay studies. The growth rates of algae in the model can be adjusted according to the limiting nutrient factors shown in the field data. Since nutrient limitation analysis data of this sort were not available, the model values for both nitrogen and phosphorous half-saturation constants were applied to encourage a phosphorus-limiting environment.

The Type B and Type C effluent alternatives at the 3 mgd discharge level demonstrated a significant change from the Type A alternative and the base case. The differences in the treatment level and subsequent changes in effluent water quality were shown in Table 5. These differences resulted in significantly greater algae production from a peak of 40 ug/l chlorophyll-a for Type A to a peak of 105 ug/l chlorophyll-a for Type C effluent. The amount of nitrogen (NH_3 + NO_3) in the lake remained somewhat similar for the 3 mgd case with a factor of 1.5 increase, but the orthophosphate concentrations by the end of the drought period hand increased from 0.067 mg/l to 1.08 mg/l, a factor of 16.

Table 11 shows the changes in nutrient concentrations and peak chlorophyll-a as a result of different AWT treatment levels.

Since the nitrogen in the lake remained similar but the orthophosphorus increased by a factor of 16, the added algal growth appears to be linked to phosphorus levels in the lake. The expected lowest possible AWT effluent phosphorus concentration of 0.1 mg/l was tested for the 3 mgd discharge rate and resulted in lowering the peak chlorophyll-a concentrations from 40 ug/l to 30 ug/l. Further reductions in phosphorus are not likely to provide additional biological control in LFPH due to the background concentrations of the runoff.

The TDS of the lake increased by approximately 120 mg/l over the year due to the increased AWT load from 800 mg/l (Type A) to 1,100 mg/l (Type C) in the 3 mgd alternative. The change would probably be slightly greater in the 17 mgd case due to the additional inflow at the higher Type C concentration of TDS in the effluent; however, this alternative was not examined.

Table 11

LFPH NUTRIENT CONCENTRATIONS VERSUS AWT TREATMENT AT 3 MGD

AWT Treatment	Near Surface Nutrient Concentrations (mg/l) Ammonia	Nitrate	Ortho-Phosphate	Peak Chlorophyll-a (ug/l)
Type A	0.57	2.67	0.067	40
Type B	0.99	1.60	0.175	102
Type C	1.29	3.89	1.080	105

The physical properties of the LFPH reservoir appear to be preserved with respect to complete mixing, no stratification, and adequate DO supplies.

Although additional algal growth will encourage more settling of organic material, the direct influence of this is only suggested in the model by changes in organic sediment. The organic sediment at the bottom of the lake is shown by the model to increase from about 21 g/m^2 for the Type A effluent to 52 g/m^2 for the Type C alternative. This increase is due to the increase in algal production coupled with greater respiration and settling to the bottom. Since the model includes the interaction of the decay of organic sediments, DO uptake, and release of nutrients into the water column, the influence of this biological activity has been included. the bottom of the reservoir shows a slight decrease in DO levels for the Type A and Type C alternatives, but the minimum amount of DO in the water column is above 7.0 mg/l. The buildup of the organic material over several years of increased biological activity should be considered in light of the changes found in the 2-year simulation.

Table 12 shows the relative changes in the DO profile for the Type A and Type C AWT effluent water quality at the 3 mgd flowrate. The apparent lack of anaerobic conditions in the reservoir hypolimnion precludes the conversion of nitrate to nitrogen gas by anaerobic bacteria, a process often found in the lower elevations of euthropic lakes. From the moderate algal productivity and the apparent lack of anaerobic conditions, the nitrate buildup may be substantial. Over a long period of time, the change in peak algae concentrations from 10 ug/l to 40 ug/l may encourage a larger organic sediment layer and thus the potential for more oxygen uptake. However, the drought condition analysis was for 2 years, and it is expected that AWT discharge during normal hydrologic conditions will have a lesser impact on both nutrients and algal production in LFPH.

Table 12

DO PROFILE CHANGES DUE TO EFFLUENT QUALITY AT 3 MGD

	DO Surface, mg/l	DO Bottom, mg/l
Type A	7.7	7.5
Type C	8.0	7.4

EVALUATION OF BASE CASE DROUGHT WITHOUT AWT

The previous base case analysis was developed on the basis of a non-drought 2-year period with a constant AWT inflow of 3 mgd using Type A (best W.Q.) effluent. This combination of conditions was selected as a reasonable pre-drought operating scenario for the Lake Fort Phantom Hill (LFPH) system.

During the review process the concern of drought conditions without the AWT discharge was raised for purposes of comparison. The need to look at drought conditions under existing operations (without AWT discharge) was appropriate to view the relative differences of what would be expected to occur.

Approach

The existing LFPH W.Q. model was set up to evaluate a two year period using the drought condition hydrology but without the AWT inflow. The model coefficient for chemical/biological/physical interactions in the reservoir were left unchanged from the previous analysis. The drought condition inflows and water supply requirements were applied to the system as noted.

The results of the two year drought period without the AWT were plotted as before for TDS, NH_3, $O\text{-}PO_4$ and chlorophyll. The time history of reservoir volume was also plotted for the two case alternatives to provide a visual comparison between themselves as well as with Figure 13 of the technical memo.

RESULTS AND COMMENTS

The six figures included herein, Figures 29 through 34, demonstrated the impacts of the drought conditions without AWT inflow. The reservoir volume drops to approximately 19,000 AF by the end of the two years. This is slightly lower, as it should be, than the amount shown for 3 mgd on Figure 13 because there is not AWT inflow. The TDS increases in the "revised" base case by about 250 ppm due to the substantial drop in the inflow to the reservoir coupled with the concentrating affects.

The ammonia nitrogen and the nitrate nitrogen both show some increases during the drought condition. This is likely due to two factors; first a concentrating of the nutrients from lesser water volumes; and secondly an increase in NH_3 due to decay of organic material (settled algae, detritus). Probably the reason the nitrate does not show the same degree of increase (since there's more NH_3 to oxidize) late in the second year is due to algae uptake.

The ortho-phosphate (soluble) shows little change from the previous base case. It seems logical this is due to the growth mechanics of the system. The $O\text{-}PO_4$ should increase due to concentration effects just like any of the parameters, however it may not show up due to the algal uptake. The system seems to be phosphorous limited from the indicators we have reviewed and the algae tend to utilize the available phosphorus down to near the half-saturation constant levels of 0.04 to 0.05 mg/l. At that level the growth rate drops off considerably and the algae uptake slows down.

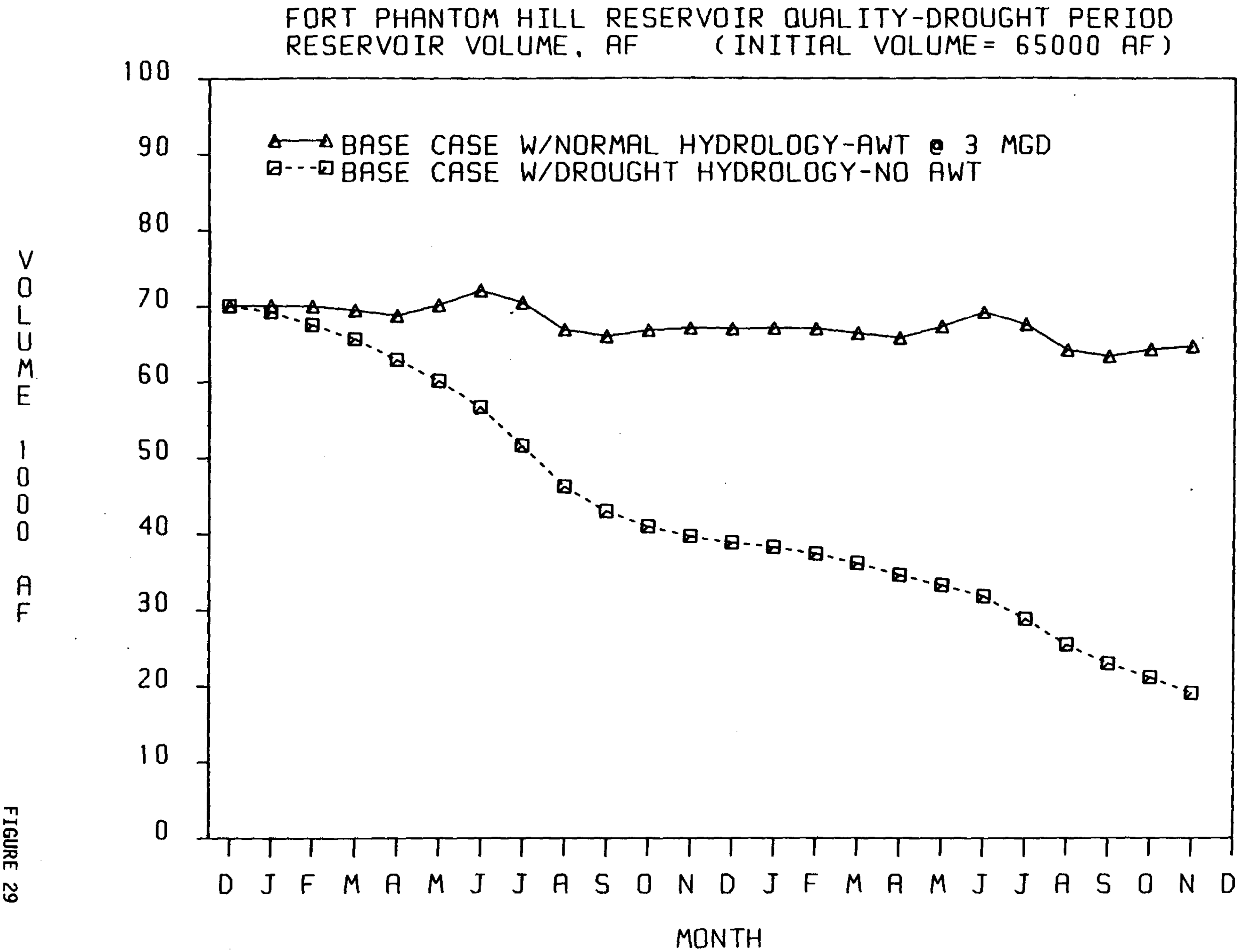

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
RESERVOIR VOLUME, AF (INITIAL VOLUME= 65000 AF)
BASE CASE W/NORMAL HYDROLOGY-AWT @ 3 MGD
BASE CASE W/DROUGHT HYDROLOGY-NO AWT
VOLUME 1000 AF
100
90
80
70
60
50
40
30
20
10
0
D J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

FIGURE 29

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
TOTAL DISSOLVED SOLIDS (INITIAL VOLUME= 65000 AF)

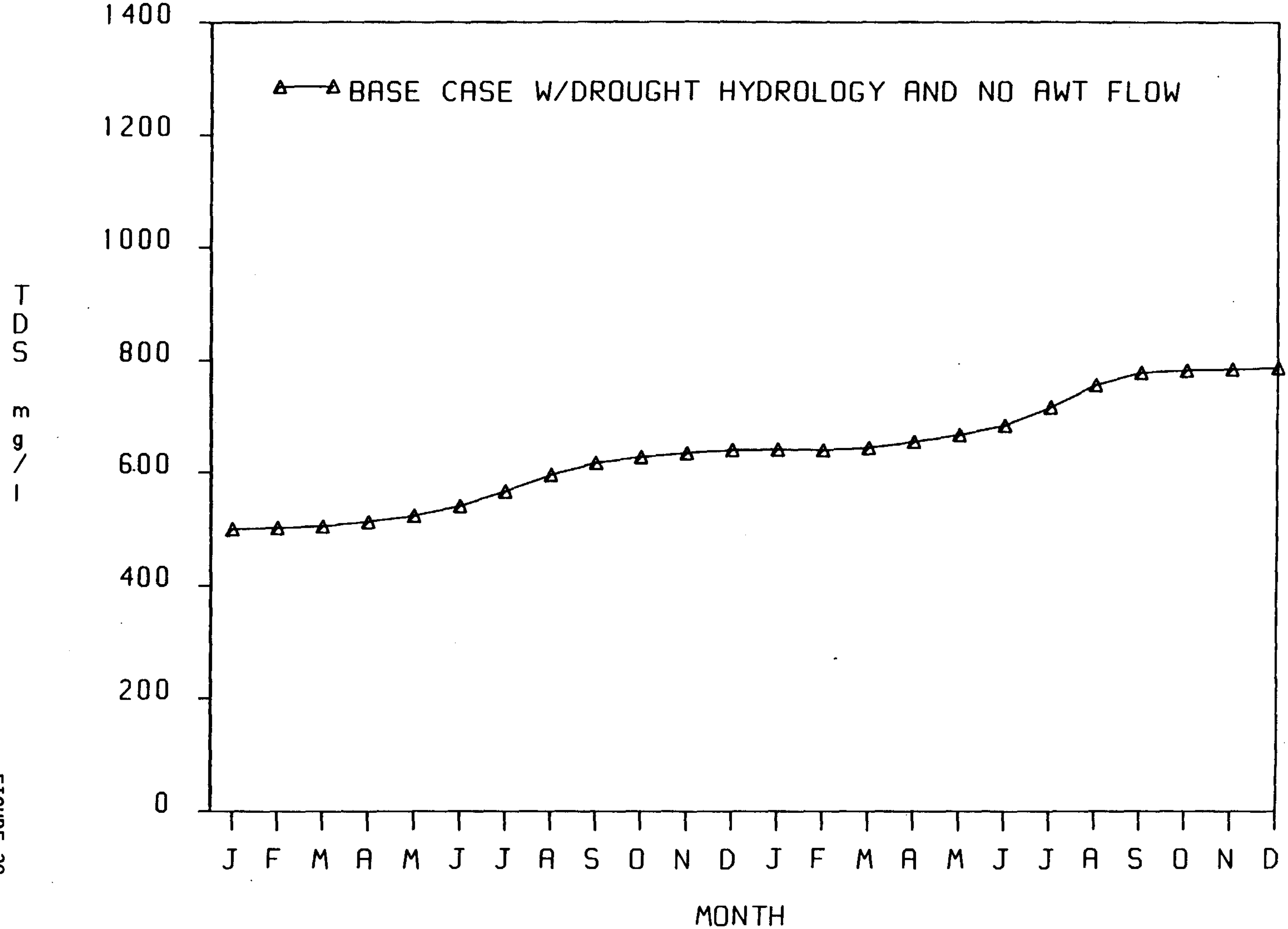


FIGURE 30

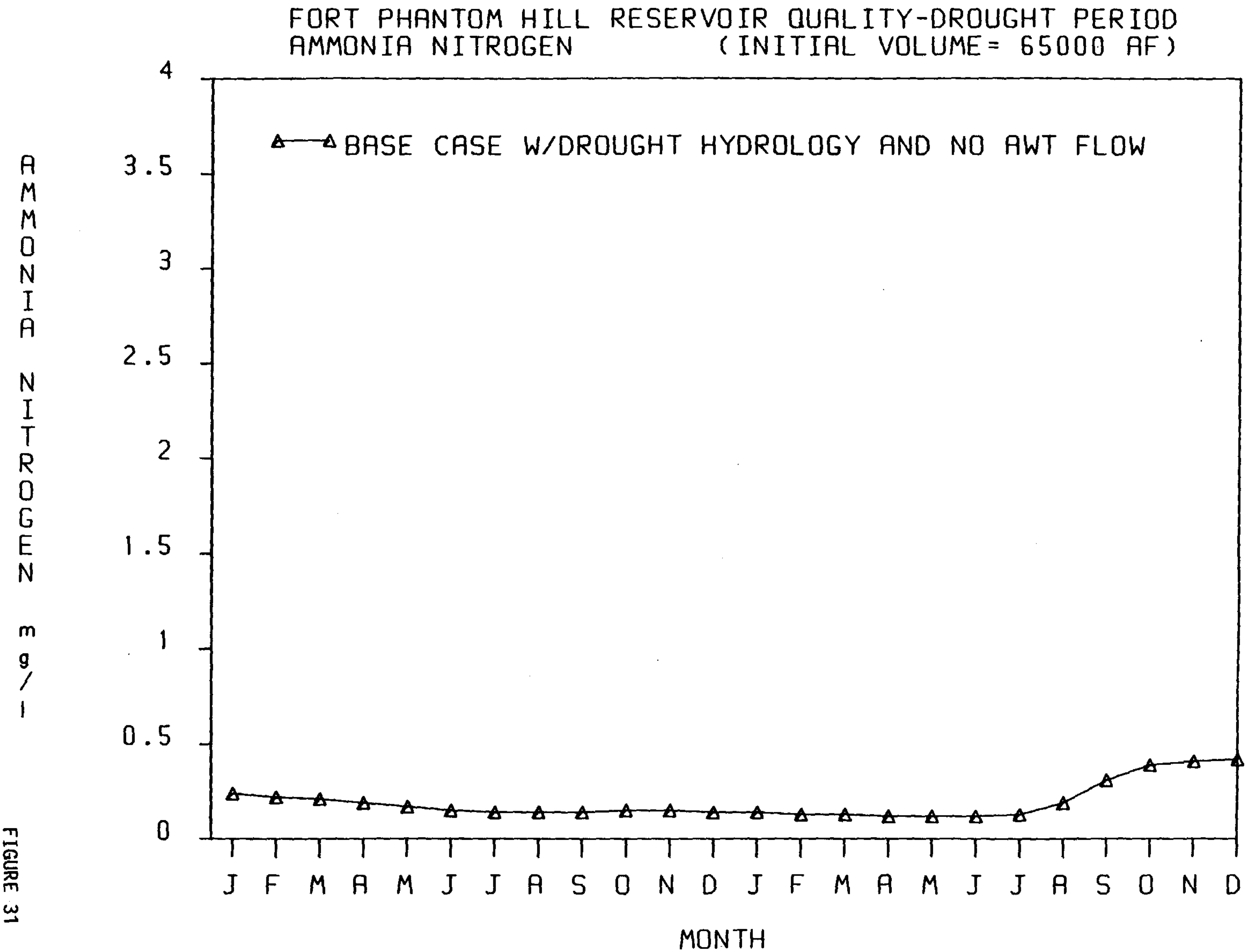

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
AMMONIA NITROGEN (INITIAL VOLUME= 65000 AF)
BASE CASE W/DROUGHT HYDROLOGY AND NO AWT FLOW
AMMONIA NITROGEN mg/l
4
3.5
3
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

FIGURE 31

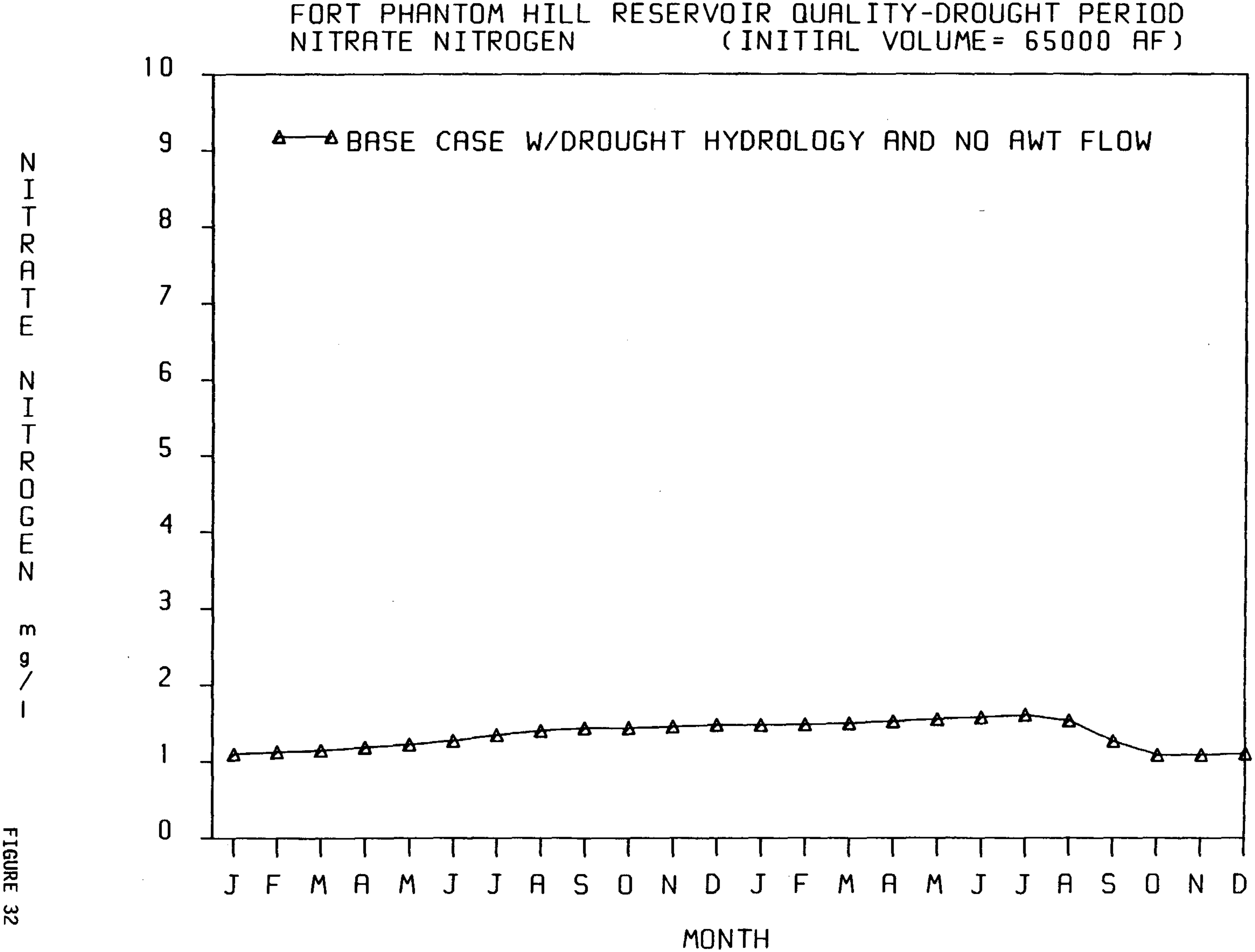

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
NITRATE NITROGEN (INITIAL VOLUME= 65000 AF)
BASE CASE W/DROUGHT HYDROLOGY AND NO AWT FLOW
NITRATE NITROGEN mg/l
0
1
2
3
4
5
6
7
8
9
10
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

FIGURE 32

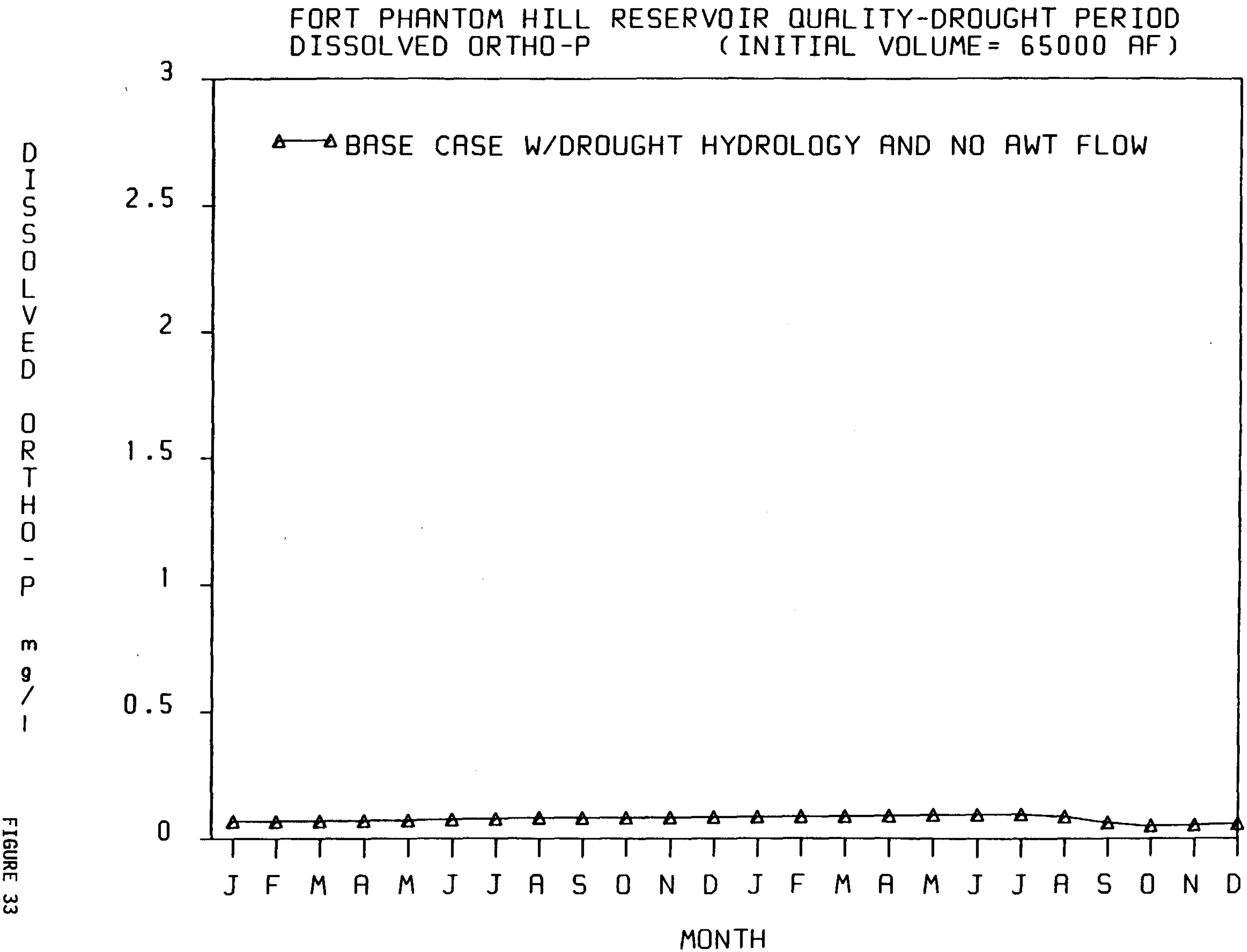
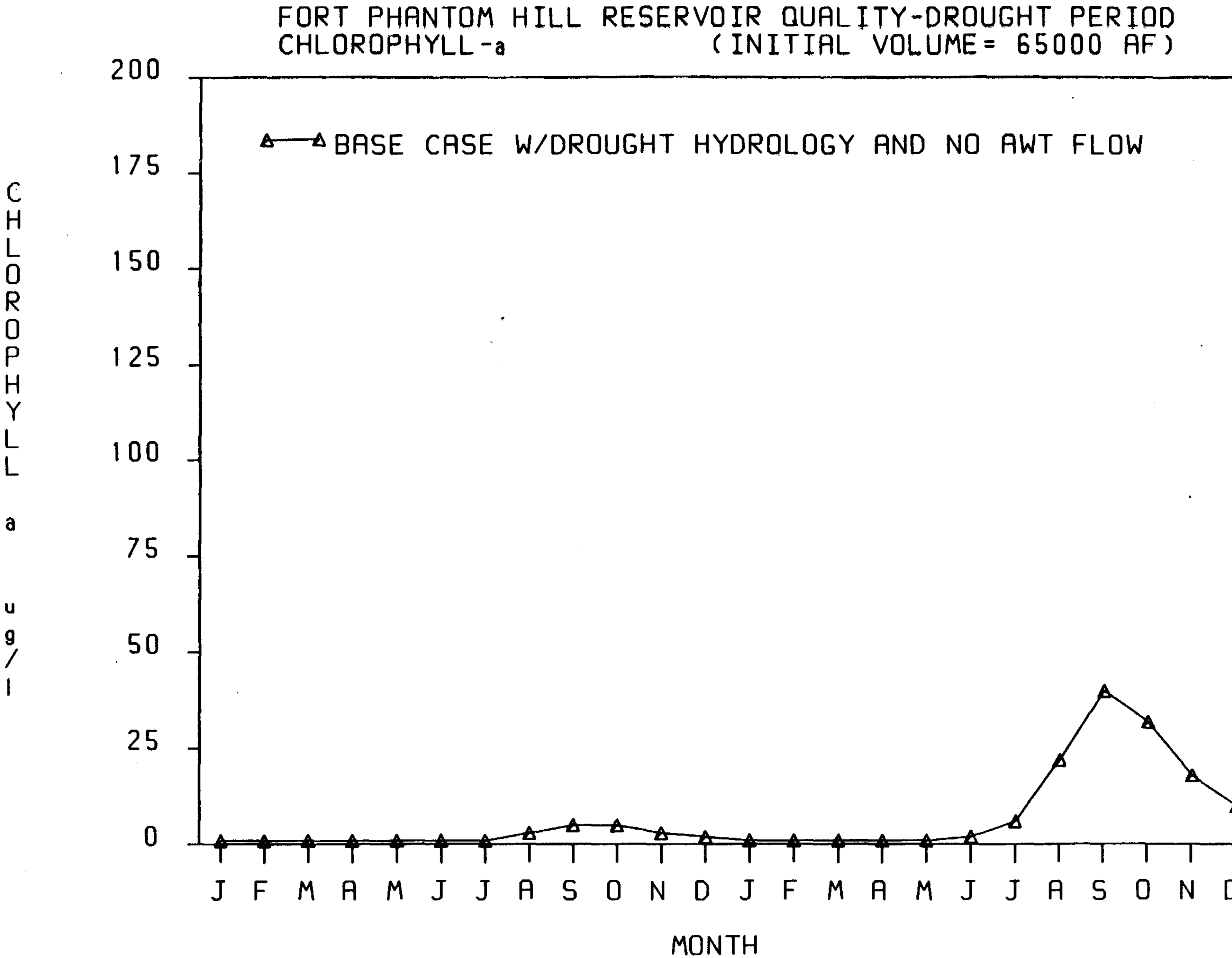

FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
DISSOLVED ORTHO-P (INITIAL VOLUME= 65000 AF)
BASE CASE W/DROUGHT HYDROLOGY AND NO AWT FLOW
DISSOLVED ORTHO-P mg/l
3
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

FIGURE 33



FORT PHANTOM HILL RESERVOIR QUALITY-DROUGHT PERIOD
CHLOROPHYLL-a
(INITIAL VOLUME= 65000 AF)
BASE CASE W/DROUGHT HYDROLOGY AND NO AWT FLOW
CHLOROPHYLL a ug/l
200
175
150
125
100
75
50
25
0
J F M A M J J A S O N D J F M A M J J A S O N D
MONTH

FIGURE 34

The chlorophyll-a response shows substantially higher peaks in the late summer periods than was prevalent in the previous base case. This would be expected in the "revised" base case due to the concentrating of nutrients in LFPH. Although the first years growth does not seem appreciably greater, the second years concentration of chlorophyll-a increase from about 10 mg/l (old base case) to 40 mg/l (revised base case). This four fold increase produces a level of chlorophyll-a approximately the same as the 3 mgd AWT - Type A case shown on Figure 18.

SUMMARY

The comparison of drought type "existing" condition with the proposed 3 mgd - Type A discharge under normal hydrology shows a substantial worsening of the water quality from the previous assumed base case. However the "revised" base case conditions without AWT inflows during a drought are nearly identical to those with the 3 mgd AWT inflow during a drought when the effluent is of Type A quality.

A conclusion to this comparison is, the water remaining in the LFPH reservoir is of about the same quality with or without the 3 mgd AWT discharge. The effects of the AWT plant do not appear to have a substantial influence over what would happen under todays existing conditions should there be a two year drought. This is true only for the Type A treatment level at the AWT plant and for the 3 mgd discharge level. When higher flows or poorer effluent quality are used, the LFPH water quality shows more degradation.

CONCLUSION

The analysis of alternatives using the WQRRS model appears to provide reasonable results and information that are consistent with our present understanding of the LFPH system and general ecological successions. Additional alternatives of water quality levels in the AWT discharge, quantities of AWT discharge, and tributary flow augmentation are possible with the present system configuration.

Key findings of the Water Quality Model are:

1. Predictive analysis of alternatives using the WQRSS model appears to provide reasonable results and information that are consistent with our general understanding of the LFPH system and general ecological successions.

2. Lack of detailed tributary water quality data limited the analysis of alternatives to major additions of flow augmentation to LFPH.

3. The apparent lack of anaerobic conditions in the reservoir hypolimnion, due to considerable mixing (power plant, mechanically induced air system), precludes the conversion of nitrate to nitrogen gas by anaerobic bacteria. The model projected that an increase level of nitrate will develop in the lake due to the limited ability of LFPH to convert nitrates.

4. A light-limited and phosphorus limited algal production was modelled at elevated nutrient levels by including self-shading characteristics of suspended material in the determination of the composite light extinction coefficient and by adjustments to the phosphorus half saturation constant. These model methods calibrate well with historical data.

5. Total dissolved solids (TDS) will increase over time due to the limited flushing of the reservoir by inflows. TDS's are projected to increase by 100 to 200 mg/l (to a total concentration in the 600 mg/l range) at normal flows with the addition of a 3 MGD

flows. Historically these parameters have not presented a known problem, periodical major flushing of the reservoir occurs.

6. During drought conditions the projected water quality with Type A treatment should equal or exceed the water quality without a discharge.

ABILENE RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 6

WATER QUALITY CRITERIA AND GOALS

Principal Author: Bob Chapman, P.E.
David Lewis, P.E.

INTRODUCTION

Developed and summarized in this memorandum are the basic water quality criteria and goals which will be the fundamental basis for subsequent selection and development of appropriate treatment processes. Appropriate criteria and goals must be adopted for each basic element of the overall water reuse scheme to assure public health and acceptance, including the quality of:

1. Reclaimed water used for landscape irrigation.
2. Reclaimed water discharged from a proposed Tributary Wastewater Treatment Plant (WWTP) which eventually flows into Lake Fort Phantom Hill.
3. Future reclaimed water discharged directly to Lake Fort Phantom Hill from the Hamby WWTP.
4. Water within Lake Fort Phantom Hill.
5. Potable water ultimately produced by the City's water treatment plants.

ADOPTED GOALS AND OBJECTIVES

The research team developed a set of goals and objectives during its initial meetings, which were subsequently adopted by the PAC. The goals and objectives are discussed in greater detail in Technical Memorandum No. 1 and are summarized below.

ACCEPTABLE EFFECTS OF THE DISCHARGED WATER ON THE WATER QUALITY OF THE RESERVOIRS

The discharge water (WWTP effluent) shall not cause any effects on the water quality which would alter its current attainable beneficial use, such as potable water supply, recreation, fisheries, irrigation.

ACCEPTABLE WATER QUALITY FOR DISCHARGES INTO PUBLIC DRINKING WATER RESERVOIRS, SPECIFICALLY LAKE FORT PHANTOM HILL

Discharges to Lake Fort Phantom Hill shall not exceed state and federal water quality regulations. In addition, the discharge will not cause aesthetic problems with the lake. The discharge to the lake should produce a water resource compatibility with production of a potable drinking water of equal or greater quality to Abilene present water resources.

ACCEPTABLE OPERATIONAL CONSTRAINTS IN SELECTION OF UNIT TREATMENT PROCESSES

Unit Treatment Processes selected shall be within the capability of Abilene to operate and maintain in a reliable and consistent manner. It is recognized that advanced treatment systems will require additional training and possible new personnel. Selection of unit processes should reflect existing operational constraints.

RISK INVOLVING PUBLIC HEALTH

Maintain or reduce the current public health risks associated with the potable water supply and wastewater treatment and disposal.

ACCEPTABLE COSTS FOR CONSTRUCTION AND OPERATION OF WATER RECLAMATION FACILITIES

Based on a comparison with other alternatives, implement water reclamation only if it is the cost-effective alternative.

GOALS FOR PUBLIC ACCEPTANCE

Public officials and selected community representatives shall be knowledgeable of the objectives, goals, findings, and recommendations of the research project.

A public meeting to present the research project shall be held to start the public involvement and participation on any followup project.

NONPOTABLE WATER SUPPLY REUSE

Investigate nonpotable water reuse options that reduce demands on the potable water system.

MULTIPLIABLE BARRIER CONCEPT

In order to comply with the goals and objectives, similar projects throughout the nation have adopted the concept of multipliable barrier. An example of a multipliable barrier would be the control of pathogenic bacteria by various processes and natural barriers. A list of barriers on a normal indirect reuse project are listed below:

- Activated sludge WWTP
- Disinfection at WWTP
- Natural cleansing of stream flow
- Natural attenuation in the lake
- Coagulation/sedimentation at WTP
- Filtration at WTP
- Disinfection at WTP

These seven barriers vary in effectiveness but taken together provide multipliable barriers to pathogenic bacteria. If any one of them fails, then public health is not endangered by that single failure.

A corollary of the multipliable barrier concept is that barriers are more effective if they are not all manmade, one type, all natural, at one location, operated by one person, etc.

Therefore in selection of processes and operations, the concept of multipliable barriers should be used in determining need. We recommend that no system of processes be considered which will utilize only one effective barrier for contaminant removal which effects public health. Any proposed system should be evaluated as a total system, WWTP, stream, lake, and WTP, not as a single site or process.

As a goal, the process selected should be able to meet design criteria at peak monthly flows with one unit out of service, and more than one barrier should be provided for contaminants which affect public health.

REVIEW OF REGULATIONS

Abilene's proposed water reuse program must as a minimum comply with the following basic water regulations:

1. Wastewater discharge regulations (NPDES permit) for purified water discharged to surface waters.

2. Nonpotable water reuse regulations for landscape irrigation and for unrestricted public contact.

3. Surface water standards (Texas Surface Water Quality Standards - TWC, 1985).

4. Federal and state drinking water regulations (National Safe Drinking Water Act; Drinking Water Standards Governing Drinking Water Quality and Reporting Requirements for Public Supply - TDH, 1987).

WASTEWATER DISCHARGE REGULATIONS

The current wastewater discharge standards for the Hamby WWTP are secondary treatment requirements, summarized below:

BOD_5	<20 mg/L
TSS	<20 mg/L
pH Range	6 - 9
Chloride Residual	1.0 mg/L

The anticipated discharge requirements, based on discussions with TWC, for a proposed Tributary WWTP are:

BOD_5	5 mg/L
TSS	5 mg/L
pH range	6 - 9
Ammonia	2 mg/L
Phosphorus (to be based on modeling)	1 mg/L
Dissolved Oxygen	5 mg/L
Chlorination	1 mg/L

The above regulations will be superceded by more stringent goals as developed hereafter in this memorandum, in accordance with the project goals and objectives.

SURFACE WATER CRITERIA

The surface water quality criteria applicable to Lake Fort Phantom Hill was presented and evaluated in Technical Memorandum No. 3. The standards are repeated hereafter for ease of reference:

Chloride (mg/L), annual mean	<200
Sulfate (mg/L), annual mean	<100
Total Dissolved Solids (mg/L), annual mean	<600
Dissolved Oxygen (mg/L), not less than	5.0
pH Range	6.0 to 9.0
Fecal Coliform (/100 ml - 30 day mean)	<200
Temperature (degrees C)	<34

DRINKING WATER REGULATIONS

Current Drinking Water Regulations were also presented in Technical Memorandum No. 3.

Drinking water regulations are undergoing major revisions as a result of the 1986 amendments to the federal Safe Drinking Water Act. The U.S. Environmental Protection Agency (EPA) has been directed to develop new Maximum Contaminant Levels (MCL's) for a wide variety of potential drinking water contaminants, including microorganisms, synthetic organic chemicals, volatile organic chemicals, inorganic chemicals, radionuclides, and disinfection byproducts. A list of contaminants currently regulated or for which MCL's must soon be developed is included in Table 1. The implementation of these regulations will likely require modifications to the City of Abilene's water treatment plants regardless of whether a water reuse program is implemented.

Table 1
REGULATED DRINKING WATER CONTAMINANTS

	Organics				
Microbiological Microbial Factors	Synthetic Organic Chemicals	Volatile Organic Chemicals	Inorganic Chemicals	Radionuclides	Disinfection Byproducts
Coliforms[a]	Endrin[a]	Tetrachloroethylene	Arsenic[a]	Radium 226[a]	THMs
Turbidity[a]	Methoxychlor[a]	Trichloroethylene	Cadmium[a]	Radium 228[a]	Others
Heterotrophic Bacteria	2,4-D[a]	1,2-Dichloroethane	Lead[a]	Gross alpha particle activity[a]	
Pathogenic Viruses	Lindane[a]	Carbon Tetrachloride	Nitrate[a]	Beta particle and photon radioactivity[a]	
Pathogenic Protozoans	Toxaphene[a]	Vinyl Chloride	Silver[a]	Uranium	
Legionella	2,4,5-TP[a]	Benzene	Barium[a]	Radon	
	cis- and trans-1,2,Dichloroethylene	1,1-Dichloroethylene	Chromium[a]		
	Dichlorobenzene(s)	1,1,1-Trichloroethane	Mercury[a]		
	Aldicarb	para-Dichlorobenzene	Asbestos		
	Chlordane		Sulfate		
	Carbofuran		Copper		
	Heptachlor		Nickel		
	Styrene		Selenium[a]		
	Polychlorinated biphenyls (PCB's)		Nitrite		
	Dibromochloropropane (DBCP)		Aluminum		
	1,2-Dichloropropane		Cyanide		
	Pentachlorophenol		Molybdenum		
	Alachlor		Sodium		
	Ethylene dibromide (EDB)		Antimony		
	Epichlorohydrin		Beryllium		
	Xylene		Thallium		
	Toluene		Vanadium		
	2,3,7,8-TCDD (dioxin)		Zinc		
	Chlorobenzene				
	Hexachlorobenzene				
	Ethyl benzene				
	Acrylamide				
	Monochlorobenzene				
	Atrazine				
	Simazine				

[a]Currently regulated contaminants.

SOURCE: "Concept Outline, August 1987, Development of Best Available Technology Criteria." Science and Technology Branch, Criteria and Standards Division, Office of Drinking Water, U.S. EPA, Washington, D.C.

DFW25/003

ADDITIONAL WATER QUALITY CRITERIA

The above-referenced regulations are intended to protect public health under a broad range of conditions and situations. However, they do not completely address aesthetic issues, nor the extra degree of care required for an indirect reuse project such as Abilene is considering. Aspects of the proposed project which require particular attention and may require treatment beyond that required to meet basic regulations are discussed in subsequent sections.

Tributary Creek Discharge Considerations

Reclaimed water discharged from a proposed Tributary WWTP will flow through suburban areas of Abilene; the flow in which will then at many times be nearly all reclaimed water. The area downstream of the present proposed discharge point is sparsely developed. The tributary steams in Abilene are not used for recreation and they have limited uses that involve human contact. However, access is not controlled and the opportunity exists for human contact. The discharge should therefore be adequately disinfected to accommodate the likelihood of occasional nonrestricted recreational contact, primarily children playing along the creek. Furthermore, the effluent should be treated to the extent required to prevent aesthetic detriment such as would occur with excessive oxygen depletion or algal growth.

Current State of Texas water quality bacterioligcal standards governing such receiving streams, are coliform concentrations, not exceeding 200/100 ml. Coliform concentration is commonly used as an indicator for determining effectiveness of disinfection. Coliform itself, is not pathogenic but indicates the likelihood of presence of other pathogenic organism, such as virus and cysts. For effluent discharged to the stream the typical disinfection treatment required to conform to this standard is disinfection for 20 minutes with an ending chlorine residual of 1.0 mg/L. At this standard, no significant known health outbreaks have been documented.

However, the trend by state regulatory agencies is towards higher stream quality standards. Discussions with Texas Water Commission staff indicate the standards are likely to be modified but no firm values were suggested. One of the strictest disinfection standards governing a stream with uses similar to Abilene's tributary streams are the State of California regulations (commonly called Title 22 regulation). The performance criteria of Title 22 are as follows:

Performance Criteria:	<2.2 coliforms/100 ml mean <23 coliforms/100 ml max on any sample during a 30-day period <2 NTU Turbidity average during each 24-hour period

The treatment criteria was also established to produce a water with a low solids content and low chlorine demand to enhance the effectiveness of disinfection on a reliable basis, as opposed to strictly relying on conforming with bacterial indicators as an index of pathogen removal or inactivation.

It is recommended that standards stricter than the current State of Texas criteria be adopted. Disinfection to achieve a maximum coliform concentration of 100/100 ml is suggested for any wastewater discharged at this point. Provisions should be made in the process design to upgrade treatment to meet future State of Texas requirements. It is anticipated the

Title 22 regulations define the strictest parameters the State of Texas would adopt. It recommended that, as a goal, the performance criteria of Title 22 standards be adopted.

To meet other aesthetic goals for water quality within the tributary stream, the discharge from the proposed WWTP should be such as to minimize oxygen depletion in the stream with resultant malodorous conditions, and minimize the nutrient content which may result in excessive algae well oxygenated with minimal carbonaceous and nitrogenous demand. Recommended effluent criteria in this regard are:

Dissolved Oxygen	>5.0 mg/L
BOD_5	<5.0 mg/L
NH_3-N	<2.0 mg/L

Recommended effluent criteria for nutrient content relates not only to conditions in the tributary stream, but conditions in Lake Fort Phantom Hill. From a practical perspective, a realistic goal for nutrient levels for water within the tributaries would be to achieve approximately the same levels as currently result from nonpoint source runoff. Very limited data on non-point runoff is available to date. Samples from Elm Creek and Cedar Creek were collected and combined as a composite sample as part of the current study primarily for inclusion in the reservoir analysis. The following results were obtained from analyses of these samples:

Parameter	Mean
Total Phosphorus, mg/L as P	.15
TKN, mg/L as N	3.89
NO_3, mg/L as N	0.15

The data include very high levels of nitrogen, but relatively low levels of phosphorus, particularly with respect to concentrations commonly occurring in treated effluent (>4 mg/L). Thus, of the two basic nutrients, phosphorus is likely to be the controlling factor preventing additional eutrophication within Elm or Cedar Creek (high turbidity values are also a likely controlling factor). As was demonstrated in Technical Memorandum No. 5, Lake Fort Phantom Hill is predicted to be sensitive to phosphorus concentrations, and discharge limitations to minimize excessive algae growth in the reservoir will require effluent phosphorus concentrations comparable to the existing background concentrations measured to date in Elm Creek. Thus, no effluent nutrient criteria will be proposed which is specific to meeting water quality within the tributary streams.

Lake Fort Phantom Hill Considerations

Developed and presented in Technical Memandum No. 3 and 4 were basic water quality data for the Lake Fort Phantom Hill source of supply, including influent characteristics, quality within the reservoir, and quality of a water pump from the reservoir for treatment and distribution to the City of Abilene. This data was used as a basis for calibration of a water quality model, which was subsequently used to predict water quality changes in the reservoir which would result from input of reclaimed wastewater following varying stages of treatment. Key conclusions drawn from these evaluations are summarized as follows:

1. The water quality in Lake Fort Phantom Hill generally is well within established limits for surface water suitable as a municipal source of supply.

2. The reservoir is generally well mixed and exhibits very little stratification, and dissolved oxygen depletion in the reservoir has not historically been nor is projected to be a problem.

3. Lake Fort Phantom Hill is considered to be borderline eutrophic, with a tendency toward growth of algae and other aquatic plants. Such growth can contribute to significant water quality problems from a potable use prospective due to the growth of filter-clogging algae, unpleasant taste and odor conditions, ammonia nitrogen release during decay cycles, and possible formation of trihalomethanes during chlorination.

4. The water in the reservoir is typically quite turbid with typical secchi readings near 2 feet and turbidity values of 20 to 40 NTU. The presence of high turbidity values in the water is believed to be one of the factors that limits algae growth in the reservoir.

Water quality modeling was performed to determine predicted impacts of wastewater discharge on Lake Fort Phantom Hill, under a critical condition of an extended 2-year drought. The variables in the model were the quantity of reclaimed wastewater discharged to the reservoir, and the degree of treatment provided to the wastewater as follows:

1. Flows of 3, 7, 12, and 17 mgd.

2. Treated wastewater quality variations as follows:

Type	BOD_5	$O\text{-}PO_4$	NH_3	NO_3
A	3.0	0.2	2.0	10.0
B	5.0	2.0	3.0	25.0
C	10.0	10.0	3.0	25.0

Basic conclusions drawn from the modeling results are that there are two primary water quality concerns relating to discharge of reclaimed wastewater to Lake Fort Phantom Hill with respect to the general water quality therein. The reservoir is predicted to be very sensitive to increased concentrations of phosphorus, a primary nutrient which will stimulate algae growth. Such growth is most undesirable due to the unpleasant taste and odors related either directly to algal secretions, or the interaction of actinomycetes with the algae. A second related problem is the release of organic nitrogen and ammonia nitrogen during the algal decay cycle. If ammonia concentrations exceed about 2 mg/L in the reservoir, fish toxicity problems may develop. The modeling results indicate that the reclaimed wastewater phosphorus concentration should be as low as practicable, which is about 0.2 mg/L, to minimize the growth of algae and the related problems.

The second basic water quality concern is with respect to the potential increase of nitrate nitrogen in the reservoir. The concentration in the reservoir must be maintained at less than 10 mg/L as nitrogen to be in compliance with drinking water standards. As reclaimed wastewater flows increase, the nitrate nitrogen concentrations must be decreased or will approach the standard. Ultimately, it appears that the nitrate-nitrogen concentration in the reclaimed wastewater should be limited to approximately 10 mg/L.

CONTROL OF TRACE CONTAMINANTS

Additional contaminants that may be found in the wastewater which have not been addressed above include trace concentrations of various organic compounds (such as TTHM's, pesticides, etc.) and metals (such as lead, cadmium, etc.) which are currently regulated or may be regulated in the future.

TRACE ORGANICS

The majority of trace organics of health concern such as herbicides, pesticides, and other synthetic organic chemicals are rarely found in significant concentrations in conventionally treated wastewater. These compounds are more likely to be found in equal or greater concentrations in natural runoff currently entering the reservoir. Volatile organic compounds such as cleaning solvents which may periodically be found in wastewater will eventually dissipate through natural aeration within the treatment plant and in the creak and reservoir.

Another family of organics of health concern is disinfection byproducts such as trihalomethanes (THM's) formed when water is chlorinated. The organic compounds which are precursors to THM formation are found in wastewater, but in most "natural" surface waters as well; decaying vegetation results in the release of humic acids which are a primary THM precursor, as an example. The water currently in Lake Fort Phantom Hill typically has a high THM formation potential already.

Residual organics in treated wastewater usually impart some color to the water. This color is of no direct health significance, and would not be particularly apparent in Elm Creek or Lake Fort Phantom Hill. However, color removal would be desirable to improve the aesthetic quality of reclaimed water in a direct reuse project or a project wherein the reclaimed water was a significant fraction of the total supply. Full implementation of a proposed Abilene reuse program, including water reclamation at the Hamby WWTP, would likely result in the need to reduce the color in the reclaimed water to assure public satisfaction. Color removal from the initial Westside WWTP discharge is not considered necessary due to the relatively small contribution to the total supply.

Trace organics remaining in the treated water may also impart a slight odor to the reclaimed water. As in the case of color, odor of the reclaimed water is not a public health issue and is only anticipated to become an aesthetic issue in the reclaimed water upon full implementation of the proposed Abilene reuse program.

The above considerations result in our recommendation that control of trace organics be implemented in the future at the City's water treatment plants rather than investing in facilities for removing trace organics as an advanced wastewater treatment process. Such treatment is not required prior to discharge of the reclaimed water to the reservoir to protect any beneficial uses other than augmenting the public water supply. Furthermore, supplemental organic control treatment will likely be required at the water treatment plants in any event to meet emerging drinking water regulations and to effectively control taste and odor challenges. Therefore, we recommend that supplemental trace organic control efforts be focused on upgrading the treatment processes at the existing water treatment plants as necessary to meet new regulations and to offset any incremental effects related to the reuse program.

One exception to this approach relates to the use of chlorine for disinfection at the wastewater treatment plants. It is common practice to heavily chlorinate treated wastewater to best assure the water is adequately disinfected prior to discharge. Often times the chlorinated effluent is dechlorinated with a chemical such as sulfur dioxide to eliminate the residual chlorine which is toxic to fish and other aquatic organisms. However, many of the chlorinated organic compounds remain in the water and are not removed by the dechlorination reactions. Given the movement towards increased regulation of chlorinated organic compounds in drinking water, consideration should be given to minimize the discharge of chlorinated wastewater to Lake Fort Phantom Hill. However, the prime need to adequately disinfect the wastewater must receive foremost consideration.

INORGANIC CHEMICALS

Trace inorganic chemicals of public health significance are listed in Table 1. These are primarily metals for which drinking water MCL's have already been established, or will be established by EPA in the future. Such metals are typically not encountered at excessive concentrations in the discharge from conventional wastewater treatment plants, particularly where the wastewater is primarily of domestic origin. Samples collected to date from the Hamby WWTP discharge have not had metal concentrations in excess of established MCL's for drinking water. Furthermore, the coagulation and/©H or lime treatment processes included at the City's water treatment plants, and anticipated as part of the advanced wastewater treatment processes if reuse is implemented, are relatively effective in precipitating these metals. Therefore, trace metals are not anticipated to represent a water quality problem with respect to the reuse program. The program should include routine monitoring to verify this condition, and emphasis on strict industrial waste ordinances to minimize the discharge of these metals to the wastewater collection system.

Nitrate is one other constituent of interest included on EPA's inorganic chemical contaminant list. An MCL of 10 mg/L of nitrate-nitrogen has been established. Projected concentrations of nitrate nitrogen in Lake Fort Phantom Hill were presented in Technical Memorandum No. 5 for various reuse scenarios. These projections indicate that full implementation of the proposed Abilene reuse program (including water reclamation at the Hamby WWTP) will require either nitrate removal at the water treatment plants or reduced discharge concentrations at the wastewater treatment plants. The latter is much more practical and economical. Therefore, the reuse program should include provisions to ultimately reduce nitrate-nitrogen concentrations in the discharge to as low as 10 mg/L.

SUMMARY AND CONCULSIONS

The above water quality considerations result in the following recommendations with respect to reclaimed water quality goals for various aspects of a proposed Tributary Water Reclamation Facility.

Reclaimed water discharged via a tributary to Lake Fort Phantom Hill:

° BOD	5 mg/L
° Turbidity	2 NTU
° Ammonia nitrogen	2 mg/L
° Nitrate/nitrite nitrogen	20 mg/L <3 mgd 10 mg/L >3 mgd
° Total Phosphorus	7.0 mg/L <3 mgd 0.2 mg/L >3 mgd
° Dissolved Oxygen	>5.0 mg/L
° Coliform Organisms	<100/100 ml mean <2.2/100 ml as a goal
° Virsus/Parasitics	4-Log Reduction Goal; Free of pathogenic virsus >1.0 pfu/ 100 liter Enteroviruses; free of pathogenic parasites <1.0 active entamoeba hartamanni/ liter

In addition, an ongoing program needs to be implemented to assure satisfactory management of water quality issues relating to control of trace organic compounds. This includes taste and odor compounds and other trace organics that are best managed at the water treatment plants in conjunction with compliance with future drinking water regulations. The program should also address the issue of chlorine disinfection at the wastewater treatment plants and whether or not alternative or modified disinfection practices are necessary or desirable in the future to minimize the discharge of chlorinated organic compounds to Lake Fort Phantom Hill.

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 7

PROCESS SELECTIONS, CONCEPTUAL DESIGNS, AND PRELIMINARY COST OPINIONS

Principal Authors: Raymond R. Longoria, P.E.
Bob Chapman, P.E.
David Lewis, P.E.

INTRODUCTION

This Technical Memorandum (TM) provides a summary of the processes that are being suggested for the wastewater and the water treatment plants as part of the proposed City of Abilene water reclamation system. The TM first reviews the basic design requirements that have been developed in other TM's and is followed by a presentation of the processes available to meet these requirements. A more detailed process evaluation is next presented. This evaluation includes a conceptual design of the most promising system configurations and a preliminary cost opinion of each configuration. From this evaluation, a recommended process system is presented. A proposed testing program is presented at the end of this TM.

The criteria established on Technical Memorandum No. 5, Water Quality Criteria and Goals are the foundation for the process selections and concept designs. There are many different process in various combinations that are capable of achieving the effluent quality established in TM No. 5. The recommended process is applicable regardless of where the water reclamation plant is located, and even if it is constructed at the existing Hamby WWTP. At the Hamby location, some of the existing units would be utilized requiring less new construction. The water reclamation system alternatives evaluated in Technical Memorandum No. 7A will incorporate the processes recommended in this TM.

PROCESS DESIGN REQUIREMENTS

Design Flows - Tributary

The proposed WWTP facility for water reclamation will accomplish four basic goals. The first is the treatment of wastewater to meet the wastewater treatment needs of Abilene. The construction of a new plant on the west side of Abilene has been shown to be more economical then constructing new sewers to transport wastewater to the Hamby WWTP ("City of Abilene, Wastewater Collection System Analysis", Freese and Nichols, May, 1987). A second goal of the Westside WWTP will be to supplement the City of Abilene's water supply in Lake Fort Phantom Hill. The third goal is to provide a source of non-potable water for use on the west and southside of the city. The fourth basic goal of the Westside WWTP is to demonstrate advanced wastewater treatment technologies. These technologies will be demonstrated when the discharge flow from the Westside plant is still relatively low (average of 2.4 mgd), so that it will not have a significant impact on the water quality in Lake Fort Phantom Hill.

From the Freese and Nichols report, the following flow rates have been determined:

Phase I

Design Average Flow	2.4 mgd
Peak Month Average Flow	3.0 mgd
Peak Day Average Flow	4.6 mgd
Peak 2 Hour Flow	10 mgd

Phase II

Design Average Flow	5.6 mgd
Peak Month Average Flow	7.0 mgd
Peak Day Average Flow	10.7 mgd
Peak 2 Hour Flow	23.3 mgd

EFFLUENT REQUIREMENTS

The water quality criteria and goals for each point in the water reclamation process were discussed in Technical Memorandum 6. Two effluent requirement sets were developed for the WWTP, each providing a different level of water quality in the receiving tributary stream and in Lake Fort Phantom Hill during drought periods. These two effluent requirement sets are repeated below:

Effluent Requirements A:

BOD	5 mg/L
Turbidity	2 NTU
Ammonia Nitrogen	2 mg/L
Nitrate/nitrite nitrogen	10 mg/L
Total Phosphorus	0.2 mg/L
Dissolved Oxygen	>5.0 mg/L
Coliform Organisms	<2.2/100 ml mean
	< 23/100 ml max

Effluent Requirements B:

BOD	5 mg/L
Turbidity	2 NTU
Ammonia Nitrogen	2 mg/L

Nitrate/nitrite nitrogen	15 mg/L
Total Phosphorus	2.0 mg/L
Dissolved Oxygen	>5.0 mg/L
Coliform Organisms	200/100 ml mean

OPERATIONAL REQUIREMENTS

The operational requirements of the proposed water reclamation WWTP will be more demanding than a typical secondary wastewater treatment process. The extra demands will be in man power, operator skill, and materials. The additional materials required will be included as part of the cost estimation. The additional operator skills required to operate the facility will be a result of the more complex nature of the biological process and the tertiary process proposed. In addition, the strict effluent discharge requirements will take special operator care of the processes.

RELIABILITY.REDUNDANCY REQUIREMENTS

Reliability and redundancy of treatment processes are important considerations when evaluating the risks involved in wastewater reclamation. The risk involved in not providing sufficient reliability and redundancy is that the discharge of the plant will not meet the required effluent standards and thereby adversely impact the receiving water.

In the case of the water reclamation facility, a higher degree of reliability and redundancy is required than for conventional wastewater treatment plants due to the high impact of not meeting the effluent standards. In other words, it is felt that to safe guard public health, the discharge from the plant should never exceed its effluent standards and a high degree of reliability and redundancy are, therefore, required. It is recommended that the design be based on meeting effluent standards at the peak monthly flow with any one unit out of service. To estimate the impact of this redundancy requirement a factor of 1.3 has been applied to the sizing of all of the critical processes for cost estimation.

PROCESS ALTERNATIVES

There are a number of treatment process that may be used to meet the design requirements discussed above. These processes are briefly discussed in this section and summarized in Table 7-1. A summary of the advantages and disadvantages associated with the alternatives is presented in Table 7-2. The discussion below is limited to those factors which are important to deciding whether the process should be considered for implementation in the Abilene water reclamation system. More detailed information on these processes can be found in many text books and EPA publications.

PACT

Description

Powdered Activated Carbon Treatment (PACT) is a patented process in which powdered activated carbon is added to an aeration basin of a activated sludge wastewater treatment system. The activated sludge system functions in a typical manner, with the exception that the carbon provides an added degree of organic material removal. The carbon serves to adsorb some of the soluble organic material that is in the wastewater. The adsorbed organic material may eventually undergo biological oxidation or it may be removed from the system with the spent carbon. To achieve effective settling of the powdered carbon containing mixed liquor, polymer is typically dosed to the secondary clarifiers at a rate of less than 1 mg/L.

Table 7-1

ABILENE WATER RECLAMATION RESEARCH PROJECT
TREATMENT PROCESS ALTERNATIVES

TREATMENT TYPE	1 HI-LIME	2 ALUM.	3 ALUM. & BIO. P.	4 NITRIFICATION
PROCESS DESCRIPTION[1]	Activated Sludge Nitrification De-Nitrification Clarification Hi-Lime Re-Carbonation Filtration Chlorination Post Aeration	Activated Sludge Nitrification De-Nitrification Coagulation Chem. P. Removal Clarification Filtration Break-Pt. Chlorination Post Aeration	Activated Sludge Nitrification Biological Phosphorous Coagulation Filtration Clarification Filtration Break-Pt. Chlorination Post Aeration	Activated Sludge Nitrification Biological Phosphorous Clarification Filtration Chlorination Post Aeration Pump Station and Force Main
EFFLUENT QUALITY	Design/Average Operating Conditions			
BOD	5.0/2.0	5.0/2.0	5.0/2.0	5.0/3.0
TSS	5.0/<1.0	5.0/<2.0	5.0/<1.0	5.0/5.0
TKN	2.0/1.0	2.0/0.1	2.0/0.1	2.0/1.5
Nitrate	10.0/5-7	10.0/5-7	15-20/15-20	15-20/15-20
Phosphorous	.2/.1	.2/.15	.2/.15	2.0/2.0
Dissolved Oxygen	5.0/6.0	5.0/6.0	5.0/6.0	5.0/6.0
Coliform	2.2/2.0	2.2/N.D.	2.2/N.D.	200.0/100
NTU	2.0/1.0	2.0/1.0	2.0/1.0	N.A./4-10
COST PRELIMINARY per 1,000,000				
Capital	13.41	11.26	10.12	11.58
O&M	0.70	0.56	0.46	0.35
Equivalent Annual[2]	2.09	1.73	1.51	1.55

NOTES: 1. All preceded by preliminay treatment, screening, and grit removal; dechlorination also provided.
2. Based on 20 years @ 8% interest.

Table 7-2

ABILENE WATER RECLAMATION RESEARCH PROJECT
SUBJECTIVE EVALUATION TREATMENT PROCESS ALTERNATIVES

	1 Hi-Lime	2 Alum	3 Alum & B.P.	4 Nitrification
Advantages	1. Total organic carbon reduction.	1. Total organic carbon reduction	1. Total organic carbon reduction.	1. Lowest capital cost.
	2. Total dissolved solids reduction.	2. Relatively easy sludge handling, if discharged	2. Relatively easy sludge handling.	2. Lowest O&M cost.
	3. Track record of success.	3. Track record of success for P removal.	3. Track record of succes for P removal.	3. Least comples operation.
	4. Relatively stable process.	4. Removals viruses/pathogens.	4. Removals viruses/pathogens.	4. Has ability to pump out of basin for reliability.
	5. High reliability because of Hi-Lime.	5. Easier maintenance than Hi-Lime.	5. Easier maintenance than Hi-Lime.	5. Removes NH_3.
	6. High disinfection capabilities, both pH and Cl_2 removals, both viruses pathogens.	6. High disinfection capabilities with break-pt Cl_2.	6. High disinfection capabilities with break-pt Cl_2	6. Removes majority of phosphorus.
	7. Removes NH_3.	7. Removes NH_3	7. Removes NH_3	
	8. Denitrified effluent.	8. Denitrified effluent.	8. Lower capital cost than Hi-Lime and Alum.	

	9. High level of phosphorous and heavy metal removal.	9. Lower capital costs.	9. Lower O&M cost than than Hi-Lime and Alum	
	10. Color and hardness removal.	10. Lower O&M than Hi-Lime, higher than and Alum & B.P.	10. Less of an increase of TDS than Alum.	
	11. Lower THM formation than BP-Cl_2.	11. Less complex operations than Hi-Lime or Alum & B.P.		
Disadvantages	1. Highest capital cost.	1. Increase TDS.	1. Still increases TDS.	1. Less effective in removal of viruses/ pathogen.
	2. Highest O&M cost.	2. Higher chemical cost than Bio-P.	2. Requires specially trained operations staff; less maintenance than Hi-Lime.	2. Not as easily expanded without additional unit operation for P-removal and nitrate reduction.
	3. Require specially trained operations staff.	3. Requires specially trained operations staff; however, simpler than Bio-P.	3. More complex operation than Alum alone.	3. Request trained operational staff, but less complex than other alternative.
	4. Lime sludge handling and disposal.		4. Higher capital cost than Alum alone.	4. Requires careful ooperation of Bio-P.
	5. High maintenance with scaling problems.			

Spent carbon is removed from the system with the waste activated sludge (WAS). The carbon can be regenerated from the WAS by wet air oxidation. Regeneration is typically only economical for large installations or where sludge disposal costs are high. If the sludge can be simply stabilized and lagooned, it is not likely to be economical to regenerate the carbon. It addition, wet air oxidation produces a number of recycle streams that may be difficult to deal with.

Activated carbon doses vary with the purpose of the addition. For the purpose of reducing the organic carbon content of the water to as low a level as possible, carbon dosages between 100 and 200 mg/L may be required.

Powdered activated carbon is a fairly abrasive material, so that pumps or piping that comes into contact with a slurry containing the carbon must be abrasion-resistant. Thus, in a typical activated sludge system, all recycle pumps and piping must have special materials of construction. This construction will add to the capital cost of the system. The activated carbon feed system is the only other additional capital cost associated with PACT, if carbon regeneration is not used.

Operations

The operations of a PACT system without carbon regeneration are reported to be only slightly more complex and time consuming that a typical activated sludge system. Some people even claim that a PACT system is easier to operate than conventional activated sludge due to the process stability that organic material adsorption provides. However, the addition of the powdered carbon can be difficult and messy. Regeneration of the spent carbon will greatly increase the operational complexity of the plant.

The operating cost of a PACT system without carbon regeneration versus a conventional activated sludge system will depend on the current cost of powdered activated carbon. In 1984 the price of powdered activated carbon ranged from $0.30 to $0.33 per pound. Thus, for a 3 mgd plant at a dose of 150 mg/L, the cost of carbon would be $411,000 per year to $452,000 per year.

Since the PACT process is a patented process, a one time license fee must also be payed. In 1984 a 3 mgd plant using a dose of 150 mg/L would have payed a license fee of $113,000.

Applicability

The need to remove organic contaminants from wastewater prior to discharge to Lake Fort Phantom Hill was discussed in TM 6. Summarizing, organic removal will reduce the THM's that are produced during chlorination and thereby reduce the build up THM's in Lake Fort Phantom Hill during drought conditions. Organic removal through activated carbon will also reduce the level of possible priority pollutants in the wastewater plant discharge and in the intake to the water treatment plant during drought conditions. However, as pointed out in TM 6, it is felt that the use of activated carbon in the water treatment plant is a much more economical means of providing organic carbon and THM removal. Thus, based on a organic priority pollutant and THM potential removal, PACT is not suggested.

The other major benefit that PACT provides is its ability to improve process stability. PACT is reported to improve the stability of an activated sludge system by adsorbing toxic organic compounds in the wastewater, thereby rendering them non-toxic. This may be a major benefit for a system that must nitrify and also has a high loading from industries that discharge toxics. The proposed WWTP will receive wastewater from mostly residential areas, but also from Dyess Air Force base. The wastewater discharge from the Air Force base could, at times contain a significant amount of organic solvents and other toxic compounds. Process stability is also improved by the addition of powdered activated carbon by it tendency to reduce the impacts of organic shock loads. A fraction of the organic shock load will be adsorbed, thereby reducing the impact of this load. It is however, impossible at this time to judge the possible merits of using PACT at the proposed WWTP.

PACT has as its major draw back, its costs. The additional capital costs for the abrasion-resistant pumps and piping and the carbon feed system must be considered. The one-time license fee must also be considered as a capital cost. The major cost of using PACT will be the cost of the carbon. At the 3 mgd initial design capacity of the proposed WWTP, carbon regeneration is not feasible, so that all of the carbon dose must be made up with virgin carbon.

These costs are difficult to justify with a process that may not provide any benefit. On the other hand, since PACT may in fact provide a benefit, it may be beneficial to design the proposed WWTP for PACT (abrasion-resistant pumps and piping on the recycle streams) in the advent it is needed at some latter point in time.

GAC

Use of granular activated carbon (GAC) was carefully considered for inclusion in the initial phases of the Abilene reuse project. GAC is capable of removing a broad range of trace organic compounds, including herbicides, pesticides, other synthetic organic compounds which are to be regulated in drinking water supplies, surface-active compounds which tend to cause foaming, and taste and odor causing compounds. For these reasons, GAC has frequently been included in water reuse projects.

The reuse concepts envisioned by Abilene are somewhat unique from many reuse schemes, primarily in that the City of Abilene has complete control over the wastewater system as the source of water, the intermediate water storage reservoir (Lake Fort Phantom Hill) and the drinking water supply system. This allows application of removal and control techniques at their overall, optimum location.

A second relevant consideration are the requirements for enhanced drinking water supply treatment as a result of the 1986 Amendments to the National Safe Drinking Water Act. Resultant EPA regulations will require additional treatment of many public water supplies, including in many instances such processes as adsorption using GAC.

Consideration of these two factors resulted in our recommendation that GAC not be included as part of the wastewater reclamation plant process. Use of GAC for advanced wastewater treatment is not necessary to meet discharge regulations, or to protect the beneficial uses of Lake Fort Phantom Hill or its tributaries. Rather it is recommended that GAC be considered for potential future application at the City's water treatment plants, when and if proven desirable or necessary. The benefits of so doing are as follows:

- The GAC would remove organic contaminants introduced to Lake Fort Phantom Hill as a result of surface runoff, which is likely to have equal or greater concentrations of synthetic organic compounds as compared to the treated wastewater.

- The GAC would reduce natural occurring humic acids from LFPH which otherwise could react with chlorine to form THMs.

- THE GAC would remove taste and odor compounds associated primarily with algae growth in LFPH.

Testing to date has not identified the presence of any priority pollutants in excess of current drinking water standards in the wastewater discharged by the Hamby Wastewater treatment plant. This fact, coupled with the limited discharge of reclaimed water to LFPH envisioned during the initial phases of Abilene's reuse, clearly do not require use of GAC at either the wastewater or water treatment plants initially. However, we recommend that evaluation begin at the water treatment plants on a pilot scale to determine the benefits and criteria for possible future GAC application to meet emerging regulations and/or produce more aesthetically pleasing water.

NITRIFICATION

Description and Operations

Biological nitrification provides a means of reducing the concentration of ammonia to relatively low levels with only slight modifications to the conventional activated sludge system. If even lower concentrations are required than can be achieved with nitrification, break point chlorination can be used to polish the effluent of ammonia. Nitrification is today, a widely accepted process.

Nitrification involves the biological oxidation of ammonia to nitrate by a class of microorganisms called nitrifiers.

Nitrifiers have a number of rather special environmental requirements for their proliferation and activity. Among these special requirements are a relatively long solids residence time (SRT) in the activated sludge system. The Texas Design Criteria calls for a SRT of 10 days for a nitrifying activated sludge system. Long SRT's require larger aeration basins, and thus, somewhat higher capital cost versus conventional activated sludge systems.

Another requirement of nitrification is dissolved oxygen. Nitrifiers will consume oxygen, and thus will increase the aeration requirements of an activated sludge system. The dissolved oxygen concentration should be maintained above about 2 mg/L for successful nitrification.

Along with oxygen, alkalinity will also be consumed during nitrification. If the incoming wastewater has a low alkalinity concentration, nitrification will reduce it even further and the resulting low alkalinity levels may inhibit nitrification and other biological processes. Chemical addition or denitrification (to be discussed below) can be used to control alkalinity. It does not appear that alkalinity should be a significant problems in Abilene since the alkalinity of the source water is relatively high.

Nitrification is also very sensitive to toxic compounds in the wastewater. Consequently, a great deal of care must be used in the operation of a nitrifying activated sludge system. A strictly enforced pretreatment ordinance is the most cost effective means of avoiding inhibition of nitrification by toxic compound, although PACT and other process alterations may be used.

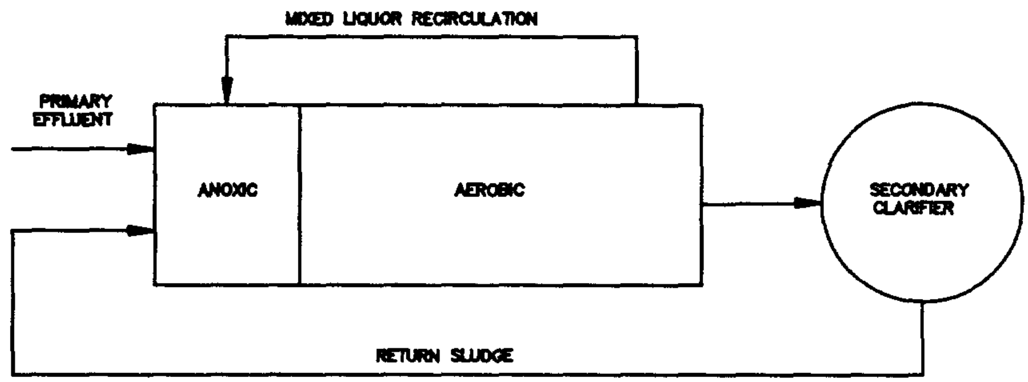
Applicability

Nitrification has proven itself as a cost effective means of removing ammonia from wastewaters. The other physical/chemical process available are more costly and often difficult to operate. The problems with nitrification may be overcome by special design and operations procedures. Thus, nitrification is recommended for implementation at the proposed WWTP and the Hamby WWTP.

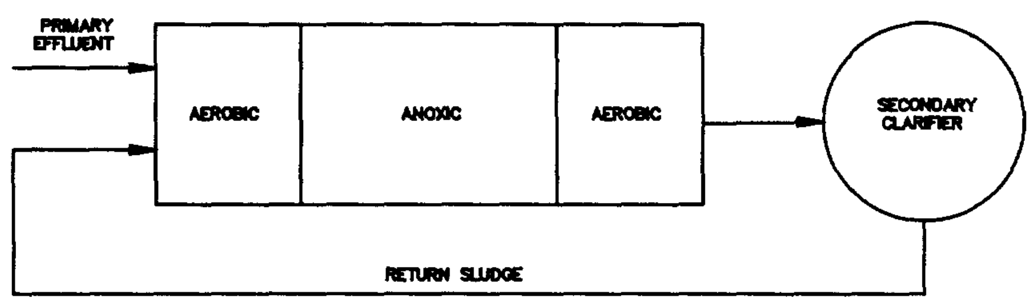
DENITRIFICATION

Denitrification is the biological reduction of nitrate to nitrogen gas in an atmosphere void of oxygen. In the process of denitrification, nitrate (produced during nitrification) serves as the terminal electron acceptor in place of oxygen for the oxidation of organic matter. In addition to providing a means of removing nitrate, denitrification also provides a number of process benefits.

To accomplish denitrification, special zones in the activated basins must be created in which oxygen will be absent. These anoxic zones may either be at the influent end of the aeration basin (upstream anoxic zones) or towards the effluent end of the basins (downstream anoxic zones). Figure 7-1 depicts these two zones. In upstream anoxic zones the rate of denitrification will be higher due to higher organic concentrations. However, nitrified mixed liquor must be recycled to provide the nitrate for denitrification. In downstream anoxic zones the nitrate will be carried in with the incoming mixed liquor so that mixed liquor recycling is not required. However, the rate of denitrification will be lower (two or three times lower) so that downstream anoxic zones must be larger. In general,



UPSTREAM ANOXIC ZONE
(ANOXIC SELECTOR)



DOWNSTREAM ANOXIC ZONE

FIGURE 7-1
ANOXIC ZONE LOCATIONS

it is more economical to use upstream anoxic zones and to recycle denitrified mixed liquor. The pumping head for the recycled mixed liquor will be relatively low, so that the cost of pumping will be relatively minor.

Operations

The operations of an activated sludge system with denitrification is general not any more difficult than a conventional activated sludge system. The microorganisms responsible for denitrification are much more hardy than are nitrifiers, and they are likely to be present in mixed liquor under almost all conditions. About the only problem that is sometimes encountered in denitrifying systems is the presence of Nocardia foam. However, this foaming problem can generally be handled by proper design and operation.

Three major process benefits can be attributed to denitrification. The first is the recovery of alkalinity lost during nitrification. About 40 percent of the alkalinity lost during nitrification can be recovered during nitrification. This is often enough to prevent the need to add chemicals for alkalinity control.

Denitrification will also reduce the amount of oxygen required for organic matter oxidation. This is a result of the nitrate being used as a substitute for oxygen during the oxidation of organic matter. Aeration requirements can be reduced by as much as 10 to 20 percent through denitrification.

The third operations benefit of denitrification is the production of a good settling sludge. The operations of upstream anoxic zones has been shown to avoid the problem of filamentous bulking. An upstream anoxic zone will act much like an aerobic "selector" in that it selects for floc forming microorganisms over filamentous organisms.

Applicability

Denitrification, in conjunction with nitrification, provides a relatively economical means of removing total nitrogen from a wastewater. Reducing the effluent nitrate concentration to 10 mg/L should be easily achieved with denitrification. The process benefits denitrification provides are also a significant advantage. These benefits alone make denitrification worth considering for both the proposed water reclamation WWTP and the Hamby WWTP. Thus, denitrification in upstream anoxic zones is recommended for implementation at the proposed Westside WWTP.

BIOLOGICAL PHOSPHORUS REMOVAL

Enhanced biological phosphorus (P) removal is a relatively new process for the removal of P from wastewaters. Enhanced biological P removal requires the addition of an anaerobic zone in the activated sludge basin. This zone must be void of both oxygen and nitrate. To be effective this zone must be at the influent end of the aeration basin. The anaerobic zone can be relatively small, requiring about 20 percent of the total volume.

The reactions involved in biological P removal are rather complex. They involve the release by certain microorganism of previously stored P in the anaerobic zone, and then the subsequent uptake of the P in the aerobic zones of the activated sludge. P is removed from the waste stream as part of the waste activated sludge. Waste activated sludge from a biological P removal system is typically three times higher in P than a conventional activated sludge system.

More detailed information on enhance biological P removal can be found in a paper by Daigger et al.

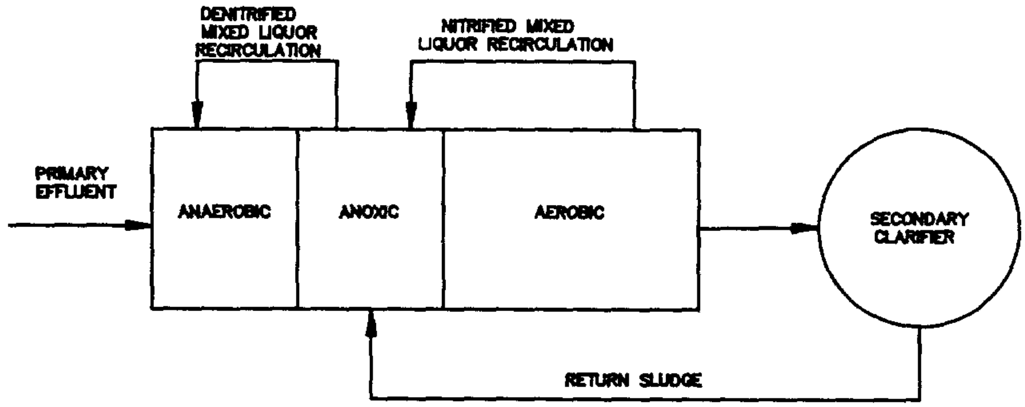
A number of named process configurations are available for biological P removal. Figure 7-2 presents schematics of three of these process. The processes pictured provide for both phosphorus and nitrogen removal. Although the differences between the process does not appear to be major, they are significant. The difference are discussed in detail in the paper by Daigger et al. For application at the proposed Westside WWTP, it is felt that the University of Cape Town (UCT) process provides the greatest benefits.

Operations

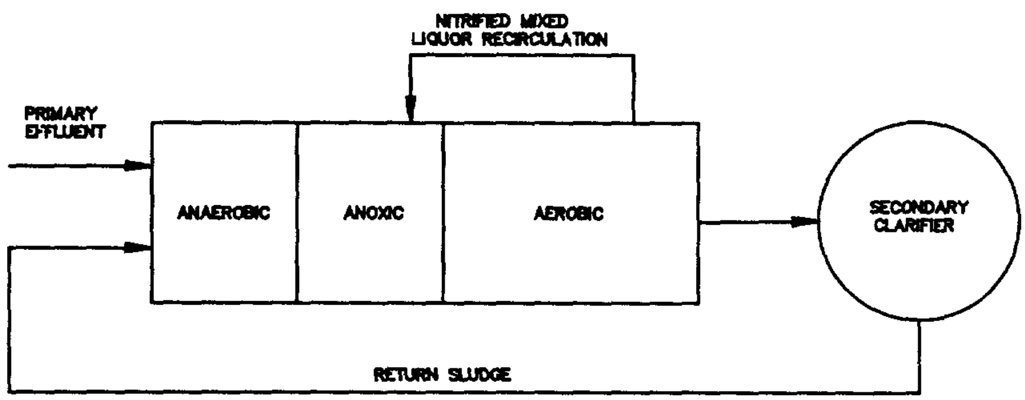
The operations of a biological nutrient removal facility requires greater skill than a conventional activated sludge system. This is primarily due to the relatively narrow "window of operation" that is available with biological P removal systems. The window of operations is defined by the minimum SRT that must be maintained for nitrification and by the maximum SRT at which P release starts to diminish. A very high SRT's the amount of P removed through biological uptake will decrease due to, among other things, the lower waste activated sludge production. Thus, a biological P removal system must be operated at as low a SRT as possible, but with a SRT great enough for nitrification.

Sidestreams from sludge treatment processes must also be closely controlled in a biological P removal process. These sidestreams may be very high in P, and thus may reduce the overall P removal in the process.

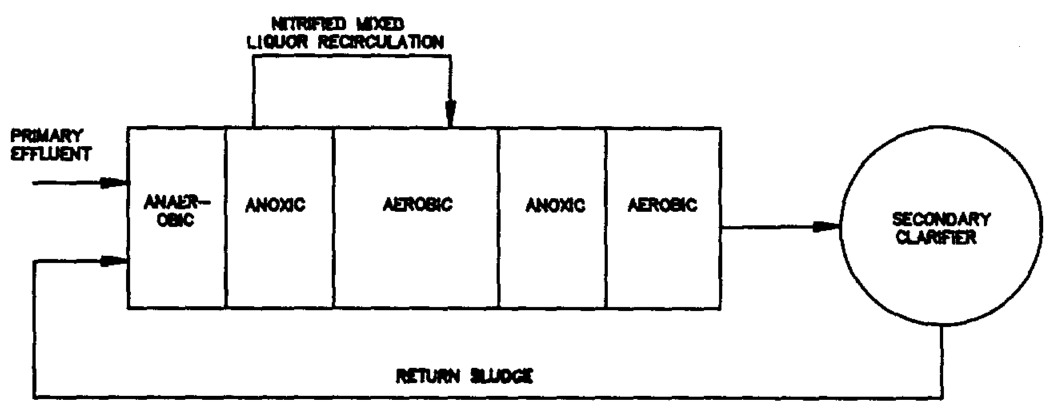
If sludge sidestreams can be controlled and the correct window of operation found, biological P removal systems can offer stable operation. The sludge settling characteristics of biological P removal systems is typically very good.



UNIVERSITY OF CAPETOWN PROCESS (UCT)



A2/0 PROCESS



FIVE STAGE BARDENPHO PROCESS

FIGURE 7-2
BIOLOGICAL NUTRIENT REMOVAL PROCESS

The effluent P concentrations achievable with a biological P removal system will depend on a number of factors. Concentrations below 2 mg/L of P are very commonly reached in these system. Under the proper conditions, it its also possible to achieve concentrations down to 0.5 mg/L of P.

The most economical means of P removal to very low levels is often a combination of biological and chemical methods. Biological P removal is used to lower the concentration to what ever is most economical and chemical (alum) addition is used to polish the remaining P to the required level. This combination of chemical and biological removal can greatly reduce the cost of alum P removal alone.

Applicability

The applicability of biological P removal is highly dependent on what downstream tertiary processes are used. If high lime treatment is used, there is no reason to use biological P removal since the lime will remove the P with no additional lime required. However, if alum coagulation with filtration is used, biological P will provide an advantage. The dose of alum can be greatly reduced with the use of biological P removal. A lower does of alum can be used for coagulation alone, rather than coagulation and P precipitation.

One significant draw back of using biological P removal is the proprietary nature of most of the named process configurations. The UCT process is the only major named process that is not proprietary. The design of a biological P removal system must be approached with caution to avoid conflicting with a proprietary process.

The installation of the basins required for biological P removal will require only a marginal increase in the required aeration basin sizing and thus, the cost of the basins. The 20 percent increase in activated sludge basin sizing required for biological P removal should only result in a small increase in the capital cost of the system.

HIGH LIME TREATMENT

Description

The addition of lime in high dosages improves the quality of the wastewater effluent by precipitating certain compounds out of solution and by promoting coagulation to remove others.

Lime reacts with alkalinity and phosphorous in the wastewater to form the precipitants calcium carbonate, calcium hydroxyapitite and magnesium hydroxide. The first and third precipitate remove calcium and magnesium reducing the hardness and total dissolved solids of the water. The calcium hydroxyapitite removes calcium and soluble phosphorous. The calcium removal reduces hardness and TDS as stated above. The near complete removal of phosphorous in the biggest benefit of the lime treatment of wastewater. In theory almost all of the soluble phosphorous is converted to the insoluble form at pH's above 9.5. The amount of alkalinity present in the wastewater greatly affects the pH level required and thus the amount of lime required for actual phosphorous removal. The higher the alkalinity the higher the pH requirement.

Less extensive, but equally important is the resulting precipitation of certain heavy metals at the elevated pH's created by the lime addition.

Additional benefits are gained by the coagulating affect of the precipitating compounds. As the coagulants settle, solids, turbidity and color are removed. With the removal of the solids and colloidal particles additional organic removal is accomplished. Additionally, a clearer effluent is achieved.

The elevated pH levels associated with high lime is effective in destroying bacteria, cysts, viruses and parasites in the wastewater. At pH's of 10.8 to 11.0 and detention times typical for wastewater coagulation, the removal of these organisms is almost complete.

Operation

High lime treatment follows conventional secondary treatment in the process train. The clarified effluent is dosed with lime, mixed, flocculated and allowed to settle. The appropriate lime dosage and treatment time vary with the wastewater. Typically 300 to 400 mg/l of calcium hydroxide dosage is required to raise the pH to 11.0. A rapid mix detention time of 2 to 3 minutes, flocculation of 5 to 15 minutes, and sedimentation of 1 to 2 hours are typical. As with all chemical coagulation treatment, it is recommended that jar tests be conducted to establish appropriate dosage and detention times for design.

The effluent from the chemical clarifier has a pH of 10.5 to 11.0. Prior to discharging into a receiving stream, the pH needs to be lowered. Most discharge permits require effluent pH's to be in the range of 7.0 to 9.0. This is accomplished in a recarbonation step where carbon dioxide (which coverts to carbonic acid) is introduced into the effluent.

Although the operation of a high lime system is not a normal wastewater treatment process, it is common in potable water treatment systems. The technology and operational expertise required is similar to what is practiced at the City of Abilene Northeast WTP.

Applicability

High lime coagulation is a proven means for removing phosphorous and colloids in a wastewater effluent and improving the bacteria and viral kill. All of the reuse facilities studied in this project included high lime treatment as a unit operation.

The construction cost and operations and maintenance cost for high lime coagulation are high. It is typical for this process to result in an increase of $0.40 to $0.50/1,000 gallons of wastewater treatment or $146,000 to $183,000/year for every 1 mgd of treatment capacity. The waste sludge generated in a high lime plant are greater than those using other chemical coagulants. Sludge disposal requirements are likewise greater.

High lime treatment, as with any coagulation process step, adds stability to plant performance. Upsets in the biological portion of the process train will result in increased organics and solids in its effluent. The presence of the high lime step following the biological will minimize the effect of the upset on the downstream units and the receiving stream. This protection serves as an additional barrier of protection and is consistent with the multiple barrier philosophy described in TM 6.

The bench scale high lime studies conducted at the Hamby WWTP and described in TM 8A revealed removal performances at Abilene similar to those described in the literature. However, the alkalinity of the wastewater is high; accordingly the lime dosage requirements were high, as was the recarbonation level. High lime treatment would be effective treatment process for water reclamation in Abilene but would carry a high operational cost.

COAGULATION SEDIMENTATION

Description

Chemical precipitation and coagulation in wastewater treatment involves the addition of chemical to enhance the removal of dissolved and suspended solids by sedimentation. It is possible to obtain a clear effluent, substantially free from suspended and colloidal particles.

There are three major classes of coagulants that are used singly or in combination: lime, polymers and metal salts. Lime precipitation is covered in detail in the discussion of high lime treatment.

The use of polymers as the primary coagulant generally is not economically favorable when compared to the inorganic coagulants available. Additionally, polymers do not provide phosphorous removal. The use of polymers as a coagulant aid would be suggested for the detailed pre-design evaluation but will not be considered here as a primary coagulant.

Metal salts include ferric chloride, ferric sulfate, copperas, aluminum sulfate and sodium aluminate. The performance efficiency of each coagulant will vary with the wastewater characteristics. Due to requirements for alkalinity and dissolved oxygen in the subject water for the iron salts to be effective, aluminum salts generally are more successful in wastewater applications. As with any chemical treatment, jar tests are recommended to identify the optimum coagulant, dosage and treatment detention times.

Whichever coagulant is used, the removal benefits are similar to those identified for high lime treatment. Good suspended and colloidal particle removal is accomplished, and a clear low turbidity effluent can be consistently achieved. With the removal of these particles suspended and dissolved organics and phosphorous and color are reduced.

Metal salt precipitation does not achieve hardness or TDS removal. In fact, TDS levels are increased by the release of inorganic ions when these chemicals are added. Although disinfection is not as complete as with the high pH of high lime treatment, a meaningful reduction of bacteria, virus, cysts and parasites is produced.

The waste sludge volume generated by inorganic coagulants is smaller than that from lime. However, it is a gelatinous sludge that is difficult to dewater.

Operation

Coagulants can be added at either the primary or secondary clarifier to enhance sedimentation. To obtain the results desired for water reclamation the chemicals are added at the secondary clarifier. Typically a dosage of 75 to 200 mg/l of alum will remove 90 percent of the phosphorous.

As with lime addition, the addition of inorganic coagulants is not typical at wastewater facilities but is a common practice at water treatment plants, such as the Grimes and Lake Abilene WTPs. The operation is less involved than high lime treatment in that less equipment is involved and pH adjustment is not required.

Applicability

Chemical coagulation/sedimentation is a proven means for removing phosphorous, suspended and colloidal particles, and malignant microorganisms from wastewater. The ability to add chemicals to improve effluent quality adds flexibility and reliability to the treatment process, and provides an additional barrier of protection to the receiving stream.

The bench scale alum studies conducted at the Hamby WWTP and described in TM8A demonstrated aluminum sulfate could be used successfully on Abilene wastewater. The removal efficiencies were comparable to those found in the literature and were adequate to achieve the desired treatment levels described in TM6. The dosage of alum required to achieve the observed phosphorous and turbidity removal was at the low end of typical dosage range. This would suggest alum coagulation would be economically favorable for the Abilene wastewater as chemical costs and waste sludge production would be relatively low.

FILTRATION

Description

Filtration involves the removal of residual solids in wastewater by passing the effluent through a granular media. The removal is accomplished by a combination of straining, sedimentation and adhesion. The use of granular-media filters for filtration of wastewater treatment plant effluent is a relatively recent practice. However, it has become well established and is now one of the most widely used unit processes for removal of residual solids.

Treated and settled wastewater effluent (either with or without chemical coagulation) is distributed to a granular media filter. Several different types of filters have been developed but the types most in use in the wastewater treatment industry are continuous backwash sand gravity filters and sand pressure filters. A dual media of sand and coal is used in the filters to improve performance.

Operation

Granular media filtration is a common treatment process in water treatment plants. All three water plants in Abilene include filtration. The technology and required operational expertise for treatment of wastewater is not significantly different and is a widely known process.

The units are typically sized for overflow rates of 2 to 6 gpd/sf of bed area, with gravity filters run at the lower end of the range. Without chemical treatment preceding the filters, TSS levels of 5 to 10 mg/l can be consistently achieved. With chemical coagulation in combination with filtration, TSS levels under 5 mg/l would be expected. Because of the greater amount of solids in the wastewater effluent, reduction of solids in the filtrate to typical potable water levels is not practical. Filters are designed to allow some penetration of solids, to obtain reasonable filter run lengths.

When the accumulation of solids on the filter increases the headloss through the filter to unacceptable levels, the media is backwashed to clean of of the solids. The filtration rate and acceptable terminal headloss are generally selected to achieve a minimum filter run length of 6 to 8 hours. The filter is then returned to service.

Most filter units in wastewater plant are set up for automatic backwashing. When headloss rises to a preset level or a present period of time is exceeded, the backwashing operation begins. Continuous backwashing units are gaining in popularity. In these units portions of the media are backwashed while the rest remains in service. The backwashing unit travels the length of the unit then stops. When the headloss or time parameter is exceeded it resumes operation.

Applicability

To achieve the desired effluent TSS levels identified in the water quality standards memorandum (TM 6), filtration will be required. Although it has a high capital cost, the operational costs are relatively low. The filters provide an additional barrier of protection of the quality of the receiving stream. In conjunction with chemical coagulation, the reliability of treatment performance and effluent quality is compatible with the requirements for water reclamation and the multiple barrier philosophy of TM 6.

DEMINERALIZATION

Description

The removal of dissolved inorganic substances from water as measured by the total dissolved solids concentration is referred to as demineralization. The main treatment processes used for demineralization include chemical precipitation, ion exchange, reverse osmosis and electro dialysis, and distillation.

Chemical precipitation has limited demineralization ability. Various inorganic ions, principally heavy metals can be removed, but some coagulants, such as slum, add ions thus increasing the total dissolved solids.

Ion exchange is a unit operation by which ions of a given species are displaced by ions of a different species in solution. For reduction of the total dissolved solids, a cation exchanger substitutes hydrogen ions for the positive ions and an anionic exchanger replaces negative ions with hydroxide ions. The substituted ions react to form water molecules.

The reverse osmosis process forces water under a 200 to 600 psi pressure through a semi-permeable membrane to separate the dissolved solids from the smaller water molecules. This process has the added benefit of removing dissolved organics which are less selectively removed by other demineralization techniques.

The electrodialysis process uses an electric field to separate dissolved inorganic substances from water. The transfer of dissolved solids ions takes place across a series of ion-selective membranes, resulting in a stream of fresh product water and a smaller stream of concentrated wastewater.

The removal of dissolved solids from water by distillation consists of raising the temperature of the water until it evaporates, leaving the dissolved chemical behind, and then condensing the pure water vapor by cooling.

Operation

Costs for demineralization in excess of $1 per thousand gallons an be expected. This would add $467,000 per year for every mgd of flow treated.

The operational requirements associated with demineralization are quite limiting. Water fed to any of the demineralization unit processes described has to be of a very high-quality for efficient operation. With the exception of chemical precipitation, demineralization has a large energy input, and suffers from frequent membrane fouling. The operation of these unit processes requires a high skill level.

A key operational benefit is the flexibility of operation. A properly designed system can handle a large variation in flow without materially affecting performance. Total dissolved solids at times of minimal concern, such as wet weather flows diluting the stream and flushing the reservoir, the units can be taken off line entirely and then reactivated when necessary.

Applicability

Recycling wastewater tends to increase the total dissolved solids concentration. In a closed loop system like Abilene/Lake Fort Phantom Hill, the concern is accentuated.

However, the results of the Lake Fort Phantom Hill Quality Model presented in Technical Memorandum 5 indicates TDS concentrations are within acceptable levels, at all flow/quality combinations evaluated. At design drought conditions and a future effluent flow of 17 mgd the TDS values were 950 mg/l. This is less than the drinking water recommended limit of 1,000 mg/l and slightly greater than the historical TDS of the Hubbard Creek water used to supplement the Abilene water supply during drought periods. The accumulation of TDS to unacceptable levels is deterred by the periodic flushing of the lake during wet weather cycles.

The results of the model evaluation, coupled with the high operational complexity and cost limits the need and applicability of demineralization for the Abilene Water Reclamation Research Project.

DISINFECTION

Disinfection of the effluent from a typical wastewater treatment plant is necessary to safe guard the health and safety of the public. Typical wastewater effluents that are not disinfected may contain pathogenic bacteria, pathogenic viruses and pathogenic parasites (such as giardia). The degree to which these pathogens are of a concern, and the degree to which they must be removed, depends on the final use of the effluent water. If the effluent is discharged to a large river that is only used for minimal body contact sports, the required degree of pathogen removal may be small. However, if little dilution is available in the receiving stream and bodily contact is likely, or if the water will eventually become a part of a potable drinking water source, pathogen removal may be of significant concern.

TM 6 presented the effluent quality requirements for the proposed wastewater treatment plants in the Abilene water reuse system. For the proposed Tributary WWTP, discharge to Elm or Cedar Creek is of major concern in terms of the degree of pathogen removal required. As discussed in TM 6, it will be assumed that to protect the health and safety of the public, the effluent discharged to the creek should have a turbidity of less than 2 NTU, a total coliform count of less than 2.2 per 100 ml, and process to significantly reduce other pathogens.

Another aspect of pathogen removal for the reuse of wastewaters is the Multiple Barrier Concept. This concept states that more than one pathogen barrier should be provided between the wastewater source and the potable reuse. The water from the proposed water reclamation plant or from the proposed Hamby WWTP tertiary system will be required to pass through a number of pathogen barriers before it becomes part of the potable water system. Coagulation and sedimentation, whether high lime or alum, will provide a certain degree of pathogen removal and thus, may be considered the first barrier. Filtration is a second barrier that is often effective in removal of pathogens associated with solids particles. Disinfection will be used to provide a positive means of pathogen removal and is thus, a significant barrier. Natural pathogen die off in the creeks and in Lake Fort Phantom Hill will provide an addition pathogen barrier before the water enters the water treatment plant. And of course, the treatment process in the water treatment plant provide a significant pathogen barrier.

As mentioned above, coagulation and filtration provide a significant removal of pathogens. There is data which suggests that with adequate coagulation and filtration only a minimal amount of disinfection is required to remove bacterial pathogens, viruses and giardia. However, since this data is as of yet not complete, it will be assumed that significant disinfection will be required for the Abilene Water Reuse Project. The definitions of significant disinfection to be used are from the "Pomona Virus Study" (Los Angeles County), "Surface Water Treatment Rules Associated With the 1986 Amendments to the Safe Drinking Water Act" (U.S. EPA), and from experience.

The technologies available for disinfection are discussed in the remainder of this section along with design criteria for the technologies.

Chlorination

Description. Chlorine has been used extensively for the disinfection of wastewater effluents and potable waters. Its disinfection properties are due to its strong oxidizing nature.

The process of disinfection with chlorine is relatively simple. A chlorine solution is added to a relatively turbulent region to ensure adequate contact between the water and the solution. A contact period is next provided to allow the chlorine to act on the pathogens. Dechlorination by the addition of sulfur dioxide typically follows the chlorine contact basin prior to discharge of the effluent.

Chlorine added to a water may be in a number forms, depending on other chemical constituents in the water. Chlorine will react with ammonia to form chloramines. Chlorine in the form of chloramines is called "combined chlorine." If little or no ammonia is present in the water, the chlorine may remain uncombined, or as "free chlorine." The disinfection properties of these two forms of chlorine vary significantly.

The degree of pathogen removal with chlorine is a function of both the concentration of chlorine in the water and the contact time between the water and the chlorine. Typically there is a trade off between contact time and chlorine concentration. The combined effects of contact time and concentration is described by "CT" values.

Design Basis. The design of chlorination facilities will vary depending on if combined chlorine or if free chlorine is available in the contact basins. For example, a CT value of about 1,100 minutes-mg/l is required for 99.9% giardia removal with a combined chlorine residual and a temperature of 15 degrees C (EPA). A similar value was also reported to achieve a 4 log reduction in virus at 20 degrees C (Los Angeles County). On the other hand, a CT value of 100 minutes-mg/l is reported to be required for 99.9% giardia removal at a pH of 7 and a temperature of 15 degrees C. Thus, free chlorine is a much more effective disinfectant.

As mentioned previously, nitrification will be employed as part of the activated sludge process of the proposed Westside WWTP. Effluent ammonia concentrations of below 2 mg/l should be relatively easy to meet with such a system. Consequently, it should be possible to achieve a free chlorine residual at the proposed WWTP. Enough chlorine must be added to oxidize any remaining ammonia and the most of remainder will be available as a free chlorine residual. A dose of between 20 mg/l and 30 mg/l may be required to achieve this goal. Thus, the proposed water reclamation plant will be designed for a free chlorine residual.

The CT value to be used for design will be based on the EPA rules for surface water treatment. These rules are applicable since the water entering the chlorination system should be of a quality near drinking water standards (in terms of turbidity and suspended solids) after it has passed through coagulations and filtration. Suspended solids are a hindrance to disinfection so that effective coagulation and filtration must be achieved. A 99.9% inactivation of giardia will be used as the criteria for selecting the CT value since giardia is more difficult to inactivate than either viruses or bacteria. With these guidelines, a conservative CT value of 200 minutes-mg/l at a pH of 8 and a temperature of 10 degrees C will be used for design.

A number of combinations of contact time and free chlorine residual may be used. A 60 minute contact time at the maximum equalized flow is a practical value. This will require a free chlorine residual of 3.3 mg/l, which is also achievable. The chlorine feed system will be designed to be able to feed 30 mg/l of chlorine at the maximum equalized flow to achieve this residual and to remove and remaining ammonia.

<u>Applicability</u>. As mentioned previously, disinfection with chlorine has a long proven history of use. Data available of chlorination, although somewhat limited, is more extensive than other forms of disinfection. In addition, its operation is fairly straight forward and most wastewater treatment plant operators are familiar with it. A number of safety precautions have to be made, although they are very standard at this point in time. Based on its extensive application, chlorination is a leading candidate as the disinfection process for the proposed facility.

The cost of chlorination is also very favorable compared to other technologies. This is true even with the higher chlorine doses required to achieve a free chlorine residual.

A significant detrimental aspect of chlorination is the production of chlorination by-product. These by-products, typically called tri-halogenated methanes (THM's), are formed when chlorine and other halogens (e.g.

bromine) bond to organic compounds in very oxidized environments. THM's are suspected carcinogens and mutagens. Government regulations on THM's in drinking water are currently being reviewed. Currently the drinking water standard in Texas for THM's is 100 ug/l. An important question is whether the production and discharge of THM's by the proposed water reclamation plant and the Hamby WWTP tertiary system will increase the THM level of the City of Abilene drinking water above the future THM limit.

It is not likely that the production and discharge of THM's in the initial 3 mgd phase of the proposed facility will have significant adverse impact on the THM level in the Abilene drinking water. Many THM's are volatile so that they will be stripped in post aeration and in the creek before they ever reach Lake Fort Phantom Hill. Degradation, both physical/chemical and biological, of the THM's is also likely to occur to some degree in the creek and in the lake. These factors, in addition to the relatively small proportion of the total potable water flow that will be from the water reclamation plant discharge, suggest that THM's will not initially be a problem.

For future expansions of the facility and for the reuse of the Hamby WWTP tertiary effluent, THM production may be a significant problem. Consequently, it is suggested that the THM production and THM fate be closely monitored at the initial phase of the proposed project. In addition, it is suggested that some of the other technologies to be discussed below be piloted at the initial facility.

Ozone

Ozone is a strong oxidant which has several potential benefits for use as a reclaimed water disinfectant as part of the Abilene reuse project. The potential benefit include: (a) excellent microbiological disinfectant,

(b) not affected by residual ammonia in the water, (c) does not result in chlorinated by-products such as THM's, (d) will probably achieve fringe benefits such as color and odor reduction. However, ozonation has substantially higher capital and operating costs relative to chlorination, and experience with the use of ozone in wastewater applications is still somewhat limited. Additional development work would be required to establish firm preliminary design criteria.

We suggest that ozonation not be included in the initial phases of the Abilene reuse project, but that it be considered for pilot plant evaluation at a later date, particularly if chlorination by-products become a significant issue.

Ultraviolet Radiation

Ultraviolet radiation (UVR) has been proven in numerous research studies to be an effective means of bacteria and virus destruction. Less is known about the efficiency of UVR in parasite inactivation. There are also a number of fairly large installations at water and wastewater plants. UVR offers several potential advantages relative to chlorination primarily in that it does not result in the production of undesirable chlorinated organic by-products. The disadvantages of the UVR process included higher maintenance requirements and limited field experience, particularly for wastewater disinfection.

We suggest that, like ozonation, UVR not be included in the initial phases of the Abilene reuse project, but be evaluated on a pilot plant basis for possible inclusion in future expansion of the reuse project.

Chlorine Dioxide

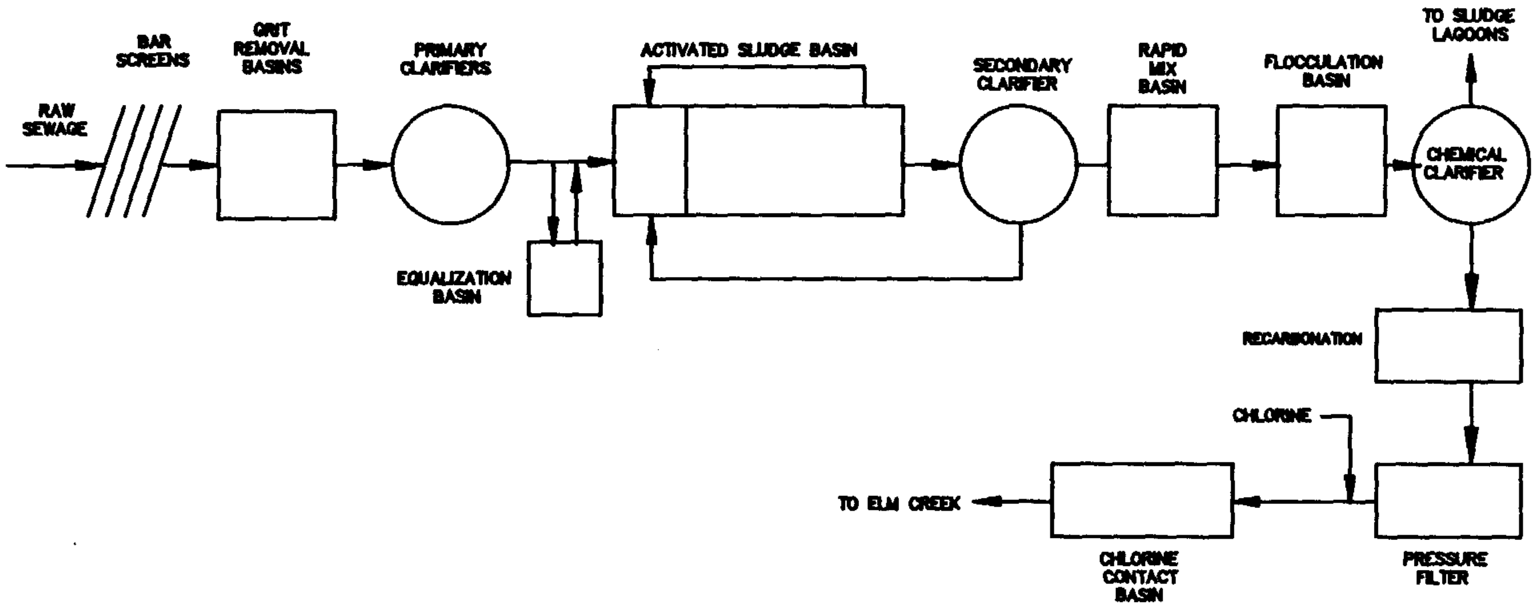
Chlorine dioxide (ClO_2) is another strong oxidant that can be used as an effective disinfectant. It is not as effective as ozone, nor does it offer some of the benefits related to ozone. However, ClO_2 is not affected by the presence of ammonia, and will not create presently regulated THM by-products. However, use of ClO_2 is more expensive than chlorine, and it is likely that other disinfection by-products resultant from use of ClO_2 may be regulated in the future, for drinking water supplies. Therefore, ClO_2 is not recommended for use on the Abilene reuse project.

DETAILED PROCESS EVALUATION

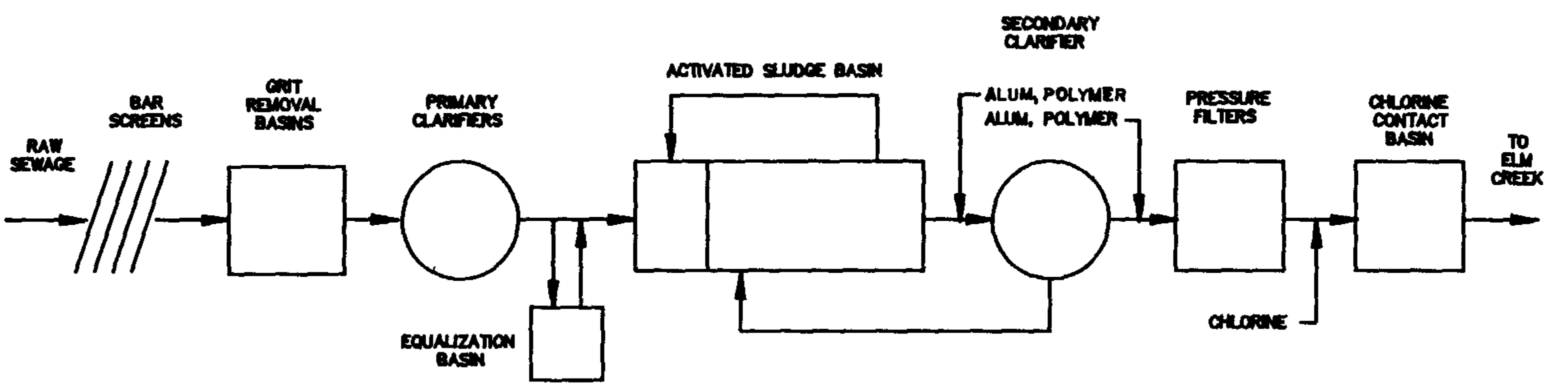
Process Configuration

The process discussed above can be configured in a few different ways to produce an effluent with the required water quality parameters as listed previously. For this evaluation, the four most likely candidate configurations are being suggested. Figures 7-3 and 7-4 are flow schematics of the four configurations. Alternatives 1, 2 and 3 will be able to achieve Type A effluent requirements, while Alternative 4 will only be able to achieve Type B effluent requirements.

The same basic treatment process are suggested for preliminary (bar screens and grit basins) and primary treatment (primary clarification). The suggested secondary systems are also the same, with the exception that biological P removal is suggested for Alternative 3 and 4. Nitrification and denitrification are suggested as components of all activated sludge systems, with the exception of Alternative 3 and 4, which only achieves nitrification.

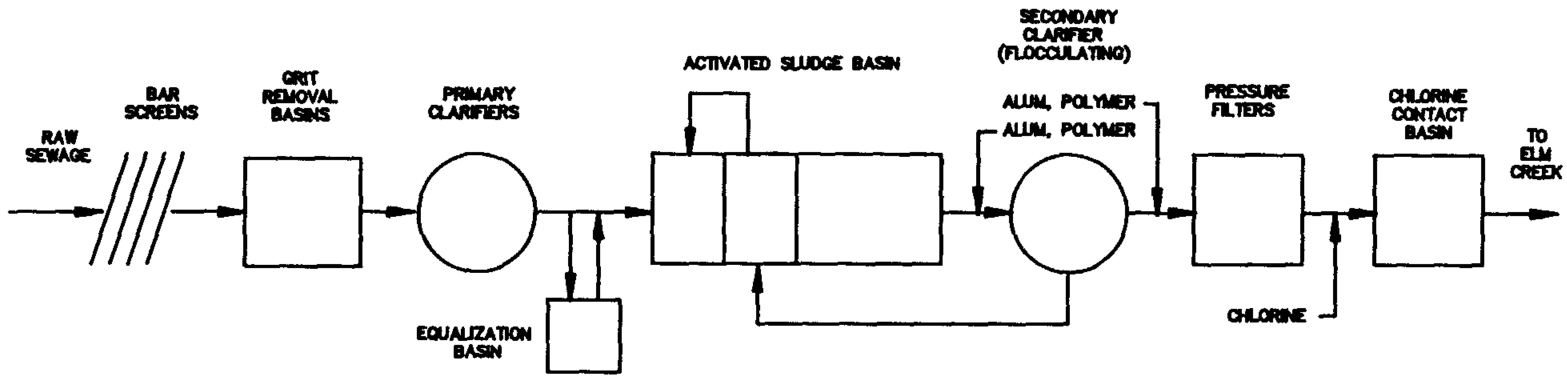


ALTERNATIVE 1 : SINGLE STAGE HIGH LIME, FILTRATION AND CHLORINATION

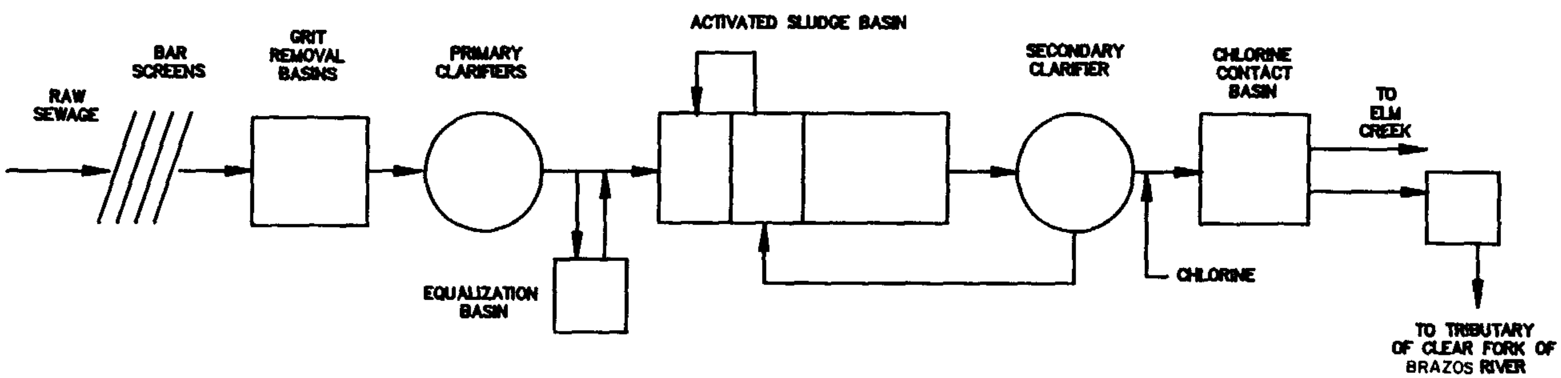


ALTERNATIVE 2 : ALUM–P REMOVAL, FILTRATION AND BREAK–POINT CHLORINATION

FIGURE 7–3
SUGGESTED PROCESS CONFIGURATION
WESTSIDE WWTP



ALTERNATIVE 3 : BIO-P, ALUM COAGULATION, FILTRATION AND BREAK-POINT CHLORINATION



ALTERNATIVE 4 : BIO-P, NITRIFICATION ONLY, BY-PASS ELM CREEK OPTION

FIGURE 7-4
SUGGESTED PROCESS CONFIGURATION
WESTSIDE WWTP

Alternative 1 can be considered as a high lime tertiary system. Since the lime dose will be independent of the P concentration, and P will be removed in the process, there is no need to use biological P removal in conjunction with high lime. A single stage system is suggested, so that recarbonation will only take place after the chemical clarifier. Since it is difficult to ensure a low suspended solids content from the lime system, filtration is suggested following recarbonation. As with Configuration A, conventional dual media pressure filtration are suggested, as well as chlorination/dechlorination with a free chlorine residual.

An oxidation ditch type of activated sludge system could potentially be used for Alternative 4. However, the benefits of an oxidation ditch do not necessarily outweigh the problems of its application. The primary benefit of an oxidation ditch is its ease of operation, and the resulting low staffing requirements. However, the water reclamation WWTP will require a relatively high level of operator attention even with an oxidation ditch, due to the tertiary treatment process that will be used. In addition, the land requirements for an oxidation ditch at the 2.4 mgd scale are fairly large, and at 7 mgd the land requirements of an oxidation ditch are prohibitive. The power requirements of an oxidation ditch are also high compared to a conventional activated sludge systems. Thus, for the many reasons discussed above, oxidation ditch type of systems were not evaluated.

The tertiary segment of Alternative 2 and 3 can be considered as alum coagulation/filtration systems. Biological P removal is suggested for Alternative 3 to cut down on the alum dose required. Alternative 2 is a purely alum P removal system, which provides a cost comparison against biological P removal. To ensure that the solids carry over from the secondary system will not over load the filters, flocculating type clarifiers are suggested for the secondary clarifiers of Alternative 2 and 3. The capability to add alum and polymer to the clarifiers or just upstream of the filters is suggested. Conventional dual media pressure filters are suggested for filtration for both. Chlorination/dechlorination with a free chlorine residual is suggested for disinfection.

Sludge Disposal

Sludge disposal can also be handled in a number of ways. The simplest means of handling the primary sludge and waste activated sludge (WAS) is to put it back into the sewer and send it to the Hamby WWTP. The other most viable option would be to anaerobically digest the primary and WAS sludge. For Phase I, it is suggested that the primary and WAS sludge be sent to Hamby. The amount of sludge flow (about 0.06 mgd) will not have a significant impact on the Hamby WWTP. For Phase II, it is suggested that anaerobic digesters be built to stabilize the sludge.

The alum concentration by the time the waste sludge reaches the Hamby plant is estimated to be between 10-15 mg/l. At this concentration there is no predicted effect on the biological system at Hamby. The current means of ultimate sludge disposal, sludge lagooning is expected to continue through the projected design year of Phase I Improvements. An evaluation of the existing treatment plant capacity was conducted under a separate study. The sludge handling and disposal capacities at Hamby are adequate to handle the projected loads of the Phase I Improvements. For additional information, reference the Response to TWDB Comments in Appendix A to this technical memoranda, Comment No. 14.

Conceptual Design

Table 7.3a-d provide a summary of the conceptual design for the four alternatives. The design criteria and the total size required are listed in these tables. The sizings presented are conceptual designs, prepared for project evaluation only. More detailed design analysis will be required during the predesign for this facility.

During the design of Phase II, a re-evaluation of the processes and the design criteria should be perform. The basis of the re-evaluation should be the results of the operation of Phase I, the pilot tests conducted, and results from other plants through out the country.

Cost Opinion

An order-of-magnitude cost opinion has been prepared for the two configurations and are presented in Tables 7.4a-d. The costs opinions presented were prepared without detailed engineering data. They have been prepared for guidance in project evaluation from the information available at the time the opinions were prepared. It is likely that the final project costs will vary from the opinions of cost presented herein.

TABLE 7.3 a

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 1 - SINGLE STAGE HIGH LIME AND FILTRATION

SUMMARY TABLE

PROCESS	DESIGN CRITERIA	TOTAL SIZE
BAR SCREENS		
GRIT BASINS		
PRIMARY CLARIFIERS	1800 GPD/SF AT PEAK FLOW	5,556 SF
EQUALIZATION		1.0 MG
AEROBIC ZONES	8.0 DAY SRT AT PM LOAD 0.7 SOLIDS YIELD	1.49 MG
ANOXIC ZONES	3.1 HR HRT AT PM FLOW	0.50 MG
TOTAL ACTIVATED SLUDGE SYSTEM		1.99 MG
SECONDARY CLARIFIER	500 GPD/SF AT AVG FLOW	5,683 SF
LIME FEED SYSTEM	400 MG/L DOSE	12,000 LBS/DAY
RAPID MIX BASINS	2.4 MIN AT MEF	11,366 GAL
FLOCCULATION BASIN	10 MIN AT MEF	47,358 GAL
CHEMICAL CLARIFIER	1100 GPD/SF	6,200 SF
RECARBONATION	2.5 MIN AT MEF	11,839 GAL
PRESSURE FILTERS	5.5 GPM/SF AT MEF	861 SF
CHLORINE CONTACT BASIN	60 MIN. AT MEF	284,146 GAL
CHLORINE DEMAND	10 MG/L AT AVG	200 LBS/DAY
SO2 DEMAND	2 MG/L AT AVG	40 LBS/DAY

TABLE 7.3 b

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 2 - ALUM P REMOVAL, ALUM COAGULATION AND FILTRATION

SUMMARY TABLE

PROCESS	DESIGN CRITERIA	TOTAL SIZE
BAR SCREENS		
GRIT BASINS		
PRIMARY CLARIFIERS	1800 GPD/SF AT PEAK FLOW	5,556 SF
EQUALIZATION		1 MG
AEROBIC ZONES	8.0 DAY SRT AT PM LOAD 0.7 SOLIDS YIELD	1.49 MG
ANOXIC ZONES	3.1 HR HRT AT PM FLOW	0.50 MG
TOTAL ACTIVATED SLUDGE SYSTEM		1.99 MG
SECONDARY CLARIFIER	500 GPD/SF AT AVG FLOW	7,182 SF
ALUM USE	176 MG/L AT AVG	3,526 LBS/DAY
PRESSURE FILTERS	5.5 GPM/SF AT MEF	861 SF
CHLORINE CONTACT BASIN	60 MIN. AT MEF	284,146 GAL
CHLORINE DEMAND	30 MG/L AT AVG	601 LBS/DAY
SO2 DEMAND	5 MG/L AT AVG	100 LBS/DAY

TABLE 7.3 c

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 3 - BIOLOGICAL P REMOVAL, ALUM COAGULATION AND FILTRATION

SUMMARY TABLE

PROCESS	DESIGN CRITERIA	TOTAL SIZE
BAR SCREENS		
GRIT BASINS		
PRIMARY CLARIFIERS	1800 GPD/SF AT PEAK FLOW	5,556 SF
EQUALIZATION		1 MG
AEROBIC ZONES	8.0 DAY SRT AT PM LOAD 0.7 SOLIDS YIELD	1.49 MG
ANAEROBIC ZONES	2 HR HRT AT PM FLOW	0.33 MG
TOTAL ACTIVATED SLUDGE SYSTEM		1.81 MG
SECONDARY CLARIFIER	500 GPD/SF AT AVG FLOW	7,182 SF
ALUM USE	40 MG/L AT AVG	801 LBS/DAY
PRESSURE FILTERS	5.5 GPM/SF AT MEF	861 SF
CHLORINE CONTACT BASIN	30 MIN. AT MEF	142,073 GAL
CHLORINE DEMAND	30 MG/L AT AVG	601 LBS/DAY
SO2 DEMAND	5 MG/L AT AVG	100 LBS/DAY

TABLE 7.3 d

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 4 - BIO-P, NITRIFYING ACTIVATED SLUDGE, WITH PUMPING DURING DROUGHT

SUMMARY TABLE

REDUNDANCY REQUIREMENT = 1

PROCESS	DESIGN CRITERIA	TOTAL SIZE
BAR SCREENS		
GRIT BASINS		
PRIMARY CLARIFIERS	1800 GPD/SF AT PEAK FLOW	5,556 SF
EQUALIZATION		1.0 MG
AEROBIC ZONES	8.0 DAY SRT AT PM LOAD 0.7 SOLIDS YIELD	1.14 MG
ANAEROBIC ZONE	2 HR HRT AT PM LOAD	0.25 MG
TOTAL ACTIVATED SLUDGE SYSTEM		1.39 MG
SECONDARY CLARIFIER	500 GPD/SF AT AVG FLOW	4,804 SF
PRESSURE FILTERS	5.5 GPM/SF AT MEF	662
CHLORINE CONTACT BASIN	30 MIN. AT MEF	109,287 GAL
CHLORINE DEMAND	10 MG/L AT AVG	200 LBS/DAY
SO2 DEMAND	2 MG/L AT AVG	40 LBS/DAY

TABLE 7.4 a

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 1 - SINGLE STAGE HIGH LIME AND FILTRATION

SUMMARY AND CAPITAL COST OPINION OF PLANT UPGRADE

USE COST CURVES IN "INNOVATIVE AND ALTERNATIVE TECHNOLOGY ASSESSMENT MANUAL"
EPA, 1980 ENR COST INDEX OF CURVES = 2475
CURRENT ABILENE INDEX = 4400 ?
OR EPA ESTIMATING WATER TREATMENT COSTS, ENR = 2851

BAR SCREENS AND GRIT BASINS

CAPITAL COST

USE FACT SHEET 3.1.12 FOR PRELIMANRY TREATMENT

AVG. DESIGN FLOW = 2.40 MGD

FROM CURVE, COST = $0.08 MILLION,

THUS CURRENT CONSTR. COST = $0.14 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1,000 + 1,300
= 2,300 KWH/YR

O&M COST = $0.015 MILLION/YR

PRIMARY CLARIFIERS

CAPITAL COST

USE FACT SHEET 3.1.1 FOR CIRCULAR PRIMARY CLARIFIERS WITH PUMP

TOTAL DESIGN SURFACE AREA = 5,556 SF

EQUIVALENT FLOW = 800 GAL/D/SF * DESIGN SF = 4.44 MG

FROM CURVE, COST = $0.25 MILLION,

THUS CURRENT CONSTR. COST = $0.44 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 40,000 KWH/YR

O&M COST = $0.016 MILLION/YR

EQUALIZATION

CAPITAL COST

USE FACT SHEET 3.1.9 FOR EQUALIZATION

TOTAL VOLUME = 1.0 MG

EQUIVALENT FLOW = TOTAL VOL 1 DAY HRT = 0.99 MGD

FROM CURVE, COST = $0.17 MILLION,

THUS CURRENT CONSTR. COST = $0.30 MILLION

OPERATIONS COSTS

O&M COST = $0.015 MILLION/YR

TOTAL ACTIVATED SLUDGE SYSTEM

CAPITAL COST

USE FACT SHEET 2.1.1 FOR ACTIVATED SLUDGE
ASSUME THAT MIXERS COST EQUIV. TO AIR SUPPLY EQUIP. COST

TOTAL VOLUME OF UPGRADE = 1.99 MG

EQUIVALENT FLOW = 6 HR HRT * DESIGN VOLUME = 7.96 MGD

FROM CURVE, COST = $1.20 MILLION,

THUS CURRENT CONSTR. COST = $2.13 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1.26E+06 KWH/YR

O&M COST = $0.070 MILLION/YR

SECONDARY CLARIFIER

CAPITAL COST

USE FACT SHEET 3.1.3 FOR CIRCULAR SECONDARY CLARIFIERS

TOTAL DESIGN SURFACE AREA = 5,683 SF

EQUIVALENT FLOW = 600 GAL/D/SF * DESIGN SF = 3.41 MGD

FROM CURVE, COST = $0.45 MILLION,

THUS CURRENT CONSTR. COST = $0.80 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 60,000 KWH/YR

O&M COST = $0.017 MILLION/YR

LIME FEED SYSTEM

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 60, INCREASE #'S BY 20%

TOTAL LBS/D = 12,000 LB/D

TOTAL COST FROM CURVE = $0.09 MILLION

THUS CURRENT CONSTR. COST = $0.17 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 70,000 KWH/YR

O&M COST = $0.030 MILLION/YR

LIME COST= $105,288 PER YEAR
@ $72 PER TON

RAPID MIX BASINS

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 115, INCREASE #'S BY 20%

TOTAL VOLUME = 1,519 CF

TOTAL COST FROM CURVE = $0.04 MILLION

THUS CURRENT CONSTR. COST = $0.07 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 600,000 KWH/YR

O&M COST = $0.001 MILLION/YR

FLOCCULATION BASIN

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 119, INCREASE #'S BY 20%

TOTAL VOLUME = 6,331 CF

TOTAL COST FROM CURVE = $0.07 MILLION

THUS CURRENT CONSTR. COST = $0.13 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 25,000 KWH/YR

O&M COST = $0.001 MILLION/YR

CHEMICAL CLARIFIER

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 130, INCREASE #'S BY 20%

TOTAL VOLUME = 6,200 SF

TOTAL COST FROM CURVE = $0.22 MILLION

THUS CURRENT CONSTR. COST = $0.41 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 70,000 KWH/YR

O&M COST = $0.039 MILLION/YR

RECARBONATION

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 190, INCREASE #'S BY 20%

TOTAL VOLUME = 1,583 CF

TOTAL COST FROM CURVE = $0.11 MILLION

THUS CURRENT CONSTR. COST = $0.20 MILLION

RECARBONATION SUPPLY

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 190, INCREASE #'S BY 20%

TOTAL LBS/D = 9,000 LB/D

TOTAL COST FROM CURVE = $0.18 MILLION

THUS CURRENT CONSTR. COST = $0.33 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 110,000 KWH/YR

O&M COST = $0.011 MILLION/YR

CO2 COST = $98,707 PER YEAR
@ $0.045 PER LB

PRESSURE FILTERS

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 233, INCREASE #'S BY 20%

TOTAL AREA = 861 SF

TOTAL COST FROM CURVE = $0.40 MILLION

THUS CURRENT CONSTR. COST = $0.74 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 200,000 KWH/YR

O&M COST = $0.044 MILLION/YR

CHLORINE CONTACT BASIN

CAPITAL COST

USE FACT SHEET 4.5.1 FOR CHLORINATION

TOTAL DESIGN VOLUME = 284,146 GAL

EQUIVALENT FLOW = 30 MIN HRT * VOLUME = 13.64 MGD

FROM CURVE, COST = $0.42 MILLION,

THUS CURRENT CONSTR. COST = $0.75 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 30,000 KWH/YR

O&M COST = $0.015 MILLION/YR

CHLORINE COST = $0.0234 MILLION/YR
@ $0.32 PER POUND

TOTAL CAPITAL COSTS

CONSTRUCION COST

BAR SCREENS & GRIT BASINS	$0.14
PRIMARY CLARIFIERS	$0.44
EQUALIZATION	$0.30
TOTAL ACTIVATED SLUDGE SYSTEM	$2.13
SECONDARY CLARIFIER	$0.80
LIME FEED SYSTEM	$0.17
RAPID MIX BASINS	$0.07
FLOCCULATION BASIN	$0.13
CHEMICAL CLARIFIER	$0.41
RECARBONATION	$0.20
RECARBONATION SUPPLY	$0.33
PRESSURE FILTERS	$0.74
CHLORINE CONTACT BASIN	$0.75
MISCELLANEOUS STRUCTURES	$0.60
SUBTOTAL 1:	$7.22

NON-COMPONENT COSTS AT

PIPING	10 %	$0.72	
ELECTR.	8 %	$0.58	
INSTRUM.	5 %	$0.36	
SITE PREP	5 %	$0.36	
SUBTOTAL 2:			$2.02

NON-COSTRUCTION

CONTINGENCY, ENGINEERING AND RELATED COSTS	45 %	$4.16
SUBTOTAL 3:		$4.16
TOTAL CAPITAL COST		$13.41 MILLION

OPERATIONS COSTS

POWER USE

BAR SCREENS & GRIT BASINS	2300 KWH/YR
PRIMARY CLARIFIERS	40000
EQUALIZATION	0
TOTAL ACTIVATED SLUDGE SYSTEM	1263922.
SECONDARY CLARIFIER	60000
LIME FEED SYSTEM	70000
RAPID MIX BASINS	600000
FLOCCULATION BASIN	25000
CHEMICAL CLARIFIER	70000
RECARBONATION SUPPLY	110000
PRESSURE FILTERS	200000
CHLORINE CONTACT BASIN	30000
TOTAL	2471222. KWH/YR
TOTAL COST @ $0.08 /KWH	$0.20 MILLION PER YEAR

O&M COSTS

BAR SCREENS & GRIT BASINS	$0.02
PRIMARY CLARIFIERS	$0.02
EQUALIZATION	$0.02
TOTAL ACTIVATED SLUDGE SYSTEM	$0.07
SECONDARY CLARIFIER	$0.02
LIME FEED SYSTEM	$0.03
RAPID MIX BASINS	$0.00
FLOCCULATION BASIN	$0.00
CHEMICAL CLARIFIER	$0.04
RECARBONATION SUPPLY	$0.01
PRESSURE FILTERS	$0.04
CHLORINE CONTACT BASIN	$0.02
LIME COST	$0.11
CO2 COST	$0.10
CHLORINE COST	$0.02

TOTAL	$0.50 MILLION PER YEAR
TOTAL OPERATIONS COSTS	$0.70 MILLION PER YEAR
OPERATIONS COST PER 1000 GAL.	$0.80 PER 1000 GAL
ANNUAL COST OF CAPITAL COSTS =	$1.39 MILL. PER YEAR FOR 20 YEARS AT 8.25 % INTEREST RATE
SUM OF OPERATIONS AND CAPITAL COST =	$2.09 MILLION PER YEAR
TOTAL COST PER 1000 GAL =	$2.38 PER 1000 GAL

TABLE 7.4 b

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 2 - ALUM P REMOVAL, ALUM COAGULATION AND FILTRATION

SUMMARY AND CAPITAL COST OPINION OF PLANT UPGRADE

USE COST CURVES IN "INNOVATIVE AND ALTERNATIVE TECHNOLOGY ASSESSMENT MANUAL"

EPA, 1980 ENR COST INDEX OF CURVES = 2475

CURRENT ABILENE INDEX = 4400 ?

OR EPA ESTIMATING WATER TREATMENT COSTS, ENR = 2851

BAR SCREENS AND GRIT BASINS

CAPITAL COST

USE FACT SHEET 3.1.12 FOR PRELIMANRY TREATMENT

AVG. DESIGN FLOW = 2.40 MGD

FROM CURVE, COST = $0.08 MILLION,

THUS CURRENT CONSTR. COST = $0.14 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1,000 + 1,300
= 2,300 KWH/YR

O&M COST = $0.015 MILLION/YR

PRIMARY CLARIFIERS

CAPITAL COST

USE FACT SHEET 3.1.1 FOR CIRCULAR PRIMARY CLARIFIERS WITH PUMP

TOTAL DESIGN SURFACE AREA = 5,556 SF

EQUIVALENT FLOW = 800 GAL/D/SF * DESIGN SF = 4.44 MG

FROM CURVE, COST = $0.25 MILLION,

THUS CURRENT CONSTR. COST = $0.44 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 40,000 KWH/YR

O&M COST = $0.016 MILLION/YR

EQUALIZATION

CAPITAL COST

USE FACT SHEET 3.1.1 FOR CIRCULAR PRIMARY CLARIFIERS WITH PUMP

TOTAL VOLUME = 1 MG

EQUIVALENT FLOW = TOTAL VOL 1 DAY HRT = 0.99 MGD

FROM CURVE, COST = $0.17 MILLION,

THUS CURRENT CONSTR. COST = $0.30 MILLION

OPERATIONS COSTS

O&M COST = $0.015 MILLION/YR

TOTAL ACTIVATED SLUDGE SYSTEM

CAPITAL COST

USE FACT SHEET 2.1.1 FOR ACTIVATED SLUDGE
ASSUME THAT MIXERS COSTS EQUIV. TO AIR SUPPLY EQUIP. COST

TOTAL VOLUME OF UPGRADE = 1.99 MG

EQUIVALENT FLOW = 6 HR HRT * DESIGN VOLUME = 7.96 MGD

FROM CURVE, COST = $1.20 MILLION,

THUS CURRENT CONSTR. COST = $2.13 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1.32E+06 KWH/YR

O&M COST = $0.070 MILLION/YR

SECONDARY CLARIFIER

CAPITAL COST

USE FACT SHEET 3.1.3 FOR CIRCULAR SECONDARY CLARIFIERS

TOTAL DESIGN SURFACE AREA = 7,182 SF

EQUIVALENT FLOW = 600 GAL/D/SF * DESIGN SF = 4.31 MGD

FROM CURVE, COST = $0.50 MILLION,

THUS CURRENT CONSTR. COST = $0.89 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 60,000 KWH/YR

O&M COST = $0.023 MILLION/YR

ALUM FEED SYSTEM

CAPITAL COST

USE FACT SHEET 5.1.1 FOR ALUM ADDITION

DESIGN AVG. FLOW = 2.40 MGD
DESIGN ALUM DOSE = 176 MG/L

EQUIVALENT FLOW = 200 MG/L * Q * DESIGN DOSE = 2.11 MGD

FROM CURVE, COST = $0.04 MILLION,

THUS CURRENT CONSTR. COST = $0.068 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 15,000 KWH/YR

O&M COST = $0.028 MILLION/YR

ALUM COST = $0.1287 MILLION/YR
@ $0.10 PER POUND

PRESSURE FILTERS

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 233, INCREASE #'S BY 20%

TOTAL AREA = 861 SF

TOTAL COST FROM CURVE = $0.40 MILLION

THUS CURRENT CONSTR. COST = $0.74 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 200,000 KWH/YR

O&M COST = $0.044 MILLION/YR

CHLORINE CONTACT BASIN

CAPITAL COST

USE FACT SHEET 4.5.1 FOR CHLORINATION

TOTAL DESIGN VOLUME = 284,146 GAL

EQUIVALENT FLOW = 30 MIN HRT * VOLUME = 13.64 MGD

FROM CURVE, COST = $0.42 MILLION,

THUS CURRENT CONSTR. COST = $0.75 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 30,000 KWH/YR

O&M COST = $0.015 MILLION/YR

CHLORINE COST = $0.0702 MILLION/YR
@ $0.32 PER POUND

TOTAL CAPITAL COSTS

CONSTRUCION COST

BAR SCREENS & GRIT BASINS	$0.14
PRIMARY CLARIFIERS	$0.44
EQUALIZATION	$0.30
TOTAL ACTIVATED SLUDGE SYSTEM	$2.13
SECONDARY CLARIFIER	$0.89
ALUM FEED SYSTEM	$0.07

PRESSURE FILTERS			$0.74
CHLORINE CONTACT BASIN			$0.75
MISCELLANEOUS STRUCTURES			$0.60
SUBTOTAL 1:			$6.07

NON-COMPONENT COSTS AT			
PIPING	10 %	$0.61	
ELECTR.	8 %	$0.49	
INSTRUM.	5 %	$0.30	
SITE PREP	5 %	$0.30	
SUBTOTAL 2:			$1.70
NON-COSTRUCTION			
CONTINGENCY, ENGINEERING AND RELATED COSTS	45 %	$3.49	
SUBTOTAL 3:			$3.49
TOTAL CAPITAL COST			$11.26 MILLION

OPERATIONS COSTS

POWER USE

BAR SCREENS & GRIT BASINS	2300 KWH/YR
PRIMARY CLARIFIERS	40000
EQUALIZATION	0
TOTAL ACTIVATED SLUDGE SYSTEM	1316586.
SECONDARY CLARIFIER	60000
ALUM FEED SYSTEM	15000
PRESSURE FILTERS	200000
CHLORINE CONTACT BASIN	30000
TOTAL	1663886. KWH/YR

TOTAL COST @ $0.08 /KWH $0.13 PER YEAR

O&M COSTS

BAR SCREENS & GRIT BASINS	$0.02
PRIMARY CLARIFIERS	$0.02
EQUALIZATION	$0.02
TOTAL ACTIVATED SLUDGE SYSTEM	$0.07

SECONDARY CLARIFIER	$0.02
ALUM FEED SYSTEM	$0.03
ALUM	$0.13
PRESSURE FILTERS	$0.04
CHLORINE CONTACT BASIN	$0.02
CHLORINE	$0.07
TOTAL	$0.42 MILLION PER YEAR

TOTAL OPERATIONS COSTS $0.56 MILLION PER YEAR

OPERATION COST PER 1000 GAL = $0.64 PER 1000 GAL

ANNUAL COST OF CAPITAL COSTS = $1.17 MILL. PER YEAR FOR 20 YEARS AT 8.25 % INTEREST RATE

SUM OF OPERATIONS AND CAPITAL COST = $1.73 MILLION PER YEAR

TOTAL COST PER 1000 GAL = $1.97 PER 1000 GAL

TABLE 7.4 c

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 3 - BIOLOGICAL P REMOVAL, ALUM COAGULATION AND FILTRATION

SUMMARY AND CAPITAL COST OPINION OF PLANT UPGRADE

USE COST CURVES IN "INNOVATIVE AND ALTERNATIVE TECHNOLOGY ASSESSMENT MANUAL"

EPA, 1980	ENR COST INDEX OF CURVES =	2475
	CURRENT ABILENE INDEX =	4400 ?
OR EPA ESTIMATING WATER TREATMENT COSTS, ENR =		2851

BAR SCREENS AND GRIT BASINS

CAPITAL COST

USE FACT SHEET 3.1.12 FOR PRELIMANRY TREATMENT

AVG. DESIGN FLOW = 2.40 MGD

FROM CURVE, COST = $0.08 MILLION,

THUS CURRENT CONSTR. COST = $0.14 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1,000 + 1,300
= 2,300 KWH/YR

O&M COST = $0.015 MILLION/YR

PRIMARY CLARIFIERS

CAPITAL COST

USE FACT SHEET 3.1.1 FOR CIRCULAR PRIMARY CLARIFIERS WITH PUMP

TOTAL DESIGN SURFACE AREA = 5,556 SF

EQUIVALENT FLOW = 800 GAL/D/SF * DESIGN SF = 4.44 MG

FROM CURVE, COST = $0.25 MILLION,

THUS CURRENT CONSTR. COST = $0.44 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 40,000 KWH/YR

O&M COST = $0.016 MILLION/YR

EQUALIZATION

CAPITAL COST

USE FACT SHEET 3.1.1 FOR CIRCULAR PRIMARY CLARIFIERS WITH PUMP

TOTAL VOLUME = 1 MG

EQUIVALENT FLOW = TOTAL VOL 1 DAY HRT = 0.99 MGD

FROM CURVE, COST = $0.17 MILLION,

THUS CURRENT CONSTR. COST = $0.30 MILLION

OPERATIONS COSTS

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O&M COST = $0.015 MILLION/YR

TOTAL ACTIVATED SLUDGE SYSTEM

CAPITAL COST

USE FACT SHEET 2.1.1 FOR ACTIVATED SLUDGE
ASSUME THAT MIXERS COSTS EQUIV. TO AIR SUPPLY EQUIP. COST

TOTAL VOLUME OF UPGRADE = 1.81 MG

EQUIVALENT FLOW = 6 HR HRT / DESIGN VOLUME = 7.24 MGD

FROM CURVE, COST = $1.15 MILLION,

THUS CURRENT CONSTR. COST = $2.04 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1.32E+06 KWH/YR

O&M COST = $0.070 MILLION/YR

SECONDARY CLARIFIER

CAPITAL COST

USE FACT SHEET 3.1.3 FOR CIRCULAR SECONDARY CLARIFIERS

TOTAL DESIGN SURFACE AREA = 7,182 SF

EQUIVALENT FLOW = 600 GAL/D/SF * DESIGN SF = 4.31 MGD

FROM CURVE, COST = $0.50 MILLION,

THUS CURRENT CONSTR. COST = $0.89 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 60,000 KWH/YR

O&M COST = $0.023 MILLION/YR

ALUM FEED SYSTEM

CAPITAL COST

USE FACT SHEET 5.1.1 FOR ALUM ADDITION

DESIGN AVG. FLOW = 2.40 MGD
DESIGN ALUM DOSE = 40 MG/L

EQUIVALENT FLOW = 200 MG/L * Q * DESIGN DOSE = 0.48 MGD

FROM CURVE, COST = $0.02 MILLION,

THUS CURRENT CONSTR. COST = $0.039 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 15,000 KWH/YR

O&M COST = $0.028 MILLION/YR

ALUM COST = $0.0292 MILLION/YR
@ $0.10 PER POUND

PRESSURE FILTERS

USE EPA ESTIMATING WATER TREATMENT COSTS, PG 233, INCREASE #'S BY 20%

TOTAL AREA = 861 SF

TOTAL COST FROM CURVE = $0.40 MILLION

THUS CURRENT CONSTR. COST = $0.74 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 200,000 KWH/YR

O&M COST = $0.044 MILLION/YR

CHLORINE CONTACT BASIN

CAPITAL COST

USE FACT SHEET 4.5.1 FOR CHLORINATION

TOTAL DESIGN VOLUME = 142,073 GAL

EQUIVALENT FLOW = 30 MIN HRT * VOLUME = 6.82 MGD

FROM CURVE, COST = $0.14 MILLION,

THUS CURRENT CONSTR. COST = $0.25 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 30,000 KWH/YR

O&M COST = $0.015 MILLION/YR

CHLORINE COST = $0.0702 MILLION/YR
@ $0.32 PER POUND

TOTAL CAPITAL COSTS

CONSTRUCION COST

BAR SCREENS & GRIT BASINS	$0.14
PRIMARY CLARIFIERS	$0.44
EQUALIZATION	$0.30
TOTAL ACTIVATED SLUDGE SYSTEM	$2.04
SECONDARY CLARIFIER	$0.89
ALUM FEED SYSTEM	$0.04

PRESSURE FILTERS			$0.74
CHLORINE CONTACT BASIN			$0.25
MISCELLANEOUS STRUCTURES			$0.60
SUBTOTAL 1:			$5.45
NON-COMPONENT COSTS AT			
PIPING	10 %	$0.55	
ELECTR.	8 %	$0.44	
INSTRUM.	5 %	$0.27	
SITE PREP	5 %	$0.27	
SUBTOTAL 2:			$1.53
NON-COSTRUCTION			
CONTINGENCY, ENGINEERING AND RELATED COSTS	45 %	$3.14	
SUBTOTAL 3:			$3.14
TOTAL CAPITAL COST			$10.12 MILLION

OPERATIONS COSTS

POWER USE

BAR SCREENS & GRIT BASINS		2300 KWH/YR
PRIMARY CLARIFIERS		40000
EQUALIZATION		0
TOTAL ACTIVATED SLUDGE SYSTEM		1316586.
SECONDARY CLARIFIER		60000
ALUM FEED SYSTEM		15000
PRESSURE FILTERS		200000
CHLORINE CONTACT BASIN		30000
TOTAL		1663886. KWH/YR
TOTAL COST @	$0.08 /KWH	$0.13 PER YEAR

O&M COSTS

BAR SCREENS & GRIT BASINS	$0.02
PRIMARY CLARIFIERS	$0.02
EQUALIZATION	$0.02
TOTAL ACTIVATED SLUDGE SYSTEM	$0.07

SECONDARY CLARIFIER	$0.02
ALUM FEED SYSTEM	$0.03
ALUM	$0.03
PRESSURE FILTERS	$0.04
CHLORINE CONTACT BASIN	$0.02
CHLORINE	$0.07
TOTAL	$0.33 MILLION PER YEAR

TOTAL OPERATIONS COSTS $0.46 MILLION PER YEAR

OPERATION COST PER 1000 GAL = $0.52 PER 1000 GAL

ANNUAL COST OF CAPITAL COSTS = $1.05 MILL. PER YEAR FOR 20 YEARS
AT 8.25 % INTEREST RAT

SUM OF OPERATIONS AND CAPITAL COST = $1.51 MILLION PER YEAR

TOTAL COST PER 1000 GAL = $1.72 PER 1000 GAL

TABLE 7.4 d

ABILENE WEST SIDE WWTP: PRELIMINARY SIZING 10/08/87

ALTERNATIVE 4 - BIO-P, NITRIFYING ACTIVATED SLUDGE, WITH PUMPING DURING DROUGHT

SUMMARY AND CAPITAL COST OPINION OF PLANT UPGRADE

USE COST CURVES IN "INNOVATIVE AND ALTERNATIVE TECHNOLOGY ASSESSMENT MANUAL"
EPA, 1980 ENR COST INDEX OF CURVES = 2475
CURRENT ABILENE INDEX = 4400 ?
OR EPA ESTIMATING WATER TREATMENT COSTS, ENR = 2851

BAR SCREENS AND GRIT BASINS

CAPITAL COST

USE FACT SHEET 3.1.12 FOR PRELIMANRY TREATMENT

AVG. DESIGN FLOW = 2.40 MGD

FROM CURVE, COST = $0.08 MILLION,

THUS CURRENT CONSTR. COST = $0.14 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1,000 + 1,300
= 2,300 KWH/YR

O&M COST = $0.015 MILLION/YR

PRIMARY CLARIFIERS

CAPITAL COST

USE FACT SHEET 3.1.1 FOR CIRCULAR PRIMARY CLARIFIERS WITH PUMP

TOTAL DESIGN SURFACE AREA = 5,556 SF

EQUIVALENT FLOW = 800 GAL/D/SF * DESIGN SF = 4.44 MG

FROM CURVE, COST = $0.25 MILLION,

THUS CURRENT CONSTR. COST = $0.44 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 40,000 KWH/YR

O&M COST = $0.016 MILLION/YR

EQUALIZATION

CAPITAL COST

USE FACT SHEET 3.1.9 FOR EQUALIZATION

TOTAL VOLUME = 1.0 MG

EQUIVALENT FLOW = TOTAL VOL 1 DAY HRT = 0.99 MGD

FROM CURVE, COST = $0.17 MILLION,

THUS CURRENT CONSTR. COST = $0.30 MILLION

OPERATIONS COSTS

O&M COST = $0.015 MILLION/YR

TOTAL ACTIVATED SLUDGE SYSTEM

CAPITAL COST

USE FACT SHEET 2.1.1 FOR ACTIVATED SLUDGE
ASSUME THAT MIXERS COST EQUIV. TO AIR SUPPLY EQUIP. COST

TOTAL VOLUME OF UPGRADE = 1.39 MG

EQUIVALENT FLOW = 6 HR HRT * DESIGN VOLUME = 5.57 MGD

FROM CURVE, COST = $0.85 MILLION,

THUS CURRENT CONSTR. COST = $1.51 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 1.26E+06 KWH/YR

O&M COST = $0.070 MILLION/YR

SECONDARY CLARIFIER

CAPITAL COST

USE FACT SHEET 3.1.3 FOR CIRCULAR SECONDARY CLARIFIERS

TOTAL DESIGN SURFACE AREA = 4,804 SF

EQUIVALENT FLOW = 600 GAL/D/SF * DESIGN SF = 2.88 MGD

FROM CURVE, COST = $0.38 MILLION,

THUS CURRENT CONSTR. COST = $0.68 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 50,000 KWH/YR

O&M COST = $0.014 MILLION/YR

CHLORINE CONTACT BASIN

CAPITAL COST

USE FACT SHEET 4.5.1 FOR CHLORINATION

TOTAL DESIGN VOLUME = 109,287 GAL

EQUIVALENT FLOW = 30 MIN HRT * VOLUME = 5.25 MGD

FROM CURVE, COST = $0.13 MILLION,

THUS CURRENT CONSTR. COST = $0.23 MILLION

OPERATIONS COSTS

ELECTRICAL ENERGY = 30,000 KWH/YR

O&M COST = $0.015 MILLION/YR

CHLORINE COST = $0.0234 MILLION/YR
@ $0.32 PER POUND

TOTAL CAPITAL COSTS

CONSTRUCION COST

BAR SCREENS & GRIT BASINS $0.14

PRIMARY CLARIFIERS			$0.44
EQUALIZATION			$0.30
TOTAL ACTIVATED SLUDGE SYSTEM			$1.51
SECONDARY CLARIFIER			$0.68
PRESSURE FILTERS			$0.57
CHLORINE CONTACT BASIN			$0.23
MISCELLANEOUS STRUCTURES			$0.50
SUBTOTAL 1:			$4.38
NON-COMPONENT COSTS AT			
PIPING	10 %	$0.44	
ELECTR.	8 %	$0.35	
INSTRUM.	5 %	$0.22	
SITE PREP	5 %	$0.22	
PUMP STATION, AND PIPELINE			$1.41
SUBTOTAL 2:			$2.63
NON-COSTRUCTION			
CONTINGENCY, ENGINEERING AND RELATED COSTS	45 %	$3.15	
SUBTOTAL 3:			$3.15
TOTAL CAPITAL COST			$11.58 MILLION

OPERATIONS COSTS

POWER USE

BAR SCREENS & GRIT BASINS		2300 KWH/YR
PRIMARY CLARIFIERS		40000
EQUALIZATION		0
TOTAL ACTIVATED SLUDGE SYSTEM		1263922.
PRESSURE FILTERS		200000
SECONDARY CLARIFIER		50000
CHLORINE CONTACT BASIN		30000
EFFLUENT PUMPS		27600
TOTAL		1613822. KWH/YR
TOTAL COST @	$0.08 /KWH	$0.13 MILLION PER YEAR

O&M COSTS

BAR SCREENS & GRIT BASINS	0.02
PRIMARY CLARIFIERS	0.02
EQUALIZATION	0.02
TOTAL ACTIVATED SLUDGE SYSTEM	0.07
SECONDARY CLARIFIER	0.01
PRESSURE FILTERS	0.04
CHLORINE CONTACT BASIN	0.02
CHLORINE COST	0.02
PUMPS & PIPELINE	0.015
TOTAL	$0.22 MILLION PER YEAR

TOTAL OPERATIONS COSTS — $0.35 MILLION PER YEAR

OPERATIONS COST PER 1000 GAL. — $0.40 PER 1000 GAL

ANNUAL COST OF CAPITAL COSTS = — $1.20 MILL. PER YEAR FOR 20 YEARS AT 8.25 % INTEREST RATE

SUM OF OPERATIONS AND CAPITAL COST = — $1.55 MILLION PER YEAR

TOTAL COST PER 1000 GAL = — $1.77 PER 1000 GAL

APPENDIX A

ABILENE WATER RECLAMATION PROJECT
RESPONSE TO DRAFT REPORT COMMENTS

TWDB Contract No. 55-61027

In response to the specific comments in the Texas Water Development Board's letter of November 19, 1987 (copy attached) we offer the following:

Draft Summary Report

QUESTION NO. 1

High levels of manganese and iron are mentioned on page 2.15 of the draft summary report. On page 2.12, Table 2.2, high levels of mercury, TTHM, and TTHMFP are mentioned. The health and environmental implications of these high levels should be discussed. We have also found the following mistakes in the table:

- Drinking water standard for Endrin is .0002 mg/l.
- Fluoride has both primary and secondary standards, 4.0 mg/l primary and 2.0 mg/l secondary.
- The coliforms do not necessarily have to be fecal coliforms.
- Need to show the locations of Lake Stations No. 1 and No. 2, and the points where the creek composite samples were taken on figure 2.5.

RESPONSE

The elevated mercury levels during the sampling were apparently a result of using the inductively coupled plasma (ICP) unit without a hybrid generator. This caused the background level from the burner noise to be high. Recent analysis with the proper instrumentation indicates no problem with mercury. The tables have been modified to reflect invalid data points.

Both the total trihalomethane (TTHM) and total trihalomethane forming potential (TTHMFP) were occasionally higher than the drinking water standards early in the sampling program. This occured only during the first two sampling trips of March and April. Apparently, the laboratory was experiencing difficulty in calibrating the analytical procedures and the data is probably invalid. Subsequent analysis indicates no problem. The tables have been revised to reflect the the invalid data points.

Given that neither mercury or TTHM is an apparent problem, no discussion on the health and environmental implications are presented.

The other corrections requested have been made.

QUESTION NO. 2

The final summary report needs to include the results of the virology and parasitology studies.

RESPONSE

The virology and parasitology reports have been included as appendices to TM-4 and a summary of findings will be included in the summary report.

QUESTION NO. 3

A tabulation of the findings of the water quality model need to be presented. Page 3.10 states LFPH is "very sensitive" to increased concentration of phosphorus, but page 2.15 states turbidity may be "limiting." Which is correct?

RESPONSE

A tabulation of key findings of the water quality model will be presented in a revised TM-5 as shown below:

1. Predictive analysis of alternatives using the WQRSS model appears to provide reasonable results and information that are consistent with our general understanding of the LFPH system and general ecological successions.

2. Lack of detailed tributary water quality data limited the analysis of alternatives to major additions of flow augmentation to LFPH.

3. The apparent lack of anaerobic conditions in the reservoir hypolimnion, due to considerable mixing (power plant, mechanically induced air system), precludes the conversion of nitrate to nitrogen gas by anaerobic bacteria. The model projected that an increase level of nitrate will develop in the lake due to the limited ability of LFPH to convert nitrates.

4. A light-limited and phosphorus limited algal production was modelled at elevated nutrient levels by including self-shading characteristics of suspended material in the determination of the composite light extinction coefficient and by adjustments to the phosphorus half saturation constant. These model methods calibrate well with historical data.

5. Total dissolved solids (TDS) will increase over time due to the limited flushing of the reservoir by inflows. TDS's are projected to increase by 100 to 200 mg/l (to a total concentration in the 600 mg/l range) at normal flows with the addition of a 3 MGD discharge into LFPH or its tributaries. The discharge of metals and other parameters are in the background range of normal inflows. Historically these parameters have not presented a known problem, periodical major flushing of the reservoir occurs.

QUESTION NO. 4

On page 3.7, the secondary effluent level parameters should be restated. Also, include the acceptable level for viruses and pathogenic parasites.

RESPONSE

The secondary effluent level parameters will be added to the recommended criteria for reclaimed water for irrigation. Secondary effluent level is taken to be 20 mg/l BOD_5, 20 mg/l TSS, and a chlorine residual of 1.0 mg/l.

There are currently no generally accepted criteria setting acceptable levels of virus in wastewater effluents. The State of Arizona has a criteria on viruses in wastewater effluent. A copy of their regulations are attached. These regulations are based on enteric viruses as a general indicator for all virus in the effluent. In their continued studies they have found enteric viruses are not a good indicator and are investigating other monitoring techniques.

There are no generally accepted criteria for pathogenic parasites. Establishing acceptable levels for these parameters is beyond the scope of the current project. We have elected to approach this issue by establishing minimum treatment levels for removal of these organisms. This includes chemical coagulation, filtration and chlorination disinfection. Discussions with Dr. Ted Metcalf from the Baylor College of Medicine Department of Virology and Epidemiology established that the level of treatment we are proposing is consistent with treatment levels at facilities he is knowledgeable of that are producing effluent acceptable for reuse applications. In particular, Monterey, California.

QUESTION NO. 5

A tabulation of projected lake levels and water quality as discussed in Section 3.2 after a two-year drought, needs to be presented for the various reclaimed water volumes and qualities.

RESPONSE

A tabulation of lake levels and water quality parameters will be included in TM-5 as presented below:

Table 7-2

Tabulation of Water Quality at Various Lake Levels[a]

	Selected Water Quality Parameters	Lake Level (ac-ft)[b]		
		65,000	45,000	30,000
1.	TDS mg/l	500	600	700
2.	Ammonia mg/l[c]	0.25	0.20	0.25
3.	Nitrate mg/l[c]	1.1	1.6	2.2
4.	Ortho-P mg/l[c]	0.05	0.05	0.06
5.	Chlorophyll-a ug/l[c]	<2	<5	<10

[a]Water quality varies both in time of year and with lake levels. The flows selected represent a near-full lake, 65,000 ac-ft; low water condition, 45,000 ac-ft; and extreme drought condition, 30,000 ac-ft. Values shown are based on Type A treatment levels.

[b]The water quality of most parameters are not independent of historic trends or time of year; i.e, the past levels of the lake influence present water quality. The 65,000 ac-ft level shown is a January date and the 45,000 ac-ft is a July date in the first year of drought condition, and the 30,000 ac-ft is a June date in the second year of drought condition for this table.

[c]Ortho-P, chlorophyll-a, ammonia and nitrate will vary from values presented depending on time of year; i.e., nitrate values projected for 30,000 ac-ft in September-October is 1.3 mg/l versus 2.2 mg/l shown for June, due to euthrophication.

QUESTION NO. 6

The draft summary report includes a equivalent annual cost analysis of four treatment trains. We understand that the cost estimates are still being refined. A summary of the economic analysis of the complete proposed system (treatment, non-potable system, capital, and O&M) needs to be included. Other alternatives that the proposed system need to be contrasted with include the cost of a "no reuse" option, and the options for discharge points (lake versus stream), the Phase I and II as described on page 4.3. What are the economics of going to advanced treatment at Hamby STP versus advanced treatment at the new Westside STP? What is the comparable cost of developing other water sources, i.e., Stacy Reservoir and brackish water. The sludge handling and proposed disposal techniques need to be included. Will dechlorination be necessary? If so, the cost will need to be included.

RESPONSE

The economic evaluation has been modified to include the complete proposed system. The alternatives are based on producing a reclaimed water in 1992 of 2000 acre-ft and in 1998 of an additional 3000 acre-ft. This is consistent with the supply curve in Figure 4.1. The complete system includes advanced wastewater treatment (AWT), wastewater collection system infrastructure improvements, non-potable water system and the operations and maintenance (O&M) costs associated with each. A summary of the cost and a net present worth (NPW) comparison of the alternatives are given in Table 3-6. The tributary plant option is estimated to be less expensive by approximately $9 million.

The two alternatives considered include 1) a reuse system centered around an AWT plant on one of the tributaries to Lake Fort Phantom Hill and 2) addition of AWT units at Hamby WWTP to produce an effluent suitable for discharge to Lake Fort Phantom Hill. A no-action alternative was developed and was added. It was resolved that the no-action alternative was inconsistent with the City of Abilene's goals and objectives, leading to the development of the alternatives described above.

Although a specific treatment plant site on Little Elm Creek was used in costing out a non-potable water system, the recommended plan is based on a tributary water reclamation plant. That is, the plant could be located anywhere along any of the tributary streams feeding Lake Fort Phantom Hill. Therefore, the evaluation of the effect of the discharge on Lake Fort Phantom Hill and the selection of the recommended process were based on the worst case situation of a direct discharge to the lake. We would not propose using different, less stringent criteria for a facility discharging to a tributary stream of the lake.

In Table 3-6, the cost of developing this additional water supply is shown to be $400/acre-ft., for the Tributary Plant option and $520/acre-ft. for the Hamby Plant option. If it is recognized that a wastewater treatment plant would be built anyway to address wastewater treatment needs, it is appropriate to describe the economics in terms of incremental cost. The incremental cost between the recommended tributary plant plan and a plan, centered around a conventional treatment plant is estimated at $335,000/year. This includes annualized capital costs and expected operations and maintenance costs. The recommended plan would generate 2,000 acre-ft. of flow to Lake Fort Phantom Hill and 340 acre-ft. for the nonpotable system for a total of 2340 acre-ft. This is a development cost of $143/acre-ft. The City of Abilene Evaluation of the Use of Brackish Water and Reclaimed Wastewater for Long-Range Water Supply, 1984, Table 6.5

presents development costs for three brackish water supplies, the Clear Fork of the Brazos River, Possum Kingdom, and Cedar Ridge. The reported comparable development costs, adjusted to 1987 dollars, are $1,085, $1,240 and $1,653/acre-ft., respectively.

For the recommended process, an alum coagulated waste activated sludge would be produced. For the Tributary Plant option it is proposed to return the waste sludge to the wastewater collection system for treatment at the Hamby WWTP. For the Hamby WWTP option, the waste sludge would be directed to the existing solids treatment facilities. The adequacy of the existing system to handle the additional load is addressed in our response to Comment No. 14 below. Dechlorination is proposed and is included in the costs presented.

QUESTION NO. 7

In TM-5, Table 6.1, the concentration of NO_3-N differs greatly with that shown in Figures 5 of TM-5. If Figure 5 is correct, then based on the Redfield ratio of C:N:P more being 100:10:1 respectively, phosphorus is not limiting but nitrogen is. Please clarify the inconsistency with the reported need to control phosphorus in the proposed plant's effluent.

RESPONSE

Table G.1 of TM-3 is incorrect and will be revised in final edition.

The Redfield ratio of 100:10:1 of C:N:P: was originally developed from studies in the Gulf of Maine to predict the uptake and release of nutrients from phytoplankton and zooplankton. The application of Redfield ratio from existing data identified during the recent monitoring program produces a ratio of 450/52/1 for total nitrogen and total phosphorous and 800/7/1/1 for inorganic nitrogen and soluble phosphorous. Based on the total nitrogen available we are of the opinion that phosphorus is the limiting nutrient. It must be stressed that light presently exert a major control on the lake's biological activity.

Studies by Joseph Shapiro and Valh Smith at the Limmology Research Center at the University of Minnesota confirm the importance of both ratios of total and inorganic, nitrogen and phorphorous in the eutrophicatic process. A key ratio in LFPH appears to be the inorganic nitrogen (ammonia and nitrate) to soluble phosphorous. Shapiro recommends a lower ratio of 5:1, N:P. This ratio is 0.48 to 0.05 or 9.6:1 historically and 0.345 to 0.04 or 6.9:1 recent monitoring program.

Based on the LFPH inability to convert nitrates, due to the lack of an anaerobic zone caused by the lack of mixing and sampling and model data, we are of the opinion that phosphorous is the control nutrient.

We will add a discussion of these conclusions in the revised TM-5.

QUESTION NO. 8

Table TM-4.10 is not completely consistent with Table TM-4.4.1. The value costing out a non-potable water system, the recommended plan is based on a tributary water reclamation plant. That is, the plant could be located anywhere along any of the tributary streams feeding Lake Fort Phantom Hill. shown for the concentrations of mercury, manganese, iron and TTHM either match or exceed the state's drinking water standard. What are the reasons or sources for this? In Figures 4.7 and 4.8 the values shown for the wet year appear to be zero, which seems unlikely. Please correct these figures.

RESPONSE

The table has been corrected to reflect the invalid mercury and TTHM data. Figures 4.7 and 4.8 have been modified. Both iron and manganese are naturally occurring in sediments in the Abilene area.

QUESTION NO. 9

What conclusions were reached in regard to the high nitrite-nitrogen levels mentioned on page 25 in TM-4?

RESPONSE

This is still under investigation and will be addressed in detail in the final report.

QUESTION NO. 10

In TM-5, the drought-condition base case assumes an initial storage pool of 65,000 acre-feet, assuming Table 6 inflows and diversions are used. It is unclear if the 65,000 acre-feet is the normal pool level of the reservoir or the useful storage of the reservoir. Table 6 does not show any consumptive use by West Texas Utilities (WTU) under drought conditions. Does the utility have a contingency plan for cooling water during caused by droughts? If it does, to what volume must the reservoir diminish before the utility implements its plan?

RESPONSE:

TM-5 will be modified to reflect that 65,000 ac-ft is near full condition (68,000 ac-ft is full). The reason for using 65,000 ac-ft is that the historic design drought and reservoir operating plan is based on initial conditions of 65,000 ac-ft. LFPH is operated in an over-draught mode in connection with Hubbard Creek Reservoir.

The consumptive use by WTU is included in the evaporative losses in Table 6. The historical consumptive uses were provided by WTU as follows:

Year	Consumptive Use (ac-ft)	
1981	1,178	
1982	1,734	(drought year)
1983	1,495	
1984	1,571	(drought year)
1985	1,282	
1986	1,266	
Average	1,421	

WTU reported its water rights at 2,500 ac-ft.

The total evaporative losses of 15,000 to 16,000 ac-ft/year, including WTU, is projected during a drought year.

WTU does not have a drought contingency plan. The reservoir has, according to its historical record, operated below 30,000 ac-ft. It is assumed that minimum capacity is 25,000 ac-ft. This will be reflected in TM-5.

QUESTION NO. 11

The base case used for modeling water quality assumes that a three MGD AWT has been discharging into the lake for a period of time previous to the drought. It would seem that modeling the lake without the discharge of the AWT would be of interest for comparison purposes. Please include information for this scenario in TM-5. Also, please assess the mitigation on lake impacts due to discharging into Elm Creek at a point about ten stream miles above the lake. Will the nutrients be attenuated by sedimentation, predation, and other factors to the extent that less treatment would be necessary?

RESPONSE

A presentation of no discharge during drought conditions will be included in the revised TM-5.

An assessment of the mitigating impact of discharging on a stream 10 miles from LFPH will also be included in TM-5. The high quality of the proposed discharge coupled with relatively short travel time (17 hours) minimizes any long-term mitigation. The research team recognizes that some mitigation will occur, but a conservative approach to this effect was chosen in site recommendations.

QUESTION NO. 12

In reference to number "8." above, what will happen to these inorganic elements in drought conditions? Particularly in the case of mercury, would the concentration increase to the point where the lake could not be used as a water source or for recreation? Would there be a dangerous accumulation of mercury in the lake's fish? Would there be health or toxicity problems with other heavy metals or sodium? What could be the fate of the heavy metals in the water column during drought conditions? Would there be movement of the heavy metals into the sediments? Since indications are that the lake does not get flushed out very frequently, could there be a long term problem from resolubilization of the metals from the sediments into the water column when the lake refills after a drought period?

RESPONSE

A discussion of accumulation of metals and toxic elements will be added to TM-5. As reflected in our response to questions 1, 7, and 8, the metal concentrations are not as high as that was indicated by the original data.

QUESTION NO. 13

In TM-6, the discussion of the trace organics indicated that the lake has a high trihalomethane potential, and the discharge to the lake would not make any appreciable difference. However, what effects would there be if the chlorinated effluent was discharged into a stream? Would dechlorination be necessary.

RESPONSE

The response to Comment No. 8 above states that the high TTHMP concentrations in the draft were invalid. Regardless of the THMP level, it is recommended that the effluent be dechlorinated prior to discharge to a receiving stream or the lake. The summary report has been modified to clarify that dechlorination is recommended.

QUESTION NO. 14

Regarding TM-7, page 26, when will sludge handling capacity at Hamby STP be reached if all Westside sludge is sent there? What is the ultimate disposal of the sludge? What are costs of sludge handling under each alternative? Will alum sludge interfere with treatment at Hamby?

RESPONSE

An evaluation of the existing treatment plant capacity was conducted under a separate study. As a supplement to that study the solids treatment units were reviewed. Currently, primary and waste activated sludge is blended, thickened in a dissolved air flotation thickener, anaerobically digested and conveyed to sludge lagoons for ultimate disposal. The digesters are the limiting unit in the solids treatment train. Presently only two of the four digesters are heated. They operate as two stage digesters, with the first stage heated and the second used for additional digestion and storage.

The attached table presents the capacity of the digesters in relation to State design criteria. Under current operation, they are rated at 14.4 MGD. If all units are operated as high rate digesters, this increases to 16.37 MGD.

Another common criteria for sizing digesters, is to design for a minimum solids retention time (SRT). For heated digesters a minimum SRT of 15 days is appropriate. Historical plant operating records were reviewed to establish the operating solids retention time (SRT). The SRT at current flows and operating conditions is approximately 27 days. Assuming the same BOD loading in the future, and a minimum SRT of 15 days, the digesters have adequate capacity for the sludge corresponding to a wastewater flow of 24 MGD.

The wastewater flow projection curve in Figure 2.4 of the Summary Report was used to estimate when the 24 MGD would be generated. The curve presents the projected average annual daily wastewater flow for Abilene. The digesters are evaluated at maximum-month average daily flows. Historically, the maximum month has been 10 percent higher than the average annual flow. A maximum month flow of 24 MGD corresponds to the projection for the year 2013.

The current facilities can accommodate the waste sludge requirements of the 3 MGD treatment plant of Phase 1 and likely can handle the sludge generated from the Phase 2 expansion to 7 MGD. The capacity of the digesters would need to be reviewed during the planning for the Phase 2 expansion to verify their adequacy.

The ultimate disposal of the sludge is sludge lagoons as is currently practiced.

Under either alternative the sludge would be treated at the Hamby plant and the costs are assumed equal.

The alum dosage at the proposed facility is 40 mg/l. During Phase 2 (the more critical flow phase) the flow from the AWT would be 7 MGD and the total system flow would be approximately 21.0 MGD. The resultant alum concentration into Hamby would be 13.3 mg/l. The sludge would be wasted continuously as is the current practice. This concentration of alum is not expected to interfere with the treatment at Hamby.

QUESTION NO. 15

Recommended discharge standards are given in TM-9. For parasitic organisms, the goal is to have a parasite free discharge. There was no indication in TM-8A that any testing was done to see if this goal is obtainable. There is some data lately obtained with regards to parasitic organisms in raw sewage, and treated effluent from the Hamby S.T.P., we believe that at the very least the recommended treatment system, "Alum with Biological Phosphorous" should be tested to discover how effective it is in removing the organisms.

RESPONSE

We proposed that testing for both parasitic organisms and viruses should be performed at facilities similar to those proposed here in Abilene. We have identified two potential candidate systems, one in Colorado and the other in Oregon. No similar systems are known in Texas. Please advise if you are aware of other likely candidates.

The preliminary cost estimates are:

Task	Estimated Costs
Parasitic Analysis[a]	\$ 3,000 - \$ 4,000
Virus Analysis[a]	\$ 4,000 - \$ 5,000
Sample Collection	\$ 2,000 - \$ 3,000
Concentration of Sample	\$ 2,000 - \$ 3,000
Coordination, Arrangements	\$ 2,500 - \$ 3,000
Report	\$ 2,500 - \$ 3,500
TOTAL	\$16,000 - \$21,500

[a] It is proposed that four tests be performed: influent, after activated sludge treatment, after filtration, and after disinfection.

It is recommended that the monitoring program be modified to perform these tasks. The original budget for the monitoring program was \$80,000. We have spent to date approximately \$46,000. Therefore, sufficient funds exists in the budget to accomplish these tasks. It is doubtful that the additional testing can be completed by the date set for final report (February 29, 1988). Please indicate your desires as specific budgets and contract modifications are required, prior to starting work.

QUESTION NO. 16

In the Water Reuse section of TM-9, it was indicated that the option of reclaimed water use for industrial/commercial operations was evaluated, but discarded due to various factors. The listing of potential users shown in Tables 11-1 and 11-2 does not include West Texas Utilities nor Dyess Air Force Base's golf course. Since there are two stream power stations located in Abilene, it would seem that they would use the reclaimed water for cooling purposes. This could be very attractive to the utility during drought periods, especially at the Lake Fort Phantom Hill Station, if the lake level lowers to the point below the station's cooling water inlets. There could also be another benefit for the City such as a trade-off of reclaimed water for a portion of WTU's water rights at Lake Fort Phantom Hill.

RESPONSE

Dyess AFB is included as a potential user on Table 11-1 at 699,233 gal/day. The non-potable system is directed at Dyess AFB during Phase I. It is proposed that an 8-inch line be constructed to provide up to 500,000 gal/day of non-potable water for Dyess AFB uses (mainly golf course irrigation).

The reclaimed water use for flow augmentation will also be used by WTU for cooling, since their once through cooling use LFPH waters.

However, no estimate of the possible water savings were made due to the decrease in LFPH temperatures due to the increase of volume in LFPH. The water savings are minimal. The WTU power plant located in Abilene was not considered due to its infrequent operations (peak-facility only).

QUESTION NO. 17

In the Specific Recommendations for Abilene section we note that recommendation number "7." advises the City to aggressively pursue all financial opportunities, including construction loans and grants from TWC among others. TWC in this area is strictly a regulatory and enforcement agency and does not provide any funding of construction by either loans or grants. We do suggest that you consider the recommendation that the City submit the application to TWC for a discharge permit in the near future.

RESPONSE

The reference to the TWC as a funding source was incorrect. It has been changed in the Summary Report.

QUESTION NO. 18

In TM-11 there is a discussion on constructing a Lake Kirby non-potable water treatment plant and later building a non-potable line from the AWT to Lake Kirby. What are the economics of building the non-potable line from the AWT to Lake Kirby now and using the reclaimed water as blend water in Lake Kirby to improve its quality. What is the availability and feasibility of using ground water in the area as supplemental water and blending it with the AWT effluent and Lake Kirby water, or with just AWT effluent and using it in a non-potable system. Has the use of using non-potable water for fire protection at Dyess, and in any industrial parks or new residential subdivision in the area been investigated?

As mentioned in Recommendation No. "15.", it seems WTU would be interested in the use of the reclaimed water for cooling purposes. Has the feasibility of the option been investigated? This option could also provide a pipeline to serve the north and northeast parts of town.

RESPONSE

During Phase 1, there is insufficient reclaimed water available from the AWT plant to make a meaningful impact on the quality of the water in Lake Kirby. Therefore the economics of building the non-potable water line as part of Phase 1 were not considered.

The availability and feasibility of using the groundwater was not considered practical based on a general review and understanding of the area's geology. No significant aquifer exist in the Abilene area. It is our general understanding that groundwater quality and the reliability of yield in the area is poor. Considering the information assembled on the nonpotable system was in addition to the contract scope, a detailed investigation of the groundwater feasibility has not been undertaken.

Use of the non-potable water for fire protection would be an appropriate application. A detailed evaluation of the feasibility was left to those specific entities which would benefit from the use. We strived to have the system be flexible and planned for yet unspecified water demands in sizing the system.

The subject of WTU using non-potable water for cooling purposes is addressed in response to Comment No. 16 above.

QUESTION NO. 19

Has the Texas Water Commission and Texas Department of Health been provided with copies and requests for comments?

RESPONSE

We met with both the Texas Water Commission, Permits Water Quality Sections, to receive input in September 1987. We discussed primarily wasteload allocations and permitting procedures. The proposed plans have been discussed with the TDH in general terms in both April and September 1987.

We propose to send copies of the summary report to both the TWC and TDH in January for their review and comments.

Table 3-6

Economic Comparison of Alternatives
Abilene Water Reclamation Research Project
(Millions $)

	Alternative 1 Tributary AWT	Alternative 2 Hamby AWT
Phase 1 Improvements (1992)[1]		
a. 3.0 MGD AWT	$10.12	$ 5.55
b. AWT O&M (NPW)[2]	4.52	2.31
c. Infrastructure[3]	9.99	25.91
d. Non-Potable System	0.57	3.15
e. Non-Potable O&M (NPW)[2]	0.50	0.25
Sub-Total	$25.70	$37.17
Phase 2 Improvements (1998)		
a. 4.0 MGD AWT Expansion	$ 9.66	$ 5.79
b. AWT Expansion O&M (NPW)[2]	5.20	2.89
c. Infrastructure[3]	11.03	20.25
d. Non-Potable System	1.60	0.83
e. Non-Potable O&M (NPW)[2]	0.20	0.12
Sub-Total	$27.69	$29.88
Net Present Worth (1987 Dollars)[4]	$29.37	$38.12
Equivalent Annual Cost[5]	$ 2.99	$ 3.88
Water Supply Development Cost[6]	$384/ac-ft.	$498/ac-ft.

Notes

1. Phase schedule years basedon implementation plan on Figure 4.1

2. Net Present Worth based on (P/A 20, 8%)

3. From Table 5.6 Wastewater Collection System Analysis, May 1987

4. Net Present Worth based on (P/F, 5, 8%) and (P/F, 11, 8%)

5. Based on (A/P, 20, 8%)

6. Based on (A/P, 20, 8%) and an additional water supply of of 7800 acre-ft.

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 7A

PROCESS SELECTION, SIZING, AND LOCATION

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Technical Memorandum No. 7A (TM-7A), Process Selection, Sizing, and Location, provides a summary of reasoning and judgments that led the research team to focus their efforts on a full scale WWTP.

INITIAL PROJECT CONCEPTION

Initially, the research team's concept of the location and size of a reclaimed water treatment facility was at the existing Hamby WWTP and approximately 0.5 to 1.0 mgd in size. It was suggested during contract negotiations that an option of a satellite facility located on a tributary to Lake Fort Phantom Hill (LFPH) in the southwest portion of the City be evaluated to provide nonpotable water for turf irrigation in addition to flow augmentation in LFPH. This option was discounted due to the additional costs of construction and operating a separate facility, and limited impact a discharge of less than 1.0 mgd would have on LFPH after stream losses.

FACILITY SIZE SELECTION

Initially, the research team (RT) concentrated the evaluations based on a flow range of 0.5 to 1.0 mgd, primarily to limit the cost impact of the project. This assumption created three basic problems for the RT:

- No economies of scale were available to the RT in process selection or operations.

- Limited direct benefits to Abilene could be derived from a project of this small size.

- Processes selected for a facility in this size range might not be effectively up-scaled to a larger size, due to the inability to identify impacts on LFPH.

The first two reasons deal primarily with costs. The last reason presented the RT with the greatest problem. If the discharge was too small to have an appreciable impact, then requirements for treatment would also be reduced. Therefore, the treatment systems selected would not be applicable at higher beneficial flows and very little might be demonstrated. We rejected a 0.5 mgd treatment plant as not being practical and used the model size of 3.0 mgd for the system size.

The problem was to select a flow at which benefits and impacts could be derived and measured, without creating significant environmental and cost concerns. A flow size that could be implemented and would provide impacts and benefits without significant risks.

The effects of different levels of treatment at various flows were made using the water quality model. The levels of treatment selected by the RT represented treatment systems believed to be applicable to full-size facilities (see TM-5 for details). Only the two higher levels of treatment were selected as satisfactory. The difference in water quality impacts between these levels of treatment became noticeable at flows in the 2- to 4-mgd range.

A flow of 3 mgd was selected as an initial size for a reuse facility. A flow in this range could provide significant benefits in terms of flow augmentation, allow for some economies of scale, and represent a system which could be expanded or upscaled.

The water quality model data indicated this treatment level would be acceptable for flows as high as 7 to 10 mgd without major modifications. Therefore, the processes selected can be expanded directly.

A review of the findings and proposed recommendations of a separate previous study, Wastewater Collection System Analysis - City of Abilene (May 1987), also was made. The report recommended a new wastewater treatment plant located on the westside of Abilene in two phases; 3 mgd (initial capacity) and 7.0 mgd (final capacity). This plan eliminated many of the concerns facing the RT.

The proposed sizing and phasing of the recommended WWTP matched the needs of the water reuse facility identified by the RT's modelling efforts. Substantial cost reductions could be realized by integrating the water reclamation treatment needs into the design of the previously recommended wastewater treatment plant. Therefore, the focus of the research project was directed towards the possibility of utilizing the plant recommended for the westside of Abilene, for water reclamation. Since no specific site had been recommended for this plant and its water reclamation effectiveness would be equal regardless of which tributary to Lake Fort Phantom Hill it discharged to, it got identified as the Tributary WWTP alternative.

COST COMPARISON OF TRIBUTARY WWTP VERSUS HAMBY FACILITY

At the time the decision was made to focus on the Tributary facility, no cost analysis was made, since it was the RT's opinion that the costs were significantly in favor of this option over the Hamby Facility. It is important to note that the water quality model assumes that discharges in the tributaries of LFPH are the same as direct discharges. Therefore, the selected treatment processes would remain essentially the same under either scenario.

A cost comparison for a comparable facility is presented in Table 7A-1.

The principal advantages of locating the water reuse facility at the Hamby WWTP are primarily:

- The centralization of operation.
- An economy of scale in conventional treatment unit process; i.e., primary clarifiers.
- Elimination of the need to transport sludge through the collection system.

The advantages of the Tributary location of the water reuse facility are primarily:

- Less costly, savings of $8 to 10 million.
- Discharge at a point further from LFPH; more publically acceptable.
- Supports a system which eliminates overflow of wastewater in the collection to the tributaries of LFPH.
- Provides a discharge which is of equal or better quality than the urban runoff presently in the tributaries.
- Greater compatibility with the nonpotable water system.

Table 7A-1

Cost Comparison Between Hamby and Tributary Location
Abilene Water Reclamation Research Project
(Millions $)

	Hamby Location	Tributary Location
Phase 1 Improvements (1992)[1]		
a. 3.0 MGD AWT	$ 5.55[2]	$10.12
b. AWT O&M (NPW)[3]	2.31	4.52
c. Infrastructure[4]	25.91	9.99
d. Non-Potable System	3.15[5]	0.57
e. Non-Potable O&M (NPW)[3]	0.25	0.50
Sub-Total	$37.17	$25.70
Phase 2 Improvements (1998)		
a. 4.0 MGD AWT Expansion	$ 5.79[2]	$ 9.66
b. AWT Expansion O&M (NPW)[3]	2.89	5.20
c. Infrastructure[4]	20.25	11.03
d. Non-Potable System	0.83[5]	1.60
e. Non-Potable O&M (NPW)[3]	0.12	0.20
Sub-Total	$29.88	$27.69
Net Present Worth (1987 Dollars)[6]	$38.12	$29.37

Notes

1. Phase schedule years from Wastewater Collection System Analysis, May 1987.

2. Based on preliminary treatment (screening, grit removal, primary clarification) and other systems being provided by existing facilities. No redundancy and equalization would be needed.

3. Net Present Worth based on (P/A 20, 8%)

4. From Table 5.6 Wastewater Collection System Analysis, May 1987

5. Based on piping Hamby WWTP effluent to proposed nonpotable system.

6. Net Present Worth based on (P/F, 5, 8%) and (P/F, 11, 8%)

For these reasons, the RT chose to concentrate the focus of the project on reclaiming water from wastewater at a tributary WWTP.

TM-7A addresses the questions posed at the October 15, 1987 PAC meeting on the draft report concerning what are the costs and advantages of constructing a reclaimed water facility at the proposed Tributary WWTP, and the request by the Texas Water Development Board to provide an economic comparison based on total sytsem costs.

SUMMARY

Basic conclusions of the RT was that:

- An optimum reuse facility should be 3.0 mgd.
- Tributary location is preferable to a Hamby location, primarily because of difference in cost.
- Tributary location is "cleaner" in planning, design, and construction of a reuse facility.

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 8A

BENCH SCALE STUDY - HIGH LIME AND ALUM COAGULATION

Principal Author: Raymond R. Longoria, P.E.

INTRODUCTION

Bench scale studies were conducted at the Hamby Wastewater Treatment Plant (WWTP) in Abilene, Texas during the week of August 3, 1987 to determine the response of Hamby WWTP secondary effluent to chemical treatment. The bench-scale studies included treatment of unchlorinated, secondary clarifier effluent with lime and alum independently. The performance of these chemicals were evaluated by measuring the removal of hardness, TOC, phosphorous, turbidity, TDS metals and other water constituents. These studies were conducted using a six-paddle Phipps and Bird variable speed jar test machine for coagulation and flocculation. After optimum pH for lime was established, a larger scale test was run and a sample collected to confirm viral reduction. All laboratory analysis was performed by City of Abilene staff at the Northeast WTP laboratory, except for TOC and TDS which was run at the Hamby WWTP lab.

SAMPLE SOURCE WATER

Unchlorinated wastewater was needed as subject water for the testing. Since the point where the effluent from the three clarifiers joined was chlorinated, the sample water was drawn from the outfall box at Clarifier No. 2. This included effluent from both Clarifiers No. 1 and 2. It was assumed the effluent from these two was representative of the total plant effluent.

The average characteristics of the secondary effluent at this point in the process were as follows:

Parameter	Range of Values
Temperature (°C)	24-27
pH	6.9-7.0
Total Alkalinity (as $CaCO_3$)	194-220
Total Hardness (as $CaCO_3$)	260-272
Calcium Hardness (as $CaCO_3$)	173-184
Magnesium Hardness (as $CaCO_3$)	79-90
Conductivity	1300-1400
Total Organic Carbon	10.4-11.0
Ortho-Phosphate (as P)	7.0-8.0
Turbidity	2.6-4.7
Fecal Coliform	TNTC (1:10 dilution)
TDS	838-876

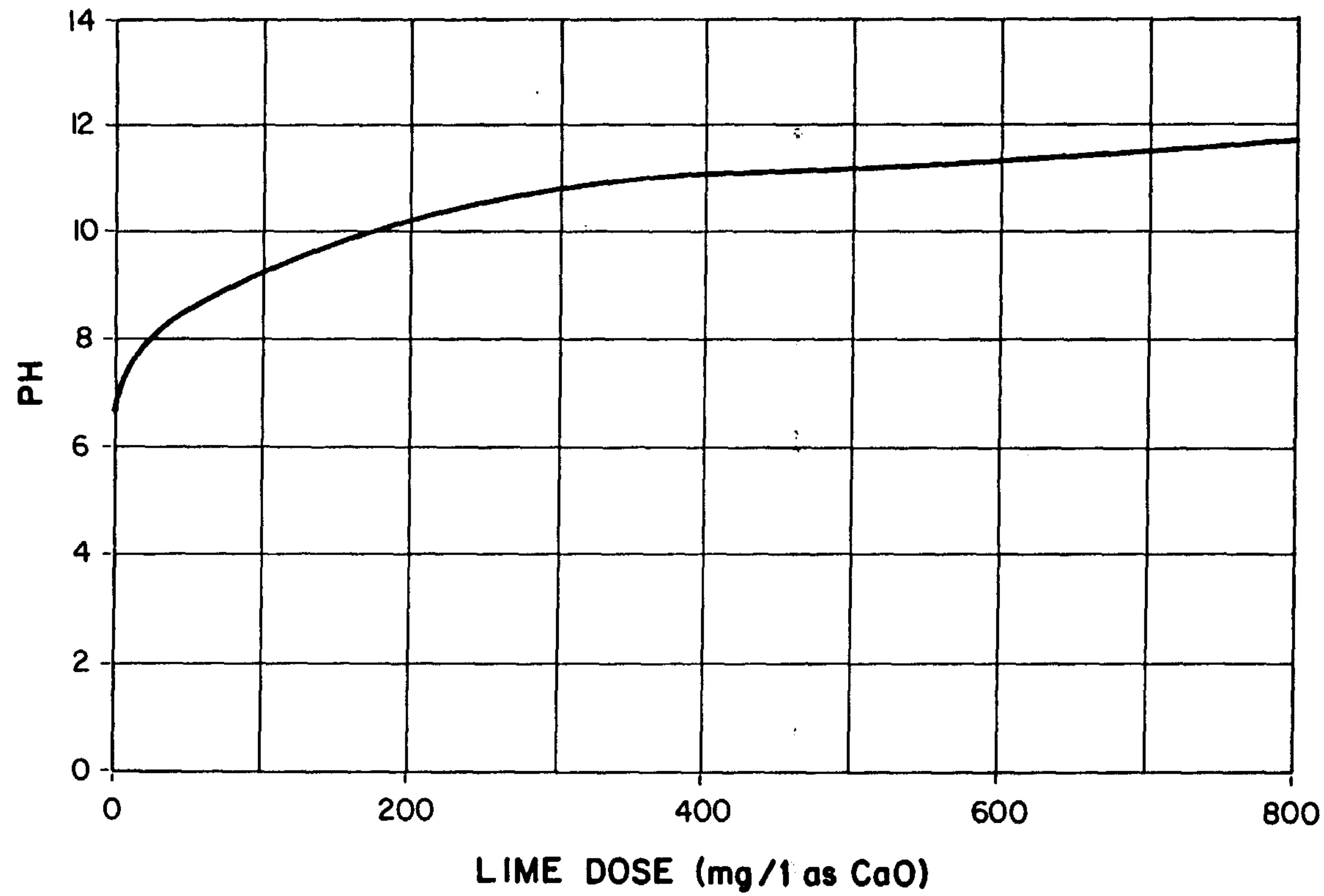
LIME TREATMENT

Bench scale studies with lime addition were begun by establishing the relationship between the lime dosage and the pH of the wastewater. Known increments of a stock solution of lime was added to the wastewater and the pH measured. A lime dosage - pH curve was developed relating the lime dosage required to reach a given pH. A new stock solution of lime using CaO was prepared. Although a $Ca(OH)_2$ stock solution was requested it was not available. The water used for preparing the lime was boiled for 5-10 minutes to purge CO_2 from the deionized water. A stock solution of 10 gm/l was prepared. Subsequently a 4 gm/l and a 20 gm/l stock solution were prepared. During the lime addition, both the stock solution and the sample were kept mixed to keep the lime in solution. A composite lime dosage - pH curve of the three runs is given in Figure 8A-I.

This was followed by a general settling test to identify an adequate sedimentation time to be used in the subsequent jar tests.

Figure 8A-I

COMPOSITE LIME DOSAGE
VS PH



A standard six-paddle Phipps and Bird gang mixer with an illuminated base was utilized. Standard size 1500 ml circular beakers were not available and 2000 ml beakers were substituted. The standard 1 liter sample did not adequately submerge the paddles in the 2 liter beakers. A 2000 ml sample was used in the sedimentation tests and 1500 ml samples were used in the remaining tests. At a rapid mix time of 1.5 minute at top speed and flocculation of 7.5 minutes at 30 rpm, sufficient sedimentation occurred by 20 minutes. This was used as the sedimentation time for all subsequent tests.

Hardness Reduction. The subject water had an average hardness of 266 mg/l (as $CaCO_3$) and average alkalinity of 207 mg/l (as $CaCO_3$). The presence of almost 60 mg/l of non-carbonate hardness would suggest only a moderate total hardness reduction might be expected.

Three series of jar tests were run to determine the pH at which the optimum hardness reduction occurred. The first series included pH's ranging from 10.8 to 11.2 but was found to not be broad enough to determine an optimum pH. The subsequent test pH's ranged from 10.2 to 11.2 and an optimum point was established. The third series spanned from 10.4 to 11.2. Figure 8A-II shows the results obtained from all three test runs.

Both total hardness and calcium hardness reached a minimum value at a pH of about 10.6 -10.8. The magnesium hardness reached a minimum and leveled off at around 16.0 mg/l (as $CaCO_3$) at a pH of 11.0. Despite a defined minimum point in hardness, the hardness value was not reduced significantly. The average hardness of the untreated secondary effluent was 268 mg/l while the average minimum after high lime addition was 197 mg/l, a reduction of 71 mg/l (as $CaCO_3$). Addition of soda-ash to remove the non-carbonate hardness would be required to achieve lower hardness levels. Even at 197 mg/l, the hardness is less than the historical 232 mg/l hardness in Lake Fort Phantom Hill.

Total Dissolved Solids. TDS removal paralleled the hardness reduction as can be seen by the TDS reduction curve on Figure 8A-II. The effect on TDS is shown as TDS reduction opposed to the absolute value, to better illustrate the quantitative effect. The TDS of the untreated product water ranged from 838 to 876 mg/l. The maximum removal occurred at a pH of 10.6 to 10.8, similar to the point of maximum hardness removal, as would be expected. For water similar to the sampled water, the test results indicate a reduction of about 260 mg/l or 30 percent of TDS can be expected at a pH between 10.6 and 10.8. This produces an effluent that is marginally (10 percent) higher than the historical TDS levels in the lake.

Total Organic Carbon. The TOC concentration of the untreated subject water ranged from 10.4 to 11.0 mg/l. This is consistent with the historical WWTP data reviewed. As expected, removal of TOC increased as pH was increased, but it leveled off beyond a pH of 10.8 to 11.1. The maximum observed TOC reduction as shown on Figure 8A-II was about 40 percent.

Phosphorous Removal. Review of the ortho-phosphate and total phosphorous analyses since March of this year indicated ortho-phosphate constituted over 80 percent of the total phosphorous. To simplify laboratory analysis, phosphorous removal was monitored by tracking the ortho-phosphate reduction. It was assumed that the majority of the phosphorous present was in the form of a $O-PO_4$ and poly phosphates and organic phosphates (or total phosphorous) would have comparable reductions. The samples were filtered through a 0.45 um filter to remove any suspended forms of phosphorous.

Since phosphate removal increases with increasing pH and improves in high alkalinity waters it was expected that good phosphorous removal would be observed. The soluble ortho-phosphate concentration was less than 0.1 at all pH's greater than 10.2. Unfortunately not enough low pH samples were tested to plot a curve depicting the removal from normal pH (6.9) up to 10.2. The curve shown on Figure 8A-II reflects the data reported and is extrapolated to lower pH's using the typical phosphorous removal curve in WPCF MOP No. 8.

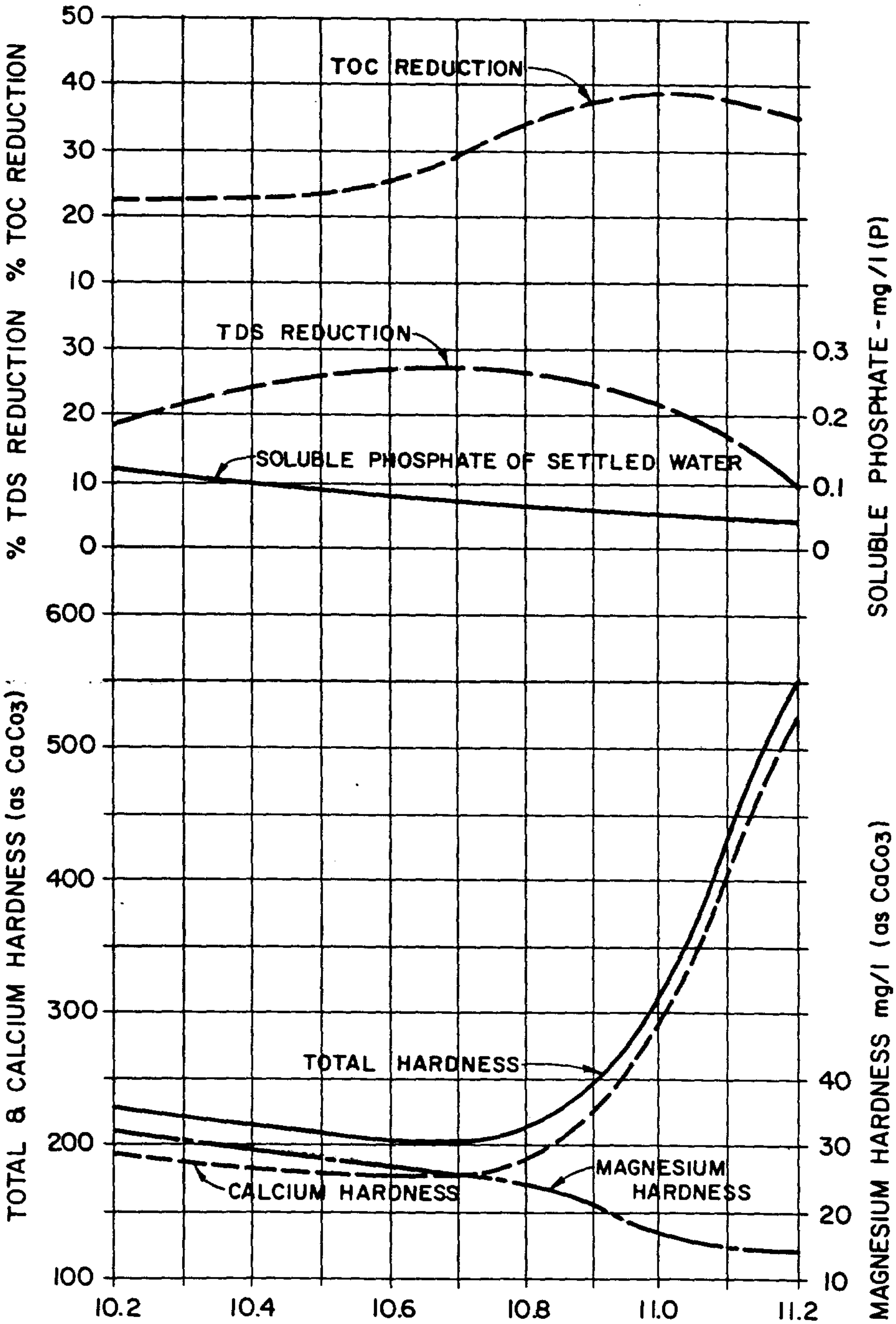


Figure 8A-2

ABILENE REUSE COMPOSITE RELATIONSHIP OF HARDNESS, TDS & TOC REDUCTION AND PH FOR HIGH LIME TREATMENT

Metals Removal. Metals removal by lime treatment was not examined in detail in the jar test runs, but metals were run on two series of the lime jar tests to determine general performance. The tests performed indicated favorable results, with removal of zinc, barium, iron, manganese and magnesium in excess of 86 percent at pH's above 10.6. Other heavy metals were also analyzed, such as arsenic, mercury, selenium and cobalt with none detected in the treated or untreated samples. Since many metals are insoluble at the pH range tested it is expected that good metals removal will result with high lime treatment.

Other Consideration. At the optimum pH range of 10.6 to 10.8 the floc formation was rapid and a large heavy fast settling floc was produced. Despite the quick forming and initial good settling, some fine particles remained suspended even after 25 minutes of settling. This tended to produce higher turbidities than expected. Turbidity of the untreated samples ranged 2.6 to 4.7. The turbidities of the lime dosed samples exceeded 2.0. Only the turbidities of the third series of lime samples reached a minimum below 1.0. This may have been the result of supernatant withdrawal technique or excessive agitation since samples had to be transported to the Northeast Water Treatment Plant for turbidity measurements.

Above pH 10.4 fecal coliform removal was complete. The untreated samples, at a 1:10 dilution had an f. coliform level that was too numerous to count. The count dropped to 10 per 100 ml at 10.4 and zero at all pH's above 10.4.

Color reduction determinations were not made. Qualitative visual observation indicated that the color in subject water was reduced by the high lime treatment.

There had been a concern that the results of the lime testing might not be applicable when Hubbard Creek Reservoir water was being used to supplement the potable water supply. Hubbard Creek water is historically higher in TDS. The secondary effluent TDS values at Hamby WWTP during the most recent period that Hubbard Creek water was being used were reviewed. Although the average values tended to be higher, no values were found that exceeded the range of TDS values when only Lake Fort Phantom Hill water was used. The results of the testing done now should be valid even during the periods that Hubbard Creek water is used as a potable water supply.

LIME FIELD TEST

On August 11, 1987, followup testing was performed on a large sample volume. The purpose of the test was to dose a sample to optimum pH (10.6 to 10.8) and analyze the viral and bacterial reduction. Approximately 150 gallons of secondary clarifier effluent was pumped into a rectangular container. A lime dosage - pH curve was prepared for the new stock lime solution. A dosage of 3600 ml of 2% lime was calculated to be required to raise the pH of the 150 gallon sample to 10.8. During the field test the initial dosage brought the pH to only 10.05. An additional 2000 ml was added which brought the pH to 10.6. After mixing, using a chemical mixer and the portable pump, flocculation and settling, 100 gallons of the supernatant was collected and then concentrated by the field crew from the Baylor College of Medicine (BCOM). This sample and a sample of the untreated subject water were to be analyzed for virus concentration, by BCOM. The results are expected in September 1987.

A separate sample of approximately 6 gallons was collected for analysis of microorganisms identified by the State for analysis. These samples were delivered to the Fairleigh-Dickinson Laboratories in Abilene.

The remaining sample was inadvertently discarded before a sample could be drawn for running the parameters of the previous week.

Recarbonation. A sample of subject water was dosed with lime to raise the pH to 11.0, was mixed, flocculated and allowed to settle. A 500 ml quantity of supernate was drawn to identify the neutralization characteristics of the treated wastewater. A titration curve using H_2SO_4 was prepared and is shown in Figure 8A-III. To lower the pH using carbon dioxide would require dosages similar to those of the CO_2 curve shown on Figure 8A-III.

ALUM TREATMENT

Two series of jar tests were run using alum (aluminum sulfate) rather than lime on the same subject water. Again, 2 liter beakers and 1500 ml samples were used with mixing and flocculation accomplished using the Phipps Bird mixer. The alum dosages ranged from 40 to 100 mg/l. An optimum dosage of about 65 to 80 mg/l of alum was observed for TOC removal. Reduction of TOC averaged about 20 percent in this range with a maximum reduction of 24 percent. Although higher removals were expected, the beginning TOC level of the subject water was relatively low (10-11 mg/l) and may explain the low removal percentages. The TOC values and reductions are shown in Figure 8A-IV.

The observed phosphorous reduction using alum was good despite the high alkalinity of the wastewater. The soluble phosphate levels dropped to less than 1.0 at concentrations of only 80 to 90 mg/l of alum. The minimum value noted was 0.56 mg/l PO_4 (as P) at an alum dosage of 93.3 mg/l. Observing the trend of the curve on Figure 8A-IV it is expected that meaningfully lower values could be expected at increased dosages.

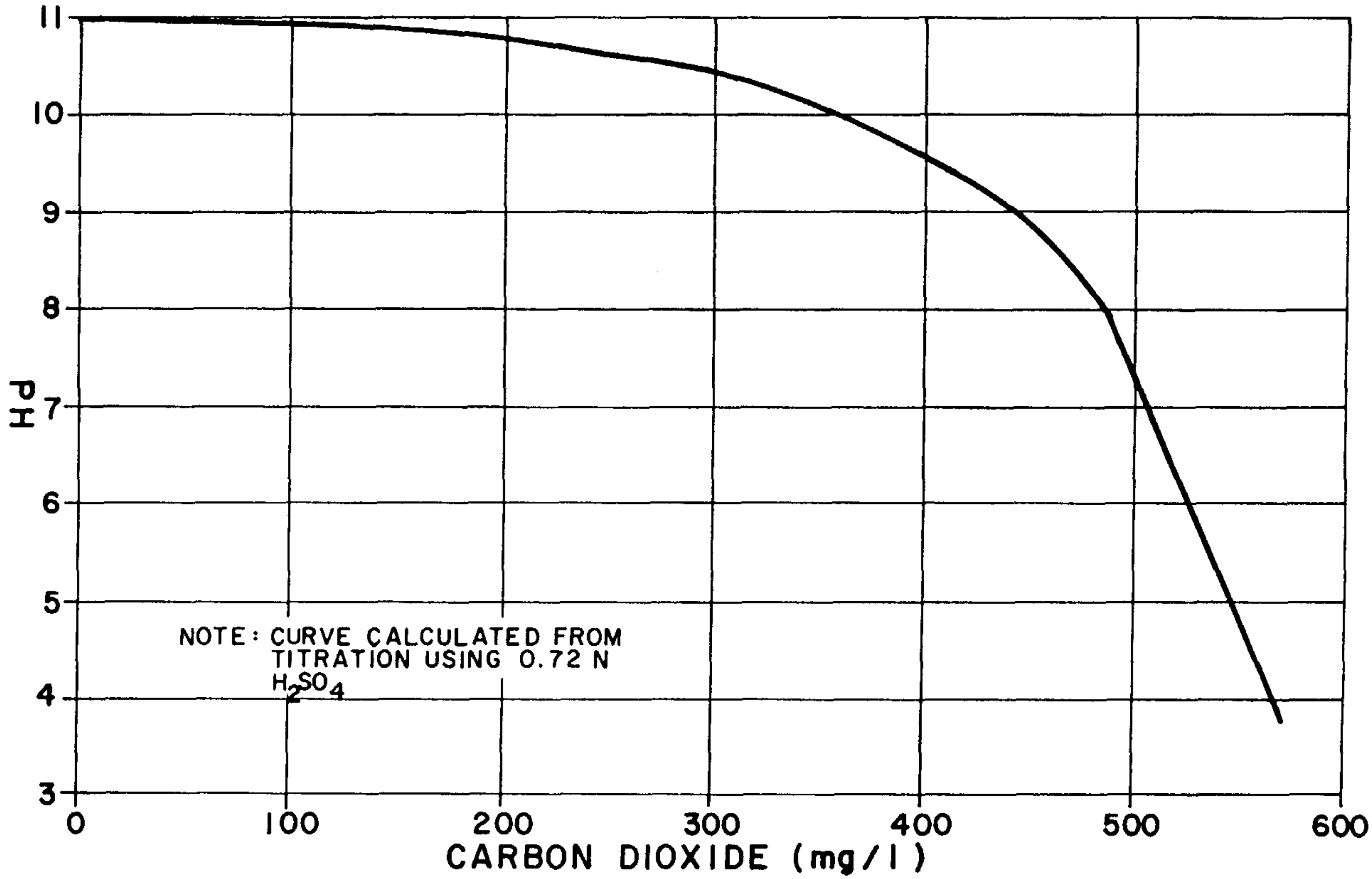
Turbidity removal was also good. Dosages of sufficient strength to reach an optimum turbidity removal were not tested. It appears that turbidity removal to a value less than 0.7 NTU could be expected and the required dosage would be around 100 mg/l.

CONCLUSIONS OF BENCH-SCALE TESTS

Lime treatment of the secondary effluent at the City of Abilene's Hamby WWTP were similar to results found in the literature and observed at

FIGURE 8A-III

CARBON DIOXIDE REQUIREMENTS FOR NEUTRALIZATION OF HIGH LIME TREATED SECONDARY EFFLUENT HAMBY WWTP-ABILENE, TEXAS



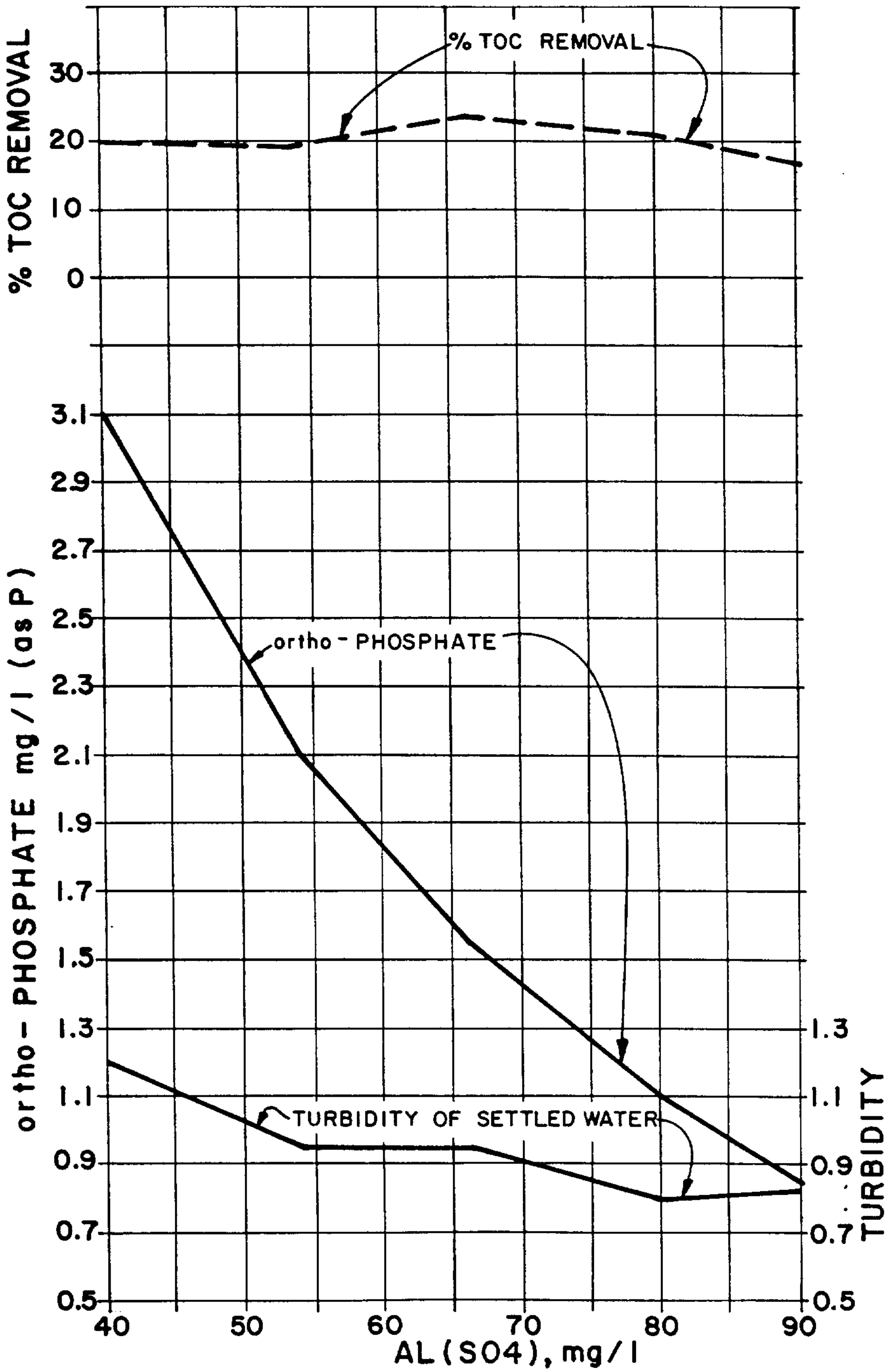


FIGURE 8A-IV
ALUM TREATMENT OF
HAMBY WWTP EFFLUENT

full-scale AWT plants in this country. A good settling dense floc occurred at a wide range of pH's (10.4 to 11.0).

At a pH of 10.6 to 10.8, TOC reduction is approximately 40 percent, phosphorous is reduced to less than 0.1 mg/l phosphate (as P), the total hardness is reduced by approximately 70 mg/l, and a TDS removal of about 260 mg/l. Metals and fecal coliform reductions were also observed.

The TOC reduction was good considering the beginning TOC was relatively low. Finished TOC's of approximately 7.0 mg/l were observed. The phosphorous removal exceeded anticipated values. Soluble phosphate concentrations less than 0.1 mg/l (as P) occurred at pH's as low as 10.2. Although the majority of the hardness in the wastewater is carbonate hardness there is appreciable non-carbonate hardness. Accordingly, only marginal hardness reduction can be expected, although TDS removal is significant.

Approximately 400 mg/l of lime as CaO was required to produce the desired pH.

Alum treatment was found to be effective in removing phosphates to a level below 1.0 mg/l (as P) at a reasonable dosage level. However, TOC removal was only one-half of what occurred in the lime treatment. Acceptable turbidity removals were observed and TDS on the one series run showed no meaningful increase. Approximately 75 mg/l of alum was required to produce the effects described.

ABILENE RECLAMATION RESEARCH PROJECT
Technical Memorandum 8B

BENCH SCALE STUDY
NITRIFICATION/DENITRIFICATION

Principal Author: Tom Simpkin, P.E.

This memorandum briefly describes the procedures for and the results of the nitrification/denitrification bench scale tests performed on August 5 and 6, 1987 at the Hamby Wastewater Treatment Plant (WWTP).

PURPOSE

The discharge of WWTP effluent from a possible Westside plant or from the Hamby plant to Lake Fort Phantom Hill for eventual reuse, will require at least partial nitrogen removal. As discussed in Technical Memorandum 6 (TM 6), both ammonia and nitrate may have to be removed. Denitrification, the process of nitrate removal, also provides a number of process advantages. More information on nitrogen removal can be found in Technical Memorandum 7 (TM 7).

The design of activated sludge systems for nitrification and denitrification is typically based on the solids retention time (SRT) and assumptions of the rates at which these two reactions will occur. However, it is often difficult to acccurately predict the rates at which nitrification and denitrification will occur. To refine the process of designing the activated sludge system for nitrification and denitrification, bench-scale batch nitrification and denitrification tests were conducted with the mixed liquor and the wastewater at the Hamby WWTP. The rates determined from these test will be used as an aid in designing the nitrification/denitrification activated sludge systems.

PROCEDURE

Relatively simple batch procedures were used for the tests discussed here. For the denitrification tests, mixed liquor, return sludge, and primary effluent samples were combined in various ratios. The samples were mixed at a slow speed, spiked with nitrite and sampled for nitrite periodically over about two hours. The rate of decrease in nitrite concentration with time was taken as the rate of denitrification. The suspended solids concentration of the sample was also determined in order to express the rate as a specific rate.

Four different ratios of wastewater to mixed liquor were used for the denitrification rate tests and are listed below:

Run	Wastewater/Mixed Liquor
1A	1.0
1B	0.5
2A	0.33
2B	0

These four ratios cover the possible range of nitrified mixed liquor recycle rates that would be used in the full scale installation. Only one ratio of wastewater to return sludge was used for the nitrification rate test. Since the rate of nitrification is not a function of the organic wastewater strength, as denitrification is, there was no need to perform more than one test.

For the nitrification rate test, samples of return sludge and primary effluent were combined and then aerated for approximately 4 hours. Samples were collected periodically and analyzed for ammonia. The decrease in ammonia concentration over time was taken as the rate of nitrification.

RESULTS

Denitrification

The results of the denitrification rate test are presented in Figures 1 and 2. For Runs 1A and 2A the rates were fairly linear until the nitrate concentrations became less than 1 mg/l. Runs 2A and 2B, for some unknown reason, had a lag of 30 minutes before denitrification proceeded. Similar results have been observed in other denitrification rate tests at other plants.

The specific rates of denitrification calculated from these results and corrected to 20 degrees C are summarized below:

Run	Wastewater/Mixed Liquor	Specific Rate (mg NO_2/g VSS-hr)
1A	1.0	3.94
1B	0.5	2.75
2A	0.33	1.64
2B	0	0.56

The above rates were corrected to 20 degrees C by the following equation:

$$R_t = R_{20} * 1.08^{(t-20)}$$

These rates are well within the range of rates that have been observed at other wastewater treatment plants, and provide a good basis for the design of the anoxic basins.

Figure 3 presents the relationship of the specific rate of denitrification observed and the ratio of wastewater to mixed liquor. As is expected, the rate increases as this ratio increases. The genal relationship expressed in Figure 3 has been observed at other wastewater treatment

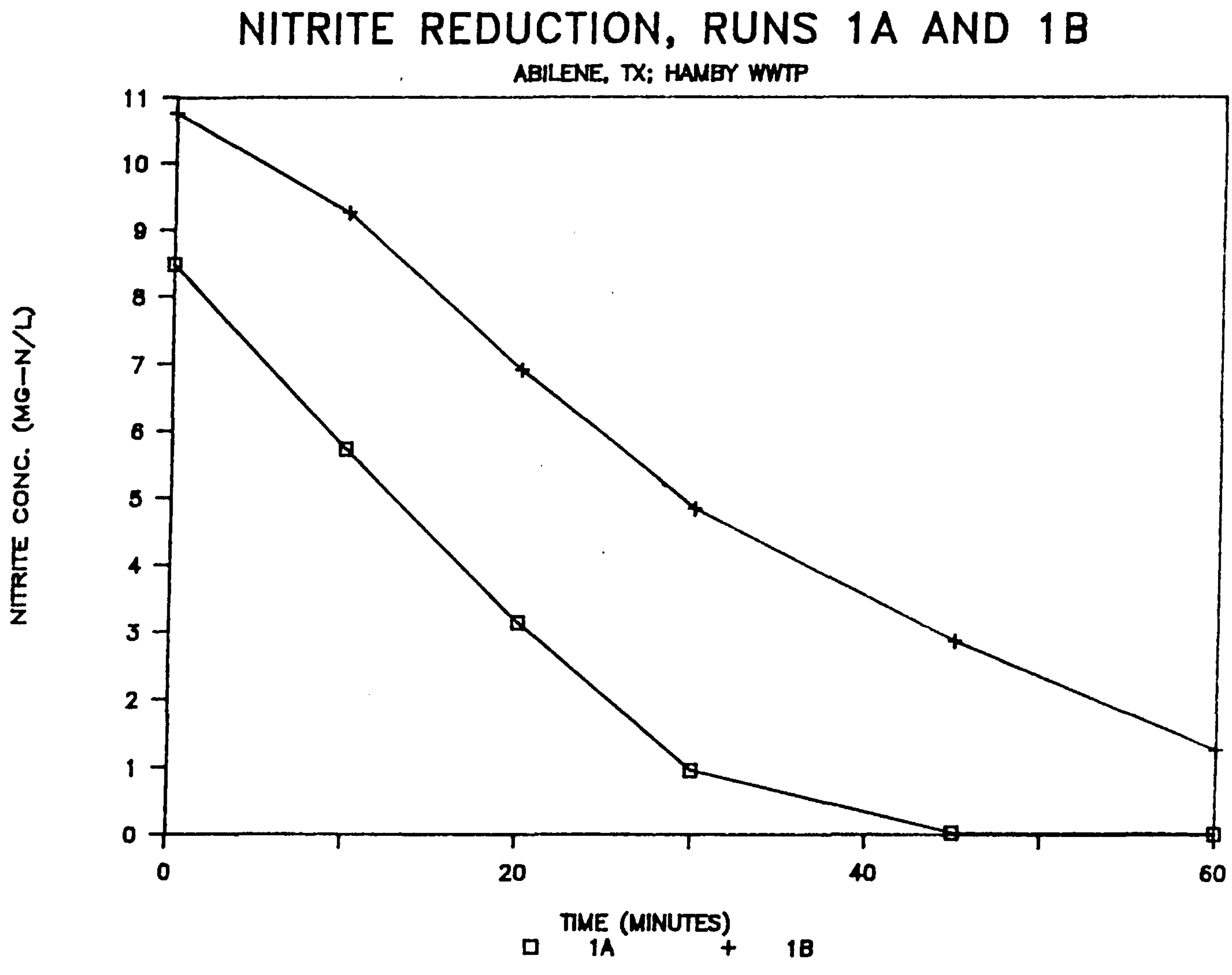
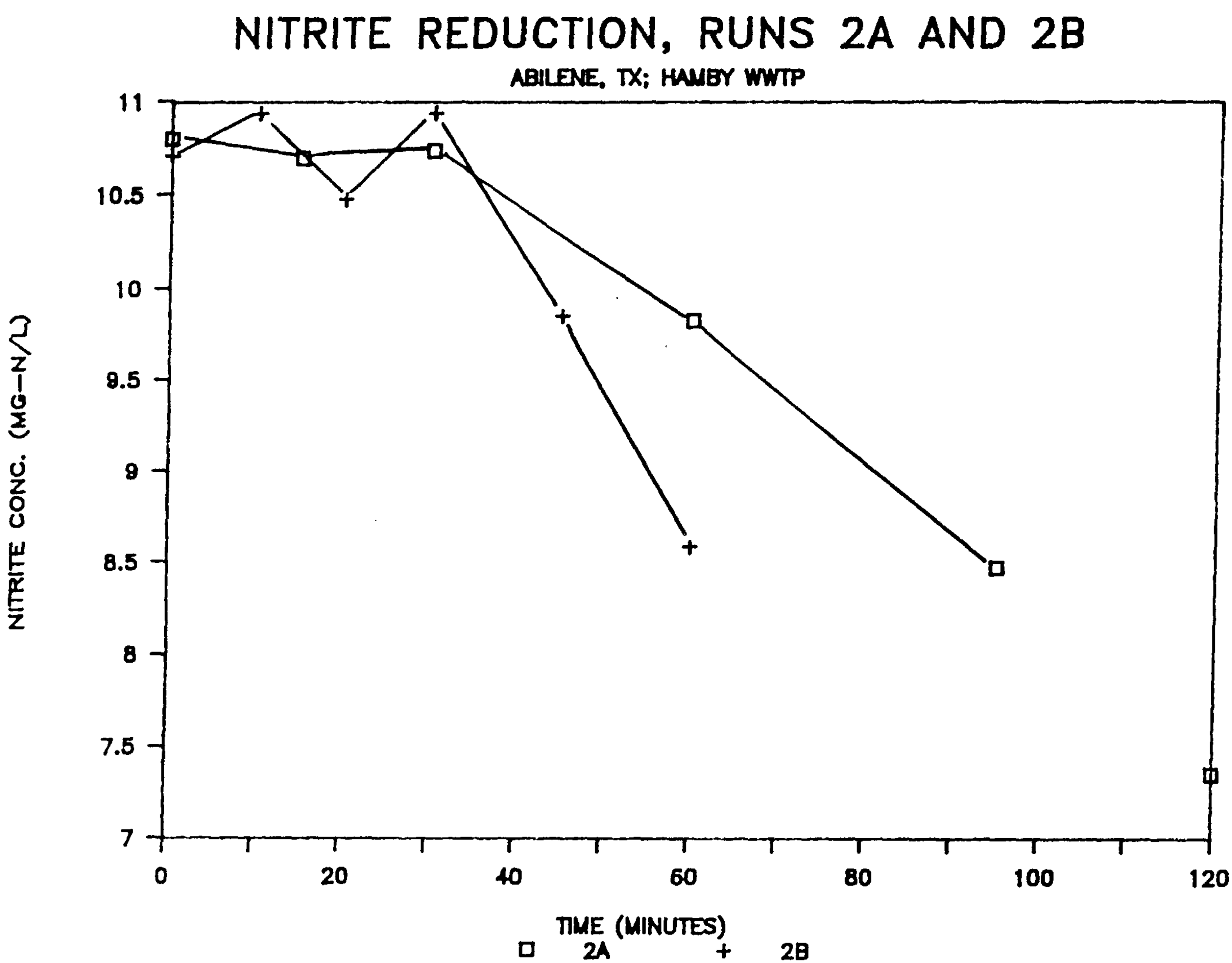

NITRITE REDUCTION, RUNS 1A AND 1B
ABILENE, TX; HAMBY WWTP
NITRITE CONC. (MG-N/L)
0
1
2
3
4
5
6
7
8
9
10
11
0
20
40
60
TIME (MINUTES)
1A
1B

FIGURE 8B.1



NITRITE REDUCTION, RUNS 2A AND 2B
ABILENE, TX; HAMBY WWTP
NITRITE CONC. (MG-N/L)
11
10.5
10
9.5
9
8.5
8
7.5
7
0
20
40
60
80
100
120
TIME (MINUTES)
2A
2B

FIGURE 8B.2

ABILENE, TX, HAMBY WWTP

NITRITE REDUCTION RATE VS. WW/ML

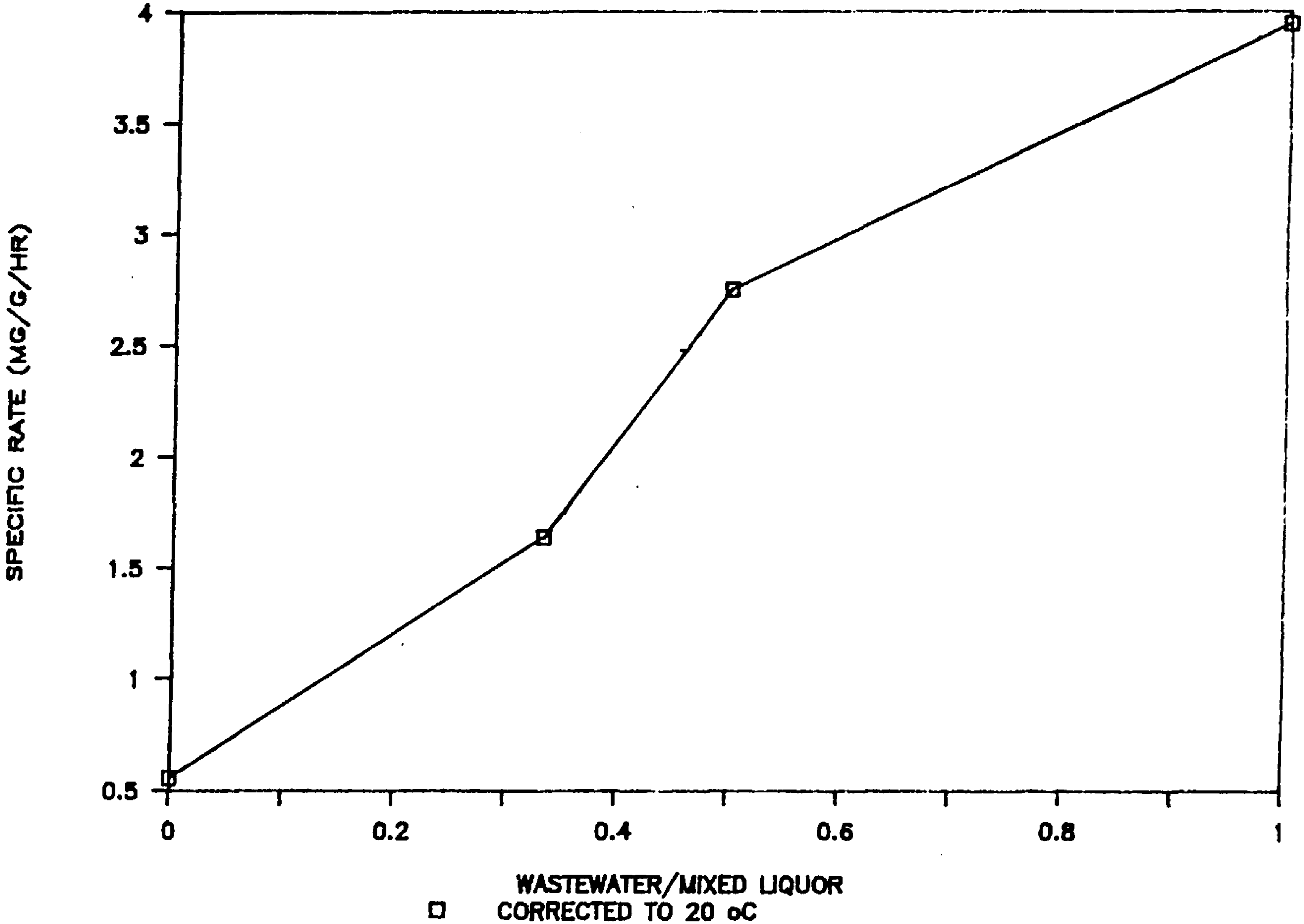


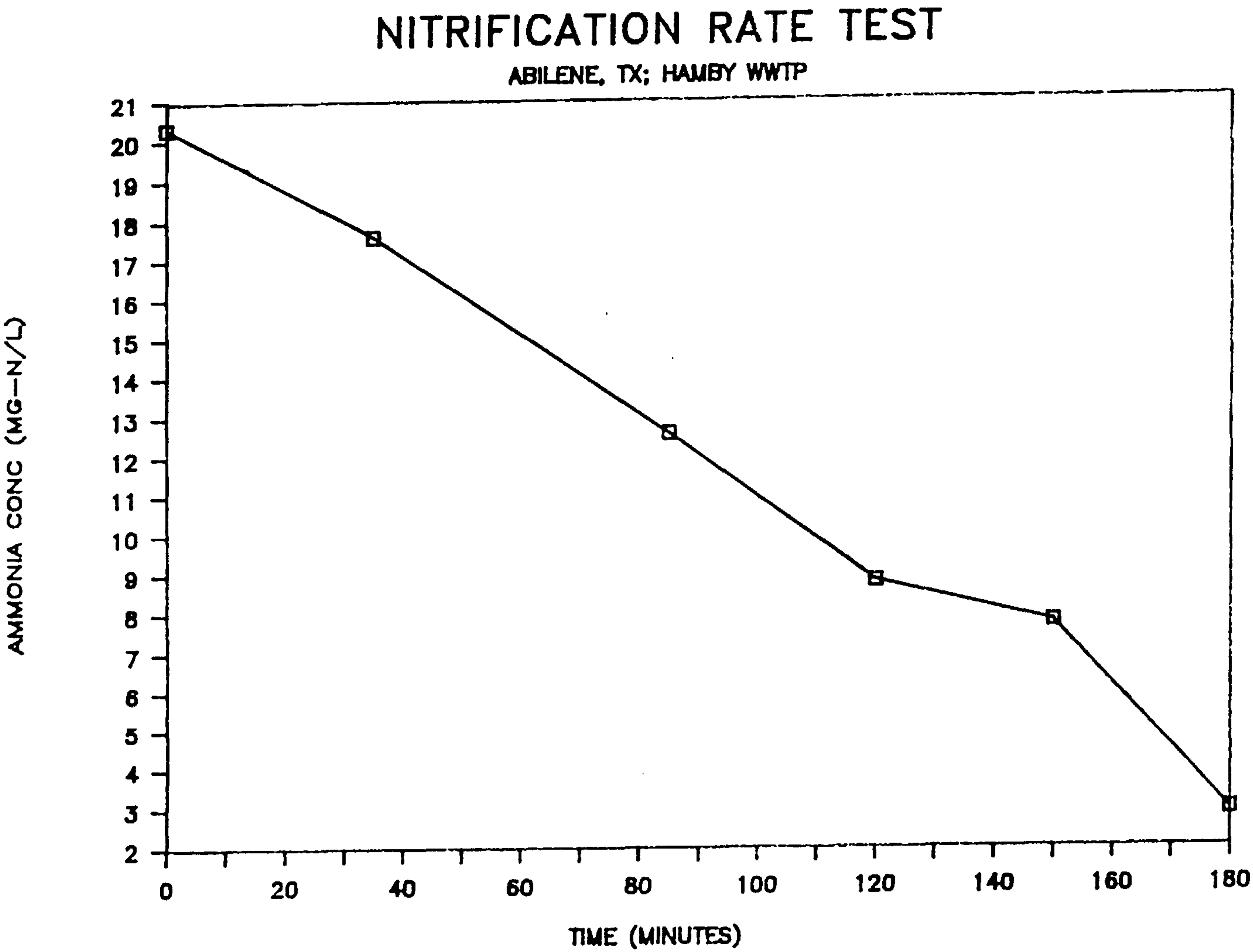
FIGURE 8B-3

facilities. This relationship can be used to estimate the effect on the rate of denitrification of varying the rate at which mixed liquor is recycled to the anoxic basin.

Nitrification

Figure 4 presents the results of the nitrification rate test. As is expected, the ammonia concentration decreased in essentially a linear fashion. The rate observed in this test was 0.04 g NH_3/g VSS-day when corrected to 20 degrees C. This rate is rather low in comparison to values reported in the literature. The low rate may be a result of a number of factors, including a low population of nitrifiers or the presence of toxic compounds. If the population of nitrifiers was low compared to other nitrifying activated sludge systems, the volatile suspended solids would contain a smaller fraction of nitrifying microorganisms, and would thus, result in a lower specific rate.

The rate determined in this test must be used in conjunction with the minimum SRT for nitrification as the basis for design of the activated sludge systems at the proposed Westside WWTP or Hamby WWTP. The volume of the aerobic basin should be determined based on the minimum SRT for nitrification. This volume should then be checked with the rate of nitrification determined in the batch test. If the volume is not large enough to remove the ammonia to the desired concentration, a larger volume should be used.



NITRIFICATION RATE TEST
ABILENE, TX; HAMBY WWTP
AMMONIA CONC (MG-N/L)
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
0
20
40
60
80
100
120
140
160
180
TIME (MINUTES)

FIGURE 8B.4

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 9

RECOMMENDED PLAN

Principal Author: David Lewis, P.E.

INTRODUCTION

Technical Memorandum No. 9 (TM-9) presents the research team's findings, conclusions, and recommendations for the Abilene Water Reclamation Research Project. The basic topics addressed in TM-9 are as follows:

- Water Quality
- Facility Types and Needs
- Implementation Needs
- Why Water Reuse for Abilene
- Specific Recommendations for Abilene
- Specific Recommendations for TWDB

WATER QUALITY

Water quality recommendations are based on the development and analysis of historic and current water quality data, modeling projections, health effects, and State and Federal regulations. This data and analysis is presented in greater detail in the following TM's:

- TM-4, Water Quality Assessment
- TM-5, Water Quality Modeling
- TM-6, Water Quality Criteria and Goals.

Historic water quality data was supplemented with a current monitoring program to provide a broad baseline of water quality data, to which comparisons can be made. A water quality model was developed and calibrated to historic and current data to allow for projections of changing conditions. Using this model, projections of future water quality based on various flows and levels of treatment were made.

As explained in the following paragraphs, it was found that water quality goals and regulations can be met by providing advanced wastewater treatment with nutrient removal for a plant discharging to Lake Fort Phantom Hill (LFPH) or its tributaries.

Level of Treatment Required

Three levels of treatment to meet the water quality goals were selected for comparsion. These levels ranged from systems that combine many of the aspects of both advanced wastewater and water treatment processes with near full nutrient removals (designated Type A herein), to advanced tertiary wastewater treatment with some nutrient removal (Type B), to advanced tertiary wastewater treatment with limited nutrient removed (Type C). The effects of discharge flows from 3 mgd to 17 mgd on LFPH were predicted by use of the model. Because of the short travel times (less than 24 hours) in the tributaries to Lake Fort Phantom Hill (LFPH) it is the opinion of the research team that discharges into LFPH or its tributaries should be treated as discharges into LFPH for modeling purposes. Due to the high levels of treatment selected, no violations of the water quality standard in the tributary are projected.

Based on these evaluations, it was determined that Type A treatment--nutrient removal-- is required for flows greater than 3.0 mgd and that Type A and B treatment levels are acceptable for flows less than 3.0 mgd., primarily due to the need for phosphorous control. Phosphorous control is important to prevent eutrophication (Algal growth) in LFPH. In a comparison of treatment costs, water quality, and health effects, the Public Advisory Committee (PAC) indicated a preference for Type A treatment for discharges into Lake Fort Phantom Hill and/or its tributaries. However, at flows of 3 mgd or less, Type B treatment is acceptable. Variation from these limits may be considered, if more detailed model and sampling was conducted to justify it.

Recommended Discharge Standards

Specific recommendations for key parameters are as follows:

Chemical and Biologial Parameters

Nutrients

Phosphorous discharge levels should not exceed 0.2 mg/l at flow greater than 3.0 mgd and 2.0 mg/l at flows less than 3.0 mgd. Ammonia discharge levels should not exceed 2.0 mg/l to prevent toxicity to the fishery in the tributaries or at the discharge point in LFPH. Nitrate levels should be closely monitored, since modeling indicates that LFPH has marginal ability to cleanse itself of this compound. At flows greater then 3.0 mgd, nitrate discharge levels should not exceed 10 mg/1.

Treatment Parameters

The following conventional treatment parameters should be adhered to:

Parameter	<3.0 mgd	>3.0 mgd
BOD	5 mg/l	5 mg/l
TSS	5 mg/l	5 mg/l
Ammonia	2 mg/l	2 mg/l
Nitrate	10 mg/l	25 mg/l
D.O.	5.0 mg/l	5.0 mg/l
NTU	2.0 mg/l	2.0 mg/l
pH	6.5-8.5	6.5-8.5

Toxics Parameters

Discharge levels should meet the Mean Contaminant Levels (MCL's) and Recommend Mean Contaminent Levels (RMCL's) for drinking water standards in LFPH.

Microbiological Parameters

The discharge levels for viruses should be less than one plaque forming unit (PFU). The specific discharge goal for individual parasitic organisms is undefined due to lack of specific long-term data, but general goal of a discharge free of parasitic organism is recommended. The discharge level for coliform bacteria should be 2.2/100 ml. A level of 100/100 ml is acceptable on some stream tributaries of LFPH.

The water quality discharge recommendations presented here are site specific for LFPH. While they may serve as a guide for other sites in the state, site specific data and modeling are recommended for every similar project undertaken in the state.

FACILITY TYPES AND NEEDS

TM-7, Process Selection, and TM-8, Benchscale Testing, present in greater detail the topics of process evaluation, operation, capital and operational cost, and background data. Results are summarized below.

The processes evaluated ranged from various biological processes to physical and chemical treatment processes. The recommended system, "Alum with Biological Phosphorous" contains the following basic processes:

- Preliminary Treatment, Screening and Grit Removal
- Primary Settling, Clarification
- Biological Treatment, Activated Sludge Nitrification
- Phosphorous Removal, combination of both Biological and Chemical
- De-Nitrification, Biological Treatment
- Coagulation, Alum Treatment
- Clarification
- Filtration
- Disinfection, Chlorination (Breakpoint Capabilities)
- Dechlorination
- Post Aeration

The capital cost for a system at 3.0 mgd is estimated to be approximately $10-12 million dollars with an operational cost of $400,000 per year. For comparsion, an advance wastewater treatment plant (15/5/3, BOD/D.O./NH_3) has an estimated capital cost of 9-10 million dollars and an operational cost of $250,000 to $300,000 per year.

Primary Alternative Considered

The primary alternative to the selected process is a system using High-Lime with re-carbonation.

The High-Lime system has several advantages over the "Alum with Biological Phosphorus" system, primarily:

- Reduction instead of increase in Total Dissolved Solids (TDS) concentration
- High disinfection capabilities, using two methods-- ph and Chlorine
- High levels of metals removal

The High-Lime system may be the system of choice at flows greater than 7-10 mgd because of TDS reduction capabilities. Modeling indicates that TDS concentration in LFPH does not exceed recommended standards under normal inflow conditions. At discharge flows greater than 7-10 mgd, Texas surface water criteria will be exceeded more frequently. Due to the length of time needed before implementation of a system with flows in this range it was not considered a significant factor in initial selection. If a system greater than 10 mgd was to be implemented and the water quality monitoring confirmed the modeling, then modifications to the selected system by conversion to High-Lime.

The High-Lime system was not selected primarily because of:

- High capital and operational cost
- Higher operational needs and staff training
- Requires complex sludge handling and disposal

The recommended system accomplishes many of same goals of Hi-Lime at less cost and with lower complexity.

All alternatives evaluated represent a high degree of treatment and subsquently produce high quality waters. The recommended treatment system provides a combination of advantages including costs (capital and operational), operational capabilities, effluent quality, and system fexibility.

Two unit processes not included were a carbon system (granular activated carbon--GAC--or powered activated carbon--PAC) and a membrane system (Reserve Omosis or EDR).

A carbon system was not included primarily because the monitoring data indicated no abnormal amounts of organic pollutants in the existing wastewater treatment plant effluent. Other proposed unit operation processes (coagulation, filtration, post-aeration) will increase normal organic removal rates as compared to existing wastewater system. A major portion of the natural drainage to LFPH consists of an urban area. The research team's opinion is that the discharge from the proposed water reclamation facility may be of better or comparable quality than the existing urban stream flow. As Abilene grows and the requirements of the Safe Drinking Water Act become more defined, it is anticipated that upgrades to the water treatment plant may be required. Therefore, the location of either of these processes (carbon or membrane) would be more effectively utilized in connection with the water treatment plant, if needed. The need for carbon or water treatment process combination in lieu of carbon (ozone and air stripping) should be addressed through a pilot plant operation at the water treatment plant. If a reclamation system greater than 7 mgd is proposed to be implemented, then a piloting facility should be considered prior implementation.

Abilene Specific Needs

Abilene's existing water and wastewater systems are under increasing pressures to expand and upgrade treatment levels. These pressures are from primarily two sources: (1) past and future population growth, and (2) increased regulation of water quality standards.

Abilene has addressed these needs by expanding and upgrading its water and wastewater treatment plants and sources of supply. Abilene has recently completed an expansion and upgrade to its Hamby WWTP and has committed to further upgrades in the near future. Abilene is presently designing and constructing additional water supply pipeline from Hubbard Reservoir and has committed to the construction of Stacy Reservoir. Both of these improvements will increase Abilene's water supply. The water treatment facilities will be evaluated as requirements for the Safe Drinking Water Act become available.

Abilene has recently committed itself to the expansion of its wastewater systems. This evaluation was performed under a separate study. This expansion calls for increasing the hydraulic capacity at Hamby WWTP-- from 13.4 to 18.0 mgd. Also the design and construction of a new WWTP on the westside of Abilene will alleviate sewer system flows from the west and southside, therefore increasing downstream capacity of the sewer system and eliminating sewer overflows. This Westside WWTP is scheduled to be developed in two phases. The first phase will be at an average daily flow of 2.4 mgd and the second at 5.6 mgd. Since this westside facility would need to meet many of the treatment requirements of a full water re-use facility or pump its discharge to another drainage basin, it provides a unique opportunity for Abilene, to address its water supply needs concurrently with its wastewater needs.

If Abilene chooses to proceed with the Westside WWTP as a Tributary Water Reclamation Facility, some of the advantages and disadvantages would be:

Advantages

- The initial size--2.4 mgd avg. daily flow-- would allow for implementation without major impacts on LFPH or its drinking water.

- Abilene would gain operational and cost experience prior to large-scale implementation of water re-use facilities.

- The cost of implementation would only be the marginal cost between a WWTP and a water reclamation facility.

- Approximately 1750 acre-foot or 1.6 mgd water supply would be created by the project.

- The proposed system would be compatible with the non-potable system and allow for a reduction in water demand, and therefore cost savings.

- Location of a water reclamation facility on a tributary more than 10 miles from LFPH of a size less than 3.0 mgd would allow for demonstration of water re-use without the problems associated with a large scale facility discharging directly into LFPH.

Disadvantages

- Implementation would increase capital and operational cost of the Westside facility.

- Public confusion regarding the differences between a Westside WWTP and a tributary water reclamation facility might delay implementation of needed wastewater systems.

- Immediate requirements to proceed with improvements to Abilene's wastewater system, might not allow for adequate time to develop public acceptance for a water reclamation facility.

Additional Needs

Abilene should consider developing a piloting facility to evaluate the need for future treatment processes at the Northeast and Grimes WTP. The Safe Drinking Water Act may require the upgrade of these WTP's. Implementation of piloting studies within the next few years might allow Abilene to reduce its cost of upgrading its water treatment plants. These studies might consist of a full-scale granular activated column, ozone with air stripping, and powder activated carbon with air stripping.

IMPLEMENTATION NEEDS

If Abilene commits to proceed with a water reclaiming facility, the recommended implementation needs are as follows:

Public Acceptance Program

The general public preception of water re-use projects is a positive one. In its general concept, its depiction is the most difficult portion of a public acceptance program. The connection between wastewater and water is not one that the general public desires to make. To ask the public to accept wastewater as a direct water source is a "difficult sell". It normally requires a public information and relations campaign to convince the public of this type of concept. The acceptance of water re-use through supplementation of existing water supplies has also been demonstrated in the state at El Paso. The public acceptance of non-potable use has been demonstrated throughout the nation and state. The development of a public information and acceptance program should begin with this study. A public meeting was held to present the study conclusion, findings and recommendation on February 23, 1988. The results of that meeting are presented in detail in TM-2.

Pilot Plant/Facilities

Abilene should consider developing a piloting facility to evaluate the need for future treatment processes at the Northeast and Grimes WTP. The Safe Drinking Water Act may require the upgrade of these WTP's. Implementation of piloting studies within the next few years might allow Abilene to reduce its cost of upgrading. These studies would also assist in the planning for any future improvements to water reclamation facilities.

Future Water Quality Monitoring Programs

Abilene should continue with a water quality montoring program to provide basic data on needs or performance in evaluating water quality effects of any program implemented or comtemplated. The monitoring program should continue with sampling locations both within the lake and its tributaries (including Clear Fork diversion). A proposed sample monitoring program is presented below:

Parameter	Frequency	Location
Metal Scan	Bi-Annual	L,T[1]
Nutrients	Monthly, Runoff[2]	L,T
Nitrogen(s)		
Phosphorus		

TOC	Monthly	L, T
BOD	Monthly	L, T
TOH	Quarterly	L, T
VOC	Quarterly	L, T
Color	Quarterly	L, T
Solids	Monthly, Runoff	L, T
TSS		
TVSS		
TDS		
Hardness	Monthly, Runoff	L, T
Alkalinity	Monthly, Runoff	L, T
Chlorides	Monthly, Runoff	L, T
Chlorophyll a	Monthly	L
Algal Identification	Monthly, S,S,F[3]	L
Microbiological		
Fecal Coliform	Monthly, Runoff	L, T
Streptococcus	Monthly	L, T
Total Coliform	Monthly	L, T
Virus	Quarterly[4]	L, T
Parasitics	Unknown[5]	Unknown
TTHMFP	Quarterly	L, T

NOTES: (1) L- Lake, T - Tributaries
(2) Run-off, measured during storm water flows
(3) Spring, Summer, and Fall
(4) Dependent on local capabilities
(5) Dependent on need, to be determined

It is estimated that a monitoring program of this type and frequency would cost approximately $30-50,000, if performed primarily by city forces and a local university. To evaluate the results and make recommendations to the City, it is recommended that a technical committee on water quality be appointed to review the data. This committee should consist of local qualified persons, state or federal personnel from TDH, TWC, or EPA, and others as needed. The responsibility of the committee would be to advise the City of Abilene on water quality in LFPH. Therefore, provide assurance to the public an effective water quality protection program is being achieved in any implementation of water reuse.

Financing

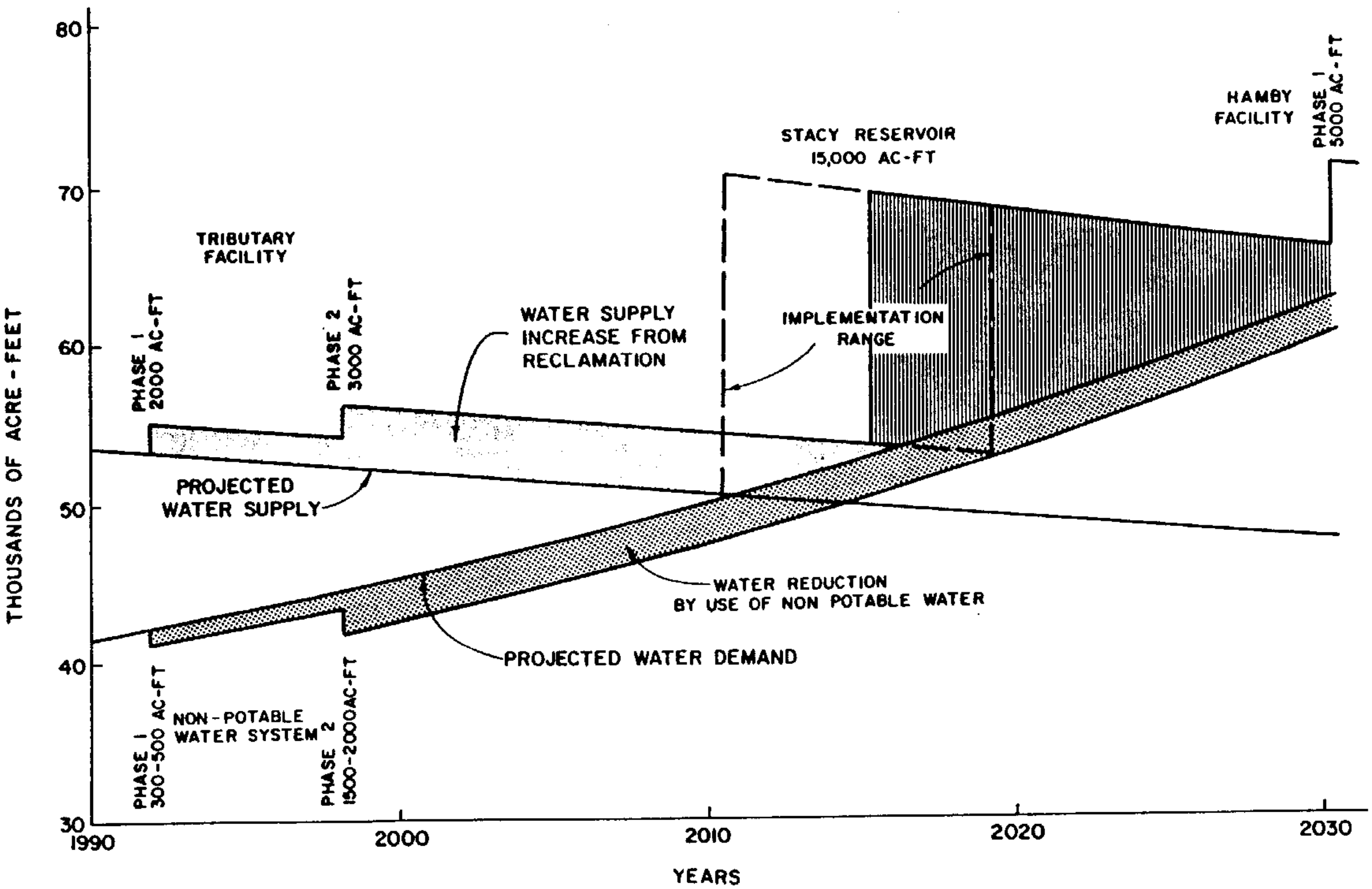
The financing need of this project and its impact on Abilene are presented in TM-10. Abilene presently has numerous water and wastewater projects proposed for implementation. The ability to finance this and other projects is a critical element in any implementation plan.

Water Rights

This study does not evaluate the requirements, or needs related to water rights in water reuse project, both general and specific. However, a specific recommendation was made to the Texas Water Development Board to study the problems associated with water rights on water reuse projects. If Abilene proceeds with implementation of a water reclamation facility, the City should establish its rights to the increased water yield in LFPH. This is a complex problem and appropriate legal and technical representation should be obtained by the City.

Scheduling of Projects

Figure 9.1 is a graphical presentation of West Central Texas Municipal Water District, (Abilene accounts 75-80% of WCTMUD), water supply versus



NOTES:

1. SUPPLY AND DEMAND FIGURE ARE FOR WEST CENTRAL TEXAS TEXAS MUNICIPAL WATER DISTRICT (ABILENE REPRESENTS 75-80% OF TOTAL).
2. PROJECTED WATER DEMAND IS FOR "DRY" YEAR USE APPROXIMATELY. 10% ABOVE NORMAL USE.

FIGURE 9.1

PROPOSED IMPLEMENTATION SEQUENCE

WATER SUPPLY VERSUS WATER DEMAND

FREESE AND NICHOLS, INC.

water demand, for the next forty years. The following assumptions and conditions were used in development of Figure 9.1:

- Projected water demand curve assumes that Abilene's population grows is at 1% rate, other WCTMUD users at zero and/or less than 1%.

- Projected water demand (lower) curve assumes that Abilene water conservation plan is in effect.

- Non-potable water system, phase 2 assumes implementation of a 1.5 - 2.5 mgd system, no present water demand is specifically identified at present for this demand.

- Projected water demand is based on a "dry" year, 10% greater than normal.

The effects of implementation of a tributary Phase 1 and 2 is that water supplies are created for 5-8 years of additional normal historic demand growth in Abilene. The effects of non-potable Phase 1 and 2 is to reduce the water deamnd and therefore provide an additional 4 to 6 years of normal growth in demand without additional water supplies. The combined effect is to provide for water supply or an increased additional 9 to 13 year period of normal Abilene growth.

The need to construct pipelines and pumps stations from Stacy Resrvoir for additional water suppies could be delayed by implementation of either or both of tributary reclamation and/or non-potable projects. The requirements for Stacy water would be in the 2010 to 2020 year period depending on growth factors.

WHY WATER REUSE FOR ABILENE

The comparison between water-reuse projects and new water development projects is not usually limited to only an economic analysis. The comparison or analysis will involve other significant items i.e. public acceptance, environmental concerns, health risks, etc.

Generally, water reuse projects vary greatly in nature and application from turf irrigation to groundwater recharge to surface water augmentation. In recommending any water reuse project it is necessary that a careful analysis of needs (water demand) and supplies be made. This analysis should identify factors which significantly affect the demand and supply, such as, water conservation measures, population growth, etc.

Generally, water reuse projects should be evaluated as alternatives and/or companion projects to the development of new water supplies when some or most of the following conditions exist:

1. Existing surface and ground supplies are near full development.

2. Distant water supply sources are being proposed or developed.

3. Major environmental concerns have been identified in the development of new sources.

4. A water conservation plan has been developed and/or implemented.

5. Major expansions of water and/or wastewater facilities is proposed or needed.

6. Cost of the development of new water supplies is high.

Implementation of water reuse projects should normally be considered in their relative order of greatest public acceptance and cost/benefit. The general order for water reuse projects:

1. Non-Potable Irrigation Systems

   ° Public lands (golf course, parks)
   ° Private lands (lawns)

2. Industrial/Commercial Uses

   ° Cooling water
   ° Process water
   ° Wash/cleaning water

3. Augmentation to Existing Sources (Indirect Potable)

   ° Groundwater recharge
   ° Surface water augmentation

4. Direct Reuse

   ° Washing, bathing
   ° Potable uses

It is recommended by American Water Works Association (AWWA) that reuse project should be considered for all cases <u>except</u> "Direct Reuse".

SPECIFIC ANALYSIS OF ABILENE POTENTIAL AND NEED FOR WATER REUSE

Abilene meets most of the conditions previously identified for when water reuse projects should be considered for development. Abilene has or is:

- Fully developed its nearby surface waters.
- No effective groundwater exist in the area.
- Distance source of supply are being developed; Hubbard and Stacy Reservoirs and/or pipelines.
- Abilene has implemented a water conservation program and drought contingency plan.
- Major expansions are planned for its wastewater treatment facilities.
- Cost of new water is high.

WATER REUSE

The recommended water reuse plan for Abilene utilizes 2 of 3 categories acceptable method of reuse technology.

1. Non-Potable System (Turf Irrigation)
2. Augmentation of Existing Surface Waters, LFPH (Indirect Potable Use)

The option of using reclaimed wastewater for industrial/commercial water user was evaluated, but proved not acceptable due to the location, size and nature of the users, see TM-11.

Abilene should implement the proposed phased program of water reuse, both non-potable and indirect potable, in concert with its development of surface water suppliers because:

- ° Abilene needs water to grow.
- ° Costs for the development of additional water from the tributary water reclamation facility to additional water from Stacy Reservoir are less or comparable.
- ° Marginal costs for the development of additional water supplies in less than 10,000 ac. ft. increments from Stacy Reservoir are significantly higher. Therefore, a capital improvement program may be developed that more closely "tracks" demand at lower incremental costs.

SPECIFIC RECOMMENDATIONS FOR ABILENE

1. Water supply in Lake Fort Phantom Hill can be augmented in an environmental sound and economical manner by using wastewater, as a supply source, if advanced treatment and operational are provided.

2. Abilene should consider designing, constructing, and operating a water reclamation facility for the purpose of augmenting water supply in Lake Fort Phantom Hill.

3. If implemented, Abilene should continue with a water quality monitoring program, possibly with the involvement of local universities, to

provide future assessments in order to evaluate the impact of expansions and/or modifications to the treatment processes.

4. Abilene should continue its program of encouraging public support for water and wastewater improvements. An increase in public information and involvement through continuation of Public Advisory Committee is recommended.

5. Abilene should proceed to acquire the water rights to any increase in water yield of Lake Fort Phantom Hill, due to implementation of this project.

6. Abilene should continue to develop all other conventional water supply sources.

7. Abilene should aggressively pursue all possible financial opportunities.

8. Abilene should implement a non-potable water reuse system. The first phase should be to eliminate the existing and future water demands from golf courses on the potable system. An expanded system of lakes and other uses should be developed as needed and as financing capabilities allows.

9. Abilene should continue with its strong water conservation program to reduce and control future water demand.

SPECIFIC RECOMMENDATION FOR TWDB

1. TWBD should consider the development of a State of Texas Water Reuse Task Force to address the desirability and implementation problem of water reuse systems in the state.

2. TWDB should consider evaluating water reuse projects, both non-potable and indirect potable water project, when the cost of new water supplies exceed $300 - 500 acre-foot.

3. TWBD should continue to provide funding for research and development of water reuse projects.

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 10

EVALUATION OF FINANCING OPTIONS

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INTRODUCTION

Technical Memorandum No. 10 (TM-10) provides a summary and evaluation of the potential funding sources available for the Abilene Water Reclamation Research Project. The basic topics addressed in TM-10 are as follows:

- Federal Financing Options
- State Financing Options
- Local Financing Options
- Evaluation of Financing Options and Recommendations

FEDERAL FINANCING OPTIONS

Recent inquiries were made at the federal level to identify potential sources of funding available for water, wastewater, reuse, and research projects. Two major legislative acts that address water were identified. These are the Clean Water Act (Wastewater), and the Safe Drinking Water Act (Water).

Many projects, with costs totalling hundreds of millions of dollars, have been funded in the past by the federal government under the Clean Water Act Construction Grants Program. Funding for this program has been approved through the year 1990. However, the Texas Water Development Board (TWDB), the managing agency for the program in Texas, plans to phase out the Construction Grants program, replacing it with the State Revolving Fund (SRF), a new program consisting of low interest loans to qualified projects. TWDB is presently establishing guidelines for the new fund under the supervision of the U.S. Environmental Protection Agency (EPA) Region VI. More information on the SRF is provided in following sections.

No funds for construction are available through the Safe Drinking Water Act. However, research projects may be eligible for funding through EPA's Research Division in Cincinnati.

In summary, it appears federal funding is not an option the City of Abilene should realistically consider.

STATE FINANCING OPTIONS

State Revolving Fund (SRF)

The State Revolving Fund Program is still in early development and is only recently capable of funding projects. An off-shoot of the Federal Construction Grants Program, the State Revolving Fund is expected to replace that program completely. At present, the Texas Water Development Board (TWDB) intends to encourage all potential recipients of federal grants under the amended Clean Water Act (PL100-4) to convert to the State Revolving Fund as soon as possible. This means that the Construction Grants Program will probably die a natural death in 1988.

Seed money for this fund will originate from an allocation from the federal grants program during the next few years. Though the program requirements are not yet complete, it appears that the State Revolving Fund will have some of the same project requirements and stipulations currently in place for the Construction Grants Program. Rules covering the requirements of this program have been drafted and will most likely be adopted in the very near future.

Since several projects are currently waiting for funding by the Grants Program, the potential for funding by the SRF program within the next couple of years is minimal. However, projects with a planned lead time of greater than 2 years prior to actual need should consider this program in earnest due to the potential availability of funds and low interest rate.

Other than the bulk of the funds coming from State revenues, the State Revolving Fund differs from the Construction Grants Program primarily in that funding is provided on a low interest loan basis rather than a grant basis. Also, there is no specific incentive for innovative/alternative projects.

The interest rate on these loans has been set at 4 percent. Loans provided by this program will be for 100 percent of eligible project components. Project eligibility will be established during the application process. Other advantages include the establishment of the amount to be loaned, if any, early in the project. Applicant's projects will be prioritized and thereafter funded on a first come, first serve basis.

Texas Water Development Board Policies

The goal of the Texas Water Development Board (TWDB) is to provide financing, where appropriate and in the public interest. An additional goal is the implementation of projects and programs to further orderly development and management of the State's water resources. As directed by the Texas Legislature, the programs are intended to assist eligible political subdivisions unable to implement projects without State assistance, and to further the development of regional wastewater facilities through loans and State participation.

Several funding programs are available to help finance water and wastewater projects including the Water Development Fund; Water, Wastewater and Storage Facility Acquisition Program; and Water Assistance Fund. In general, an applicant seeking assistance must submit information on project design and cost, other potential sources of funding, and bonds being pursued. The funding available for any one project is determined on a project-by-project basis. Funding amounts and maturity on loan repayments are structured to maximize financial resources available to the Board and encourage maximum utilization of any other funding source.

It is the policy of TWDB to finance wastewater projects involving collection systems and treatment facilities. The funding allocation is based on the need and benefit of projects relative to state-wide needs, project compliance with state policies such as regionalization, conservation of water resources, and the applicant's use of all available financial resources to the maximum extent prior to seeking state assistance. Interest rates are based on fair market rates at the time of project bidding. At present, this ranges from 7.8 to 8.0 percent.

Through 1984, the board was authorized to issue up to $600 million in general obligation bonds to finance the Water Development Fund. However, in 1985 new state laws and constitutional amendments approved by Texas voters authorized issuance of up to $980 million in additional bonds to fund the programs. These actions also established the Water Bond Insurance Program for the commitment of up to $250 million in local government bonds.

Under the Water, Wastewater and Storage Facility Acquisition Program, the State may purchase up to 50 percent interest in a reservoir, regional water supply facility and/or regional wastewater collection and treatment facility to allow construction of the reservoir to its optimum size or in the case of regional water and sewer facilities, provide funds for excess capacity. When local needs develop, the State's interest is to be bought back.

In an application several points must be covered. Time estimates for the recovery of the Board's investment and evidence of the project's consistency with the State Water Plant and/or the State Water Quality Management Plan are required. In addition, proof of inability to finance without state participation must be provided, unless the project is a regional system or facility. The City of Abilene wastewater system is considered a regional system since Tye and Impact are served. Therefore this limitation would not be applicable.

In addition to these funds, the board has access to the Water Assistance Fund, established in 1981 to provide loans to local governments for water and wastewater utility and treatment projects as well as storage acquisition, water research, flood control, and regionalization of water and wastewater systems. However, this fund is extremely limited in funding power compared to the Water Development Fund.

Texas Capital Access Program (TEXCAP)

The TEXCAP Program was originated by the Texas Small Business Industrial Development Corporation (TSBIDC) as a source of low-cost funds for public entities in Texas to use in their economic development efforts. The Texas Economic Development Commission (TEDC) is the "governing body" of TSBIDC. Public entities applying for loans to TSBIDC are approved based on their eligibility, their project's eligibility and their credit worthiness.

TSBIDC funds were acquired through a tax-exempt bond sale on July 15, 1986. The 1986 tax reform laws do not affect participants in this program due to the timing of the sale. The amount of money in the acquisition fund is limited by the original bond sale to approximately $660 million. All TEXCAP bond proceeds must be distributed to borrowers prior to July 15, 1989. At present, no loans have been made through this program.

To qualify for this program, an applicant must be a public entity legally eligible to participate, or an entity proposing to lease and/or sell a project to a public entity legally eligible to participate. A minimum debt rating is also required.

A project is eligible if it is located in Texas and is within the power of the eligible public entity to finance. Any project determined by TEDC to be a benefit to economic development is eligible for funding. Development and expansion of sewage facilities are considered eligible projects. However, it is TEXCAP's policy on all water projects to provide funds only when funding from TWDB is unavailable.

The TEXCAP Program provides flexibility regarding the terms of borrowing. In particular, the form of obligation, terms of repayment and variable rate risk may all be selected by the borrower. Although a variable funding interest rate may seem risky, the current rate is approximately 5 1/2 percent for an entity with an A credit rating. Also, the borrower can either refinance the note or terminate the loan on a 30 day notice if it finds more advantageous financing.

In the opinion of some financial advisers, TEXCAP is difficult and costly to access and has many uncertainties, such as the variable interest rate.

The average term of loan is twenty years. While the minimum loan offered is $250,000, no maximum amount is set on the loan for an individual project. Allocation of TEXCAP funds is on a first come, first serve basis.

LOCAL FINANCING OPTIONS

General Fund

The general fund of the City is the "base" of financing for municipal programs, with revenues from a number of sources including property taxes, excise and sales taxes, business licenses and taxes, utility taxes, and fees of several types. It supports wholly or partially those city functions which do not have other sources of funding such as service charges.

City officials have discretionary control of the general fund through the budget process. Identified municipal responsibilities and political realities tend to define how most of these revenues are spent, however. It has historically been difficult for programs which focus on long-term, capital intensive, public facilities construction and maintenance to compete effectively in an annual municipal budget process.

There are few explicit limitations of the use of general fund revenues. They can be spent on both operational and capital expenses, although most often they are used for annual operating costs. Capital outlays which are sometimes paid from the general fund include equipment and land acquisition, but only rarely major construction.

General fund revenues are often relatively susceptible to economic conditions in the community. Sales tax and excise tax receipts drop during a bad economic slump. Property values may decline leading to reduced tax assessments. Property tax delinquencies tend to increase during periods of recession and high interest rates. At the same time, demand for many municipal services (especially police and social services) increases.

In Abilene, general funds are viewed as a low preference means of financing utility construction.

General Obligation Bonding Repaid by Property Taxes

Capital improvements are often too expensive to finance from operating revenues, especially when an activity is funded from the general fund. General obligation bonding is a form of municipal borrowing in which the full credit of the city is pledged to service the bond debt. These bonds require voter approval, and usually involve an excess property tax levy. They have been used for many purposes in the past, though use of them for utility projects has diminished with greater acceptance of revenue bonds.

Because they are backed by the full credit of the local government, general obligation bonds normally receive the most attractive (lowest) interest rates of any municipal borrowing instrument. They can be issued with varying maturities and other provisions which may affect their marketability and the interest rate they must pay.

Revenue Bonding Repaid by Service Charge Revenues

Enterprise funds, such as utilities, which have a source of financing separate from the general fund can borrow money for capital improvements through bonds to be paid off with service charge revenues. These bonds do not require a voted approval, but are usually subject to slightly higher interest rates than general obligation bonds because the full credit of the city is not pledged.

Revenue bonds do not authorize an increase in taxes, nor do they usually authorize a specific increase in utility service charges. If necessary to support the bonds, a rate increase is normally enacted separately. It is possible to use service charge revenues from throughout a service area to repay revenue bonds or to specify that only revenues from one area or even certain properties be used for the bond payments. In most cases, it is best to place few limitations within the bond ordinance which relate to revenue sources, while still being consistent with financing philosophies and local policies. This provides the bondholders with some assurance of payment, and may result in a lower interest rate.

Although typically the bonds are repaid from the regular service charge revenues, municipalities may also establish system development charges, hook-up fees and other financing methods and earmark those funds for repayment of the revenue bonds. This reduces the revenue required from the standard service charge by the amount generated by the special fees and charges, and ensures that developing properties help pay for the project.

Certificate of Obligation with Ad Valorem Tax and Pledge of Surplus Revenue

Since 1979, the preferred means of financing utility construction projects in Abilene has been to acquire Certificate of Obligation (General Obligation Bonds) with an Ad Valorem Tax to obtain favorable interest rates. Since general funds cannot be permanently transferred to a utility fund, the money is loaned to the utility and repaid on a defined schedule. Surplus utility revenues are also pledged to repayment of the Certificates of Obligation to further enhance their ability to attract lower interst rates.

Fees and Charges

Cities have developed a variety of special fees and charges to cover expenses which are associated with permits and other services for individuals. In most cases an identifiable "client" is assessed the fee or special charge, which is often earmarked to support that specific function.

Impact Fees: Impact fees are charges or assessments against new development to fund the cost of capital improvements or facility expansions necessitated by and attributable to the new development. As of June 1987, Texas cities are expressly authorized to assess impact fees for wastewater facilities provided that the fees are directly associated with actual impacts and earmarked to ensure they are used to mitigate those effects. Further, the costs of oversizing facilities constructed prior to adoption of an impact fee ordinance may be recouped through the fees.

Impact fees are perceived as a mechanism to make growth pay it's own way by participating in the cost of new facilities at the front end of a project rather than indirectly through long-term enhancement of the tax base and increased local employment. The new law requires that, prior to adoption of an ordinance establishing impact fees, the City conduct several studies to determine the real impact of new development on the infrastructure. These studies include land use assumptions, establishment of service areas, a capital improvements plan, and an analysis relating the costs of improvements to individual "service units". The statute also prescribes a definitive adoption procedure and requirements for earmarking and accounting, refunds, and assessment and collection of the fees. Prohibitions on the use of fees inlcude "repair, operation or maintenance of existing or new capital improvements" and "administrative and operating costs" of the City.

Impact fees are sometimes confused with the other types of special fees and charges cited in this memorandum. Care should be taken to differentiate between impact fees, which are associated specifically with the impact of a project, and the general need for new facilities to serve the community.

System Development Charges (SDCs): System development charges differ from other similar charges in that they are associated with specific improvements and are often levied on new developments after the improvements are constructed as a means of balancing financial participation. SDCs are intended to enable a community to achieve excess capacity improvements in advance of growth, yet place an equitable portion of the cost on those properties which later develop and make use of the extra capacity that was built into the system.

When revenue bonds (supported by utility service charges) are used to finance capital improvements, SDCs can ensure that all properties equitably participate in the financing of the infrastructure. Major water and sewer improvements are normally sized with future development in mind and have a design life longer than the bond maturity. One purpose of the SDC concept is to ensure that the properties which develop after the bonds are sold also help to pay for the improvements. SDCs should be consistent with the amount paid by developed properties when the improvements were constructed.

The SDC provides a rational financing method which responds to the sensitive issue of who pays for oversizing to accommodate future growth. Care must be taken, however, not to place too much confidence on future growth as a revenue source. If the growth slows or does not occur, the existing developed properties might have to pay a larger service charge in the future to cover the shortfall of the SDC revenue. Unanticipated increases in service charges due to SDC shortfalls can erode a utility's credibility with the public, and should be avoided through conservative projections.

General Facilities Charges: General facilities charges are similar to the SDC concept, although they are more often used for overall improvement to a system, or for maintenance or replacement than for specific capital improvements. This method of financing is most often used when improvements which will benefit an entire service are involved.

The general facilities charge is probably most appropriate when a simplified rate structure is used which lumps operating and capital expense into a uniform system of charges or an "equivalent residential unit" approach. In such cases, the cost of all elements of the program are spread area-wide without a highly refined cost distribution formula.

The underlying philosophy of this approach is that the improvement serves everyone, or the system is viewed as a fairly uniform whole rather than as a number of discrete parts. There is usually no need to break down a general facilities charge into component parts, whereas a system development charge is often associated specifically with revenue bonds for individual improvements, which suggests that much closer accounting practices are justified.

Latecomer's Fees: These charges are especially useful in developing areas or where major reconstruction or upgrading of a water or sewer system is needed, public funds are limited or not available, and a private development is contingent on the improvement. Through a developer extension agreement, the City can allow the developer to construct the improved and oversized facility in conjunction with the project.

Developer extensions are common for water and sewer systems in new developments. The latecomer's fee is usually only used for oversizing costs, for example in the case of sanitary sewer interceptors or to ensure water system fire flow capacity to other properties.

EVALUATION OF FINANCING OPTIONS AND RECOMMENDATIONS

Federal Financing Options

Federal financing is not a realistic option, and thus no funding source at the federal level is recommended.

State Financing Options

Only one of the State of Texas financing options described above are recommended for further consideration by the City of Abilene. The State Revolving Fund accords with the requirements and needs of both the City and the project. Funding from this program will most likely be available in 1988; definitely by the early 1990s, at the time of Abilene's need. Although the funding is provided on a loan rather than a grant basis, the low interest rate of 4 percent is advantageous. Moreover, the loa covers 100 percent of the project cost; thus, local contribution or matching funds are not required.

Local Financing Options

Two of the local level financing options discussed above are recommended for further cnsideration by the City of Abilene. This includes revenue bonds and Certificates of Obligation with Ad Valorem Tax and pledge of revenue surplus.

For large wastewater utilities operated on a self-supporting basis (i.e., service charges), revenue bonds are a frequently used financing technique. The significant advantage of revenue bonds is that they are not a drain on the general municipal tax base. Another advantage is their potential use in financing projects extending beyond normal municipal boundaries. The bonds may be pledged against the collection of service charges in any legitimate and ongoing area of operation, in or out of the geographical limits of the borrower. Revenue bonds do not count against a city's direct debt, and are not considered overlapping debt. This can be a crucial advantage for a community near its debt limit or for the rating agencies, which consider very closely the amount of direct debt when assigning credit ratings.

The second recommendation, Certificates of Obligation with monies loaned to the utility fund is consistent with the pay as you go philosophy of revenue bonds but has the advantage of lower interest rates. Historically, where the voters have approved Certificates of Obligation for use in this fashion, as in Abilene, it is the preferred means of financing.

SUMMARY

State Revolving Fund loans, revenue bonds, and/or Certificate of Obligation funds loaned to a utility are the recommended means of financing water reclamation projects for Abilene. It is likely that a combination of thee funding sources would be involved in implementing the recommended project. For instance, some of the turf irrigation water reclamation recommendations primarily benefit specific entities. It would be appropriate that these entities assist in financing those projects, while the remaining projects would be financed through more conventional means.

ABILENE WATER RECLAMATION RESEARCH PROJECT
Technical Memorandum No. 11

NON-POTABLE WATER SYSTEM

Principal Authors: David Lewis, P.E.
Raymond R. Longoria, P.E.

INTRODUCTION

This Technical Memorandum (TM) investigates the possibility of a non-potable water system for turf irrigation to reduce drinking water demands. Different alternatives are evaluated, including the use of reclaimed waste-water and Lake Kirby surface water. A phase program and cost estimates are developed for implementation.

OBJECTIVES AND GOALS

The primary objective is to develop a nonpotable water system to provide safe water for uses other than potable uses, i.e., turf irrigation, at a cost less than potable water. Therefore, to induce the water user to conserve the potable water supply source. If this objective is successful, then the goal of a reduction in potable water demand will be achieved and the need for additional new potable water supplies may be delayed.

A nonpotable system must meet several specific goals:

- Acceptable water quality
- Costs below potable water
- Availability of water to potential users

It is necessary that this water meet standards in excess of that normally required for discharge directly to a stream. This is because of the health effect related to contact with reclaimed wastewater. In addition, the water must not be deleterious to the customers intended uses and safe for human contact. A later section of this TM discusses the health aspects and water quality goals in greater detail. The costs must be sufficiently lower than potable water costs to justify its use and encourage a customer to change water supplies. These costs must include any treatment, operations, and distribution costs. A separate costs base may be required in implementing a nonpotable system. Separate contractual relationships may be needed with each user.

The availability of the nonpotable water was restricted to control access areas, i.e., parks, airports, etc. during this initial investigation phase. The TWC and TDH presently prohibit reclaimed wastewater application on noncontrol areas, i.e., private lawns. A proposed transmission and distribution system was developed for delivering the nonpotable water to each potential identified client.

IDENTIFICATION OF NON-POTABLE WATER DEMAND

Existing Non-Potable Water Systems

Presently, two non-potable water systems are operated in the City of Abilene. One system uses surface water from Lake Kirby for turf irrigation of three golf courses on the southside of the City. The second system uses reclaimed wastewater from the City's Hamby Wastewater Treatment Plant (WWTP) for agricultural crop irrigation on the northside of the City. The golf course turf irrigation system is privately owned and operated. The agricultural crop system is operated by the City on a contractual basis with local area farmers.

The turf irrigation system uses untreated Lake Kirby water, pumped directly to each golf course for distribution. Lake Kirby total water yield in normal rainfall years, is relatively small, less than 1,000 ac-ft.

per year. However, this system has alleviated the need for providing approximately 300 million gallons per year of potable water for turf irrigation to the golf courses. Specifically about 275,000 gallons per day on average and 500,000 gallons per day of peak demand per golf course. This is the equivalent water demand of more than 1,000 homes in Abilene.

The basic problem with the existing golf course turf irrigation system is the water quality. Lake Kirby's water contains a high concentration of colloidal clays (non-settleable particles). This clay coats the grass and over time builds a surface hard pan in the soils. This increases maintenance and affects play. The problem has not advanced to the point where existing management practices cannot cope with the difficulties caused by the poor water quality. The City has been approached on an informal basis to address the operations of the existing system.

The agricultural crop irrigation system using Hamby WWTP effluent provides an important source of water for local farmers but is primarily a disposal system and does not directly effect the potable water system demand. Therefore, it was eliminated from further consideration.

A non-potable waterline which transports raw Lake Fort Phantom Hill water to the Grimes Water Treatment Plant (WTP) exists. It could be used as a source of non-potable for an area on the northeast and southeast sides of the City. However, its use would reduce the capacity of the waterline to Grimes WTP and directly reduce the availability of water from Lake Fort Phantom Hill. Therefore, alternatives using this waterline were eliminated from further study.

The only available effective existing non-potable water system which could effect the potable water system by reducing present or future water demand is Lake Kirby's golf course turf irrigation system. This system could be upgraded by construction of a non-potable WTP to improve the water quality.

The non-potable WTP envisioned would provide only limited treatment, sufficient only to meet the needs of turf irrigation and health considerations. This WTP could consist of coagulation, limited flocculation, and settling.

This upgraded system would eliminate the possible future need of potable water supplies for the existing golf courses in the area. The water yield of Lake Kirby is relatively small, therefore expansion of the system without additional supplies is limited.

The upgraded system's water supply could be augmented by construction of a non-potable waterline from the proposed Westside WWTP. This would allow for the transfer of non-potable water from the westside of the City through the southwest, south, southeast, east, and northeast portions of the City. The two systems could possibly support and compliment each other.

Identification of Existing and Future Non-Potable Demands

Lake Kirby represents the only surface water supply source available for non-potable water uses which does not effect existing potable water supply sources. However, it is assumed that this source will continue to be totally committed for golf course irrigation.

Groundwater exists in small quantities and at varying degrees of quality throughout the Abilene area. Past studies have evaluated its possible use and have concluded it is impractical on a large-scale basis for Abilene. A review of the existing needs and data indicates groundwater as a supply of either a non-potable or potable water is not practical. Therefore, groundwater as a possible source of supply was eliminated from further consideration.

Reclaimed wastewater is available as a source of supply for non-potable water. It is assumed permits could be obtained and both the proposed water reclamation WWTP and Hamby WWTP effluents are available as a source of supply. The identification of demands are limited to those uses compatible with reclaimed wastewater.

Five areas of possible demands and/or uses for non-potable water investigated were:

- Agricultural
- Industrial and Commercial
- Recharge of Existing Sources
- Turf and Landscape Irrigation
- Aesthetic

Agricultural demand exists throughout the surrounding Abilene area. A portion of the existing Hamby WWTP effluent is presently used for crop irrigation on a contractual basis with local farmers. This portion of the effluent has declined in recent years, mainly due to climatological conditions. It is envisioned that a portion of the Hamby WWTP effluent will continue to be used for crop irrigation for many years. The agricultural demand at the Hamby WWTP will not reduce existing or future potable water demand. The proposed water reclamation WWTP also is not expected to have a long-term agricultural demand.

Industrial and commercial potable water users were evaluated for possible future demands of non-potable water. The twenty largest water users in Abilene are identified in Table 11-1. These water users vary in average water demand from 4,000 to 700,000 gallons per day, with only six greater

Table 11-1

Average Annual Industrial and Commercial Water Flows
City of Abilene, Texas

Industry	Demand (gal/day)
Texas Instruments	40,083
Victor Equipment	13,110
Humana Hospital	41,008
Baird Bakeries	12,252
State School	136,081
ACCO (Mill & Ref.)	18,134
Martin Linen	13,742
Gooch Packing	210,820
Abilene Linen	23,028
Coca-Cola	19,781
U.S. Brass	101,241
Hendrick's Hospital	94,596
Crown Cork & Seal	211,129
Abtex	34,321
General Dynamics	232,734
Borden's Milk	12,603
Dyess AFB	699,233
Martin Sprockett	4,159
Bandag, Inc.	18,162
Band Instrument Plating	20,501
	1,956,718

than 100,000 gallons per day. A review of the type of water use and SIC codes reveals that most are food processors, schools, and metal plating industries. The geographic distribution of the potential user is not favorable for reuse of wastewater as major distribution lines would be required. Only one potential user was identified, Dyess Air Force Base (AFB). Further analysis of Dyess AFB water demand indicates that a major portion is used for golf course irrigation which will be addressed later as turf irrigation. The remaining portion is used for domestic needs and as washdown water. The washdown portion is normally compatible with reclaimed wastewater, however, separate distribution system would be required at Dyess AFB. Due to the relatively small quantity and the special needs of one user no further detail investigation will be made. If a turf irrigation system is installed, then Dyess AFB may wish to consider an internal dual distribution system. No major industrial or commercial demand exist for non-potable water.

Recharging existing source is possible and is addressed in detail in TM-9 for Lake Fort Phantom Hill. Other source are too distant to be considered at this time.

Turf and landscape irrigation can reduce potable water demand in the Abilene area. On a seasonal basis, Dyess AFB golf course uses between 200,000 and 500,000 gallons per day of potable water. Water from the water reclamation WWTP could be used to replace this higher quality water at minimum cost. This is addressed in greater detail later in this technical memorandum. Table 11-2 identifies existing and future non-potable water demand for public turf irrigation needs in Abilene.

Aesthetic demands for water exists throughout Abilene. The demand for water vistas and fountains in an urban semi-desert environment is always present, provided it can be done at a reasonable cost. The development of detail plans for this type of uses are beyond the scope of this study.

Table 11-2

Potential Future Users of Non-Potable Water

	Approximate Possible Users	Seasonal Average Day Flow (gpd)
1.	Abilene Christian University	300,000
2.	Abilene Zoo/Park	300,000
3.	Future 18-Hole Golf Course	275,000
4.	Parks/Greenbelts on Catclaw Creek	200,000
5.	Parks/Greenbelts on Upper Elm/Kirby (200,000 gpd each)	400,000
6.	Northeast Golf Course	275,000
7.	Unknown Future and Existing Sources	500,000
	Total of Future Potential User Demand	1,750,000 - 2,250,000

However, the basic infrastructure is identified later in this technical memorandum.

ALTERNATIVES AND COSTS

Three potential sources of non-potable irrigation waters were identified to meet the current and future demands. This included (1) surface water from Lake Kirby with treatment provided to remove turbidity/colloidal particles, (2) pump treated effluent from Hamby WWTP to meet demands and (3) pump treated effluent from the proposed water reclamation WWTP to meet the demands.

Alternative 1

The Lake Kirby alternative follows logically from the current practice, in which three of the existing four golf courses are irrigated with this lake water. The three are the Municipal, the Abilene County Club and Fairway Oaks golf courses. The fourth golf course is at Dyess AFB and currently uses potable water for irrigation.

The quality of the water would need to be improved to address the concerns of the golf course grounds keepers. The water has a high colloidal clay concentration which tends to blind the greens detracting from appearance, hardening the ground, decreasing irrigation efficiency, and affecting play.

Inorganic colloidal particles in water typically are removed by coagulation/sedimentation. Under this alternative, it is proposed that a solids contact basin be constructed at the Lake Kirby site. Modified design criteria would be utilized since drinking water requirements are not applicable. Chemical coagulants would be introduced in a rapid mix chamber then directed into the basin. Chlorination facilities would be provided for algal control, if necessary. Transmission of the treated water supply to Abilene Country Club, Fairway Oaks and Abilene Municipal golf courses would continue as currently practiced. Pump and piping facilities to convey the treated surface water to the Dyess AFB golf course would have to be constructed.

Although Lake Kirby meets the water requirements of three of the existing golf courses it is uncertain if the water quantity requirements of all four can be met, and doubtful that the additional future demands given in Table 11.2 can be met. Since this alternative cannot meet the demand requirements on its own, it will be considered only in combination with the other two alternatives.

Alternative 2

Effluent from wastewater treatment plants treating to secondary effluent quality is commonly used to irrigate parks and golf courses. The effluent from the existing City of Abilene 13.4 mgd (Hamby WWTP) meets this standard.

Specific disinfection requirements for these effluents are related to the level of access control practiced at the receiving end. Parks typically have little access control. The municipal and private golf course have some level of access control but it is not fully controlled. The Dyess AFB golf course has greater control over access. Accordingly, any wastewater effluent discharged to parks should have stricter disinfection requirements than turf irrigation water for the Dyess golf course. Current requirements would allow effluent from Hamby, at existing disinfection abilities to be applied. However, the TWD has produced "draft" design criteria that are more strict and would require increased disinfection ability. This is discussed in more detail in the Water Quality Requirements section of this technical memorandum.

The City of Abilene is obligated to return a minimum of 40 percent of the water drawn from it surface water supply sources back to the Brazos River Basin. With this quantity accounted for, sufficient effluent is still discharged to meet the water quantity requirements of the golf courses and the projected future needs identified in Table 11-2.

Under this alternative, it is proposed that pumping equipment and a transmission line would be constructed to convey the effluent to the golf courses and other non-potable user sites. Additional treatment will be required to produce water compatible with the anticipated future disinfection requirements.

The Hamby WWTP is at the extreme northeast portion of Abilene while the golf courses are in southern Abilene. Pump and piping facilities to transport the effluent to the golf courses would be substantial. Figure 11-1 delineates the proposed improvements.

Alternative 3

Under a separate study, a new 3 mgd Westside WWTP has been proposed. To allow cost estimates to be prepared, a site consistent with the Westside WWTP recommendation was adopted. Location of the water reclamation facility at a different location on the stream on a separate tributry to Lake Fort Phantom Hill would have comparable results. The general site of the proposed Westside facility is in western Abilene, north of Dyess AFB and would collect and treat wastewater from south and southwest Abilene. The effluent quality would meet or exceed secondary effluent quality and would be suitable for use for golf course irrigation even under the draft changes proposed for disinfection. Under this alternative it is proposed that effluent would be pumped to the various non-potable user sites. This system is shown in Figure 11-2.

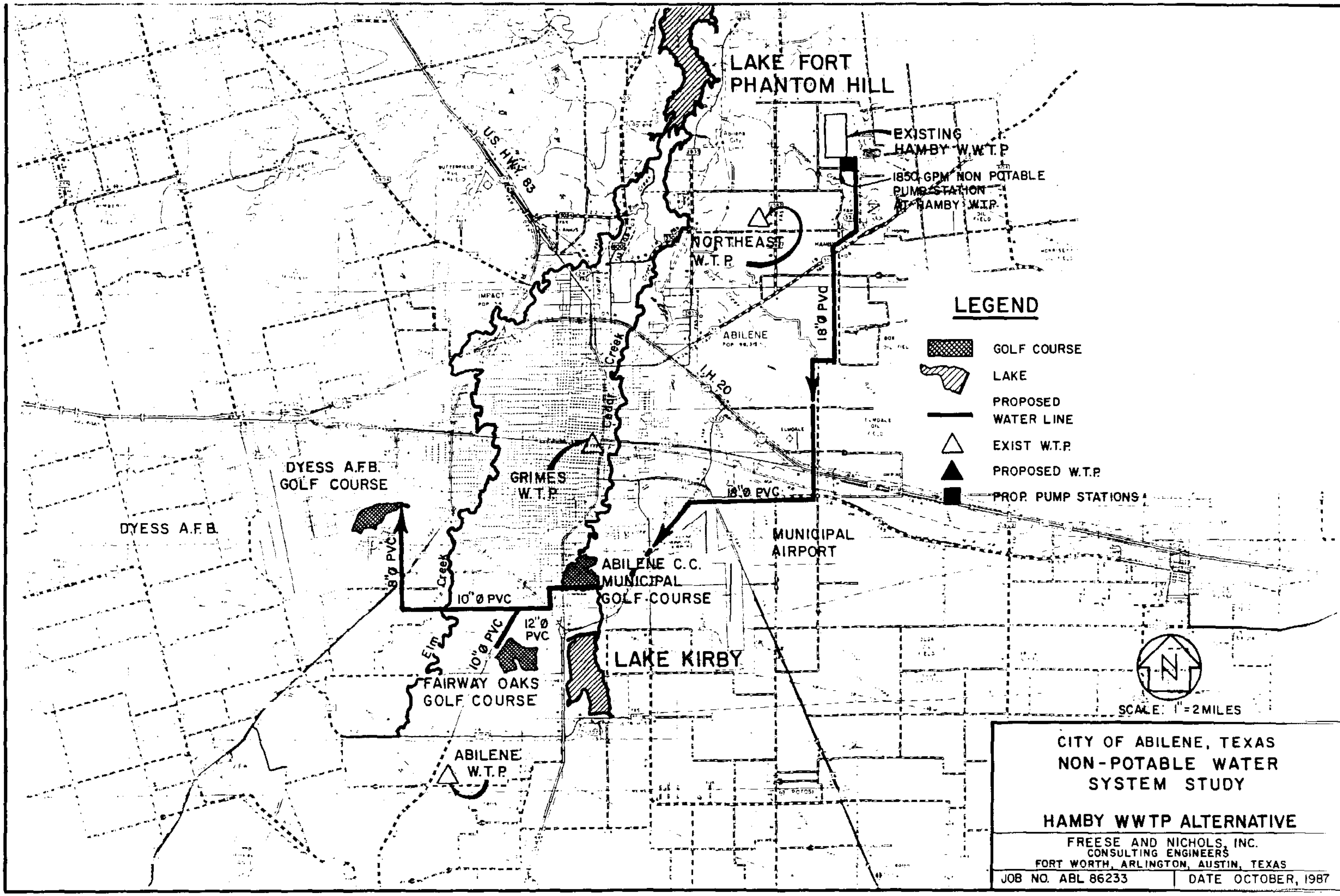
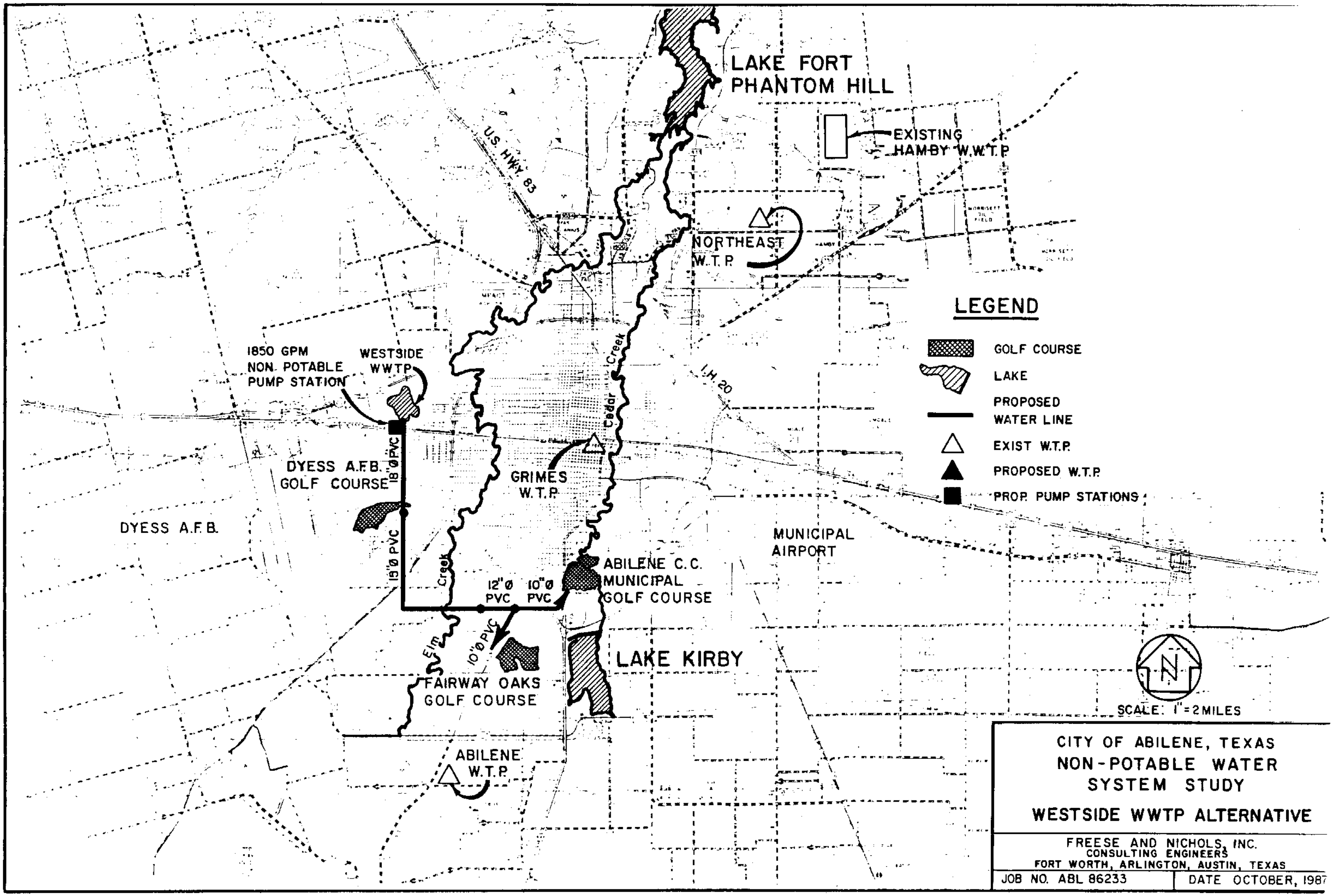

LAKE FORT
PHANTOM HILL
EXISTING
HAMBY W.W.T.P
1850 GPM NON POTABLE
PUMP STATION
AT HAMBY W.T.P
U.S. HWY. 83
NORTHEAST
W.T.P
18"Ø PVC
LEGEND
GOLF COURSE
LAKE
PROPOSED
WATER LINE
EXIST W.T.P.
PROPOSED W.T.P.
PROP. PUMP STATIONS
ABILENE
I.H. 20
Cedar Creek
GRIMES
W.T.P
DYESS A.F.B.
GOLF COURSE
DYESS A.F.B.
18"Ø PVC
MUNICIPAL
AIRPORT
8"Ø PVC
Creek
10"Ø PVC
ABILENE C.C.
MUNICIPAL
GOLF COURSE
12"Ø
PVC
10"Ø PVC
Elm
LAKE KIRBY
FAIRWAY OAKS
GOLF COURSE
ABILENE
W.T.P
N
SCALE: 1"=2 MILES
CITY OF ABILENE, TEXAS
NON-POTABLE WATER
SYSTEM STUDY
HAMBY WWTP ALTERNATIVE
FREESE AND NICHOLS, INC.
CONSULTING ENGINEERS
FORT WORTH, ARLINGTON, AUSTIN, TEXAS
JOB NO. ABL 86233
DATE OCTOBER, 1987

FIGURE 11.1



LAKE FORT PHANTOM HILL
EXISTING HAMBY W.W.T.P.
U.S. HWY. 83
NORTHEAST W.T.P.
LEGEND
GOLF COURSE
LAKE
PROPOSED WATER LINE
EXIST W.T.P.
PROPOSED W.T.P.
PROP. PUMP STATIONS
1850 GPM NON. POTABLE PUMP STATION
WESTSIDE WWTP
Cedar Creek
I.H. 20
18"Ø PVC
DYESS A.F.B. GOLF COURSE
GRIMES W.T.P.
DYESS A.F.B.
MUNICIPAL AIRPORT
15"Ø PVC
Creek
12"Ø PVC
10"Ø PVC
ABILENE C.C. MUNICIPAL GOLF COURSE
10"Ø PVC
Elm
LAKE KIRBY
FAIRWAY OAKS GOLF COURSE
ABILENE W.T.P.
SCALE: 1"=2 MILES
CITY OF ABILENE, TEXAS
NON-POTABLE WATER SYSTEM STUDY
WESTSIDE WWTP ALTERNATIVE
FREESE AND NICHOLS, INC.
CONSULTING ENGINEERS
FORT WORTH, ARLINGTON, AUSTIN, TEXAS
JOB NO. ABL 86233
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FIGURE 11

Alternative Evaluation

From preliminary screening of the alternatives it was clear that Alternative 2 (pumping from Hamby WWTP) differed little from Alternative 3, (pumping from Westside WWTP) except for cost. Clearly, pumping from Hamby would be more costly because of the greater distance and elevation rise to the non-potable user sites and capital improvements cost necessary for upgrading the disinfection ability at the Hamby WWTP. Alternative 2 was dropped from further consideration.

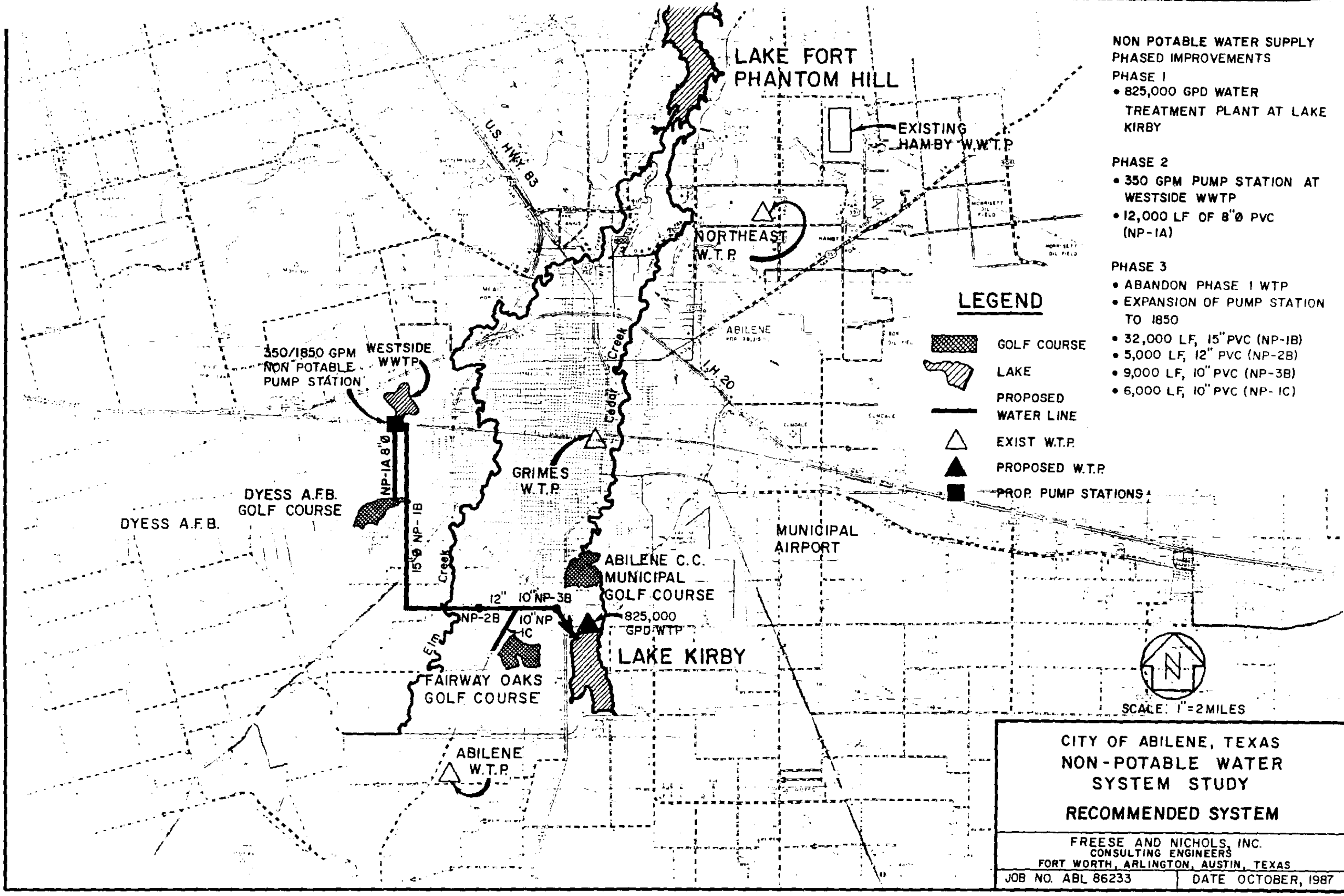
It is also appeared that a combination of the remaining two alternatives formed a logical solution to the irrigation needs.

Since three of the golf courses are currently being irrigated from Lake Kirby, a continuation of this practice with coagulation/sedimentation treatment added would offer an economical approach to satisfy those water demands. It is assumed the water quantity available for the three course would be adequate since it is currently supplying those demands. To meet the demands of the fourth golf course and potential future demands an additional supply is necessary. It is proposed the effluent from the Westside WWTP would be used to supply the irrigation needs of the Dyess AFB golf course and the potential future non-potable water users in southwest Abilene. This system is shown in Figure 11-3.

Opinion of Estimated Construction Costs

A summary of the estimated construction and operation costs are given on Table 11-3.

The opinion of estimated construction cost for the 825,000 gpd Lake Kirby WTP is $350,000. Including the estimated operations and maintenance cost the unit cost for these improvements is $0.30/1000 gallon. This would be in addition to the pumping costs for the current system.



LAKE FORT PHANTOM HILL
EXISTING HAMBY W.W.T.P.
U.S. HWY 83
NORTHEAST W.T.P.
ABILENE
I.H. 20
350/1850 GPM NON POTABLE PUMP STATION
WESTSIDE WWTP
NP-1A 8"Ø
15"Ø NP-1B
DYESS A.F.B. GOLF COURSE
DYESS A.F.B.
GRIMES W.T.P.
Cedar Creek
Creek
MUNICIPAL AIRPORT
ABILENE C.C.
MUNICIPAL GOLF COURSE
12"
10"NP-3B
NP-2B
10"NP 1C
825,000 GPD WTP
LAKE KIRBY
Elm
FAIRWAY OAKS GOLF COURSE
ABILENE W.T.P.
NON POTABLE WATER SUPPLY PHASED IMPROVEMENTS
PHASE 1
• 825,000 GPD WATER TREATMENT PLANT AT LAKE KIRBY
PHASE 2
• 350 GPM PUMP STATION AT WESTSIDE WWTP
• 12,000 LF OF 8"Ø PVC (NP-1A)
PHASE 3
• ABANDON PHASE 1 WTP
• EXPANSION OF PUMP STATION TO 1850
• 32,000 LF, 15" PVC (NP-1B)
• 5,000 LF, 12" PVC (NP-2B)
• 9,000 LF, 10" PVC (NP-3B)
• 6,000 LF, 10" PVC (NP-1C)
LEGEND
GOLF COURSE
LAKE
PROPOSED WATER LINE
EXIST W.T.P.
PROPOSED W.T.P.
PROP. PUMP STATIONS
N
SCALE: 1"=2 MILES
CITY OF ABILENE, TEXAS
NON-POTABLE WATER SYSTEM STUDY
RECOMMENDED SYSTEM
FREESE AND NICHOLS, INC.
CONSULTING ENGINEERS
FORT WORTH, ARLINGTON, AUSTIN, TEXAS
JOB NO. ABL 86233
DATE OCTOBER, 1987

FIGURE 11.3

Table 11.3

Estimated Opinion of Probable Construction and O&M Cost for Using Westside WWTP Effluent to Irrigate Dyess AFB Golf Course

		Construction[1]	Annual[2] O&M	Cost/[3] 1000 Gallon
Phase 1				
825,000 gpd Modified Water Treatment Plant[4]		$ 350,000	$43,000	$0.30
Phase 2				
Westside Pump Station (350 gpm)		36,000	$ 3,100	-
Westside Non-Potable Line	NP-1A (12,000 LF, 6" PVC)	184,000	-	-
TOTAL		$ 220,000	$ 3,100	$0.25
Phase 3				
Expand Westside Pump Station (1850 gpm)		$ 75,000	$17,600	-
Non-Potable Line	NP-1B (32,000 LF, 15" PVC)	1,000,000	-	-
	NP-2B (5,000 LF, 12" PVC)	130,000	-	-
	NP-3B (9,000 LF, 10" PVC)	220,000	-	-
	NP-1C (6,000 LF, 10" PVC)	150,000	-	-
TOTAL		$1,600,000	$17,600	$0.37

[1]Exclusive of land and right-of-way costs. Includes 20 percent contingency.
[2]Addition of alum only at WTP, power cost at $0.06/KWH.
[3](A/P, 30, 8%) for equivalent annual construction cost. Cost per thousand based on cumulative non-potable system improvements.
[4]WTP only. Assumes existing distribution system operation continues.

An opinion of the estimated construction cost for providing the 275,000 gpd (500,000 gpd - peak) of non-potable irrigation water to the Dyess AFB is $220,000 or $0.25/1,000 gallon with the operations and maintenance cost included.

The Dyess irrigation estimate include only the cost for the conveyance, as the Westside WWTP would be required regardless of the non-potable issues.

In determining an acceptable means of irrigation, the golf course operators would need to evaluate which total cost would be less between the following:

1. Use untreated Lake Kirby water and accept the additional turf maintenance cost associated with the colloidal clay component, or;

2. Use treated Lake Kirby water, or;

3. Use potable drinking water.

RECOMMENDATIONS

The recommended actions for implementation of a large-scale gray water system for Abilene center around the existing Lake Kirby system and the proposed water reclamation WWTP. Staged improvements are proposed. The initial phase involves construction of an 825,000 gpd modified water treatment plant at Lake Kirby at an estimated construction cost of $350,000. The treatment facility would operate in conjunction with the existing pumping station to serve Abilene Country Club, Fairway Oaks and the Municipal

Golf Courses. The additional cost for the treatment will be approximately 30 cents/1,000 gallons.

The second phase would be tied to the schedule for the water reclamation WWTP. Pumping facilities and a pipeline to transport treated effluent to the Dyess AFB Golf Course would be constructed at the time of construction of the plant. The pump station would be sized for an initial peak flow of 500,000 gpd (350 gpm) to meet the needs of the Dyess AFB Golf Course. An opinion of the estimated construction cost for the 350 gpm pump station and approximately 12,000 feet of 6-inch non-potable water line is $220,000.

The annual cost for this system including pumping is estimated at $25,000/year or approximately $0.25/1,000 gallons.

The final phase would involve expansion of the pump station to 2,000 gpm and extension of the non-potable water line to Lake Kirby. The expanded system would provide non-potable water for all of the golf courses, feed water for greenbelt/parks along Catclaw Creek, and provide additional supply to Lake Kirby as well as other industrial and/or irrigation needs along its route. The Lake Kirby WTP would be abandoned at this time. The inflow to Lake Kirby would be sufficient to supply the nonpotable water needs downstream of the spillway. The cost for this phase of improvement is estimated at $1,600,000 and will supply up to 2,650,000 gpd of non-potable water supply.

WATER QUALITY REQUIREMENTS

The TWC "draft" design criteria for the disinfection of reclaimed wastewater to be used for irrigation is shown below:

(b) "Disinfection ...

(4) Chlorination of effluent used for irrigation of controlled public access areas: Irrigation of controlled public access areas requires a disinfected secondary effluent having a maximum BOD of 20 mg/L, a maximum suspended solids level of 15 mg/L, and a fecal coliform limit of 100/100 ml. The effluent must be disinfected sufficiently so as to produce a combined chlorine residual of 1.0 mg/L after 15 minutes of contact at maximum daily flow or after 30 minutes contact time at average flow.

Reclaimed waste water used to irrigate controlled public access areas that abut residential property should be free of fecal coliforms and pathogens.* Irrigation of landscaped areas that have uncontrolled access, such as parks and playgrounds, is not allowed.

* Emphasis added.

(c) Other Means of Disinfection

(1) Disinfection techniques not in widespread use, such as ozonation, bromime chloride chlorine dioxide, will be considered for approval on a case-by-case basis. Full details of application, operation, and maintenance; results of pilot and developmental studies; and the effects on the receiving stream and aquatic life shall be furnished to the reviewing authority by the designing engineer for each proposal.

Discussions with TWC and the authors of this section have provided conflicting approaches to problem of disinfection. The interpretation of phase "free of fecal coliform and pathogens" seems to provide the greatest conflict. Dr. Robert Sweag of Texas Tech, the original author, stated that it was his intent that free was not to mean absolute zero, and that pathogens referred to pathogenic bacteria only. Staff at TWC have advised that the second paragraph could be interpreted in its extreme as a prohibition on irrigation of these type of lands, if free is interpreted as zero. Zero is not an achievable number. Pathogens is defined by TWC as disease causing microorganisms, including viruses, etc.

We should recognize that the present TWC standards are under revision at this time. The present standards might be interpreted as you can swim in water at 200 counts/100 ml, walk on it at 100 counts/100 ml and live near it at zero or close too. However, we should expect that this conflict will be corrected in the future.

A review of other states standards indicates a similar conflict. The current and past procedure in many states have been to collate disinfection to chlorination, which address primarily bacterial disinfection. Several states have in recent years adopted more specific standards for both treatment criteria and performance for disinfection. The most notable of these are the California Title 22 standards adopted in 1976. Since then, several other states have adopted similar standards. It is unknown if Texas will or will not adopt similar specific disinfection standards rather than chlorination design criteria.

The Title 22 standards require the coagulation and filtration of secondary treatment effluent. The purpose of requiring these unit processes in front of disinfection is to remove particulate matter, which contains and protects many microorganisms from disinfection by the normal chlorination process. The Title 22 fecal coliform standard is 2.3 counts/100 ml on average.

A review of epidemiology studies of this issue indicates that the health risk for this type of application is not well defined below a fecal coliform level of 200 counts/100 ml. Several studies by V. J. Cabelli on the health effects in fresh recreational waters indicates that fecal coliforms are a poor indicator organisms and the E. coli or enterric coli are more predictive. Only limited work has been performed on virus and parasitic organisms to determine acceptable exposure levels. It is this lack of information that has caused many states to adopt a low fecal coliform limit with requirements for particulate removal. It is generally accepted that if clear effluent (less than 2 NTU) is provided prior to disinfection then removal rate for viruses and parasitic organisms is greatly increased.

Phase 1 would not be subject to these standards since no wastewater effluent is involved. For Phase II, which involves only the Dyess AFG golf course it is recommended an interim standard of 100 f. coliform/100 ml be adopted. For implementation of the Phase III, when the Westside effluent is tied into the entire system, it is recommended that a standard similar to California Title 22 be used as a guide and that the nonpotable discharge meet these minimum standards:

Secondary treatment

<2.2 coliforms/100 ml
<23 coliforms/100 ml max on any sample during a 30 day period
<2 NTU

In addition, nutrient control to prevent algae growth in receiving ponds may be required by the customer.