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ANALYSIS OF AQUATIC PLANT AND NUTRIENT CONDITIONS IN LAKE DUNLAP

Texas Clean Rivers Program
Guadalupe-Blanco River Authority
with
Espey, Huston & Associates, Inc.

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EXECUTIVE SUMMARY

ANALYSIS OF AQUATIC PLANT AND NUTRIENT CONDITIONS IN LAKE DUNLAP

Lake Dunlap has a history of nuisance plant problems, most of which are associated with aquatic macroscopic plants called macrophytes. A moderate amount of macrophytes are desirable as fish habitat, but high densities can restrict boating and other uses. Several ways to control macrophytes in Lake Dunlap have been used including chemical (herbicides), and biological (grass carp and water lettuce weevils). Also, mechanical cutting has been used in nearby areas and is being considered again. Another method that has been considered in the past and discussed recently is restricting the concentration of nutrients, primarily phosphorus from domestic wastewater. The main focus of this study is on the nutrient control alternative, but the other methods are considered in parallel. This study is part of the Texas Clean Rivers Program (CRP), operated by the Guadalupe-Blanco River Authority (GBRA).

A conclusion of previous studies is that where nutrients exert a limiting effect on aquatic plant growth, the nutrient most likely to be limiting is phosphorus (P). The main reason is that nitrogen, particularly nitrate-N, exists in relatively high concentration (about 1 mg/L as N) in Comal Springs, a major source of water to Lake Dunlap, while P tends to be relatively low, on the order of 0.01 mg/L or less. While P is most often in relatively low supply, there is still enough P in Comal Springs to support extensive plant growth. Also, while P generally is the nutrient that is least available, relatively high P concentrations exist in Canyon Lake releases during the summer. Under those conditions there can be an excess of all nutrients and it cannot be said that P will necessarily be limiting.

New Braunfels Utilities (NBU) operates three wastewater treatment plants that discharge to the system; the South and North Kuehler plants together discharge 3 to 4 million gallons per day (mgd) on average, and the much smaller Gruene plant. The GBRA operates the relatively small Lake Dunlap plant. Presently, none of these plants are designed to remove P from the effluent. During times when the river flow is low, the treatment plants can contribute a significant percentage of the system P concentration. For example, with a river flow of 300 cubic feet per second (cfs) and a combined background concentration of 0.01 mg/L of total-P, the combined effluent of about 5 cfs with a total-P of 5 mg/L constitutes less than 2% of the flow but over eight times the background P load. Under these circumstances the effluent can have a significant effect on the lake P concentration. However, when the background P concentration is higher, as it often is, or the flow larger, the relative impact of the point sources on lake P concentration can be markedly less.

To estimate the effect of reducing the point source P load, numerical modeling work done during the late 1970s was revisited. Using model coefficients and background data that are more representative of current conditions, our study found that reducing point source P concentrations down to 0.5 mg/L, which is about as low as technically achievable with tertiary treatment, would reduce the peak chlorophyll a concentration (a measure of microscopic algae that floats with the water) as much as 60%. This reduction is sensitive to the coefficients employed that have a substantial margin of error, and the reduction percentage would be less if river flows were higher. This analysis must be viewed as a preliminary estimate with much room for uncertainty.

However, this analysis deals only with plankton (chlorophyll a) and does not address rooted macrophytes such as hydrilla. The original study in the 1970s did address macrophytes, but had little in the way of calibration data to support the values presented. Furthermore, the study did not consider the sediments as a source of nutrients for macrophytes. The hydroelectric lakes were built between the years 1928 and 1932. Canyon Reservoir, located upstream from the chain of hydroelectric lakes, traps sediment during high flows, but did not begin to impound water until 1964. During the intervening years, Lake Dunlap accumulated an abundance of nutrient laden sediment. Rooted macrophytes such as hydrilla have the ability to derive needed nutrients from the sediment, which means that reductions in the water concentration of nutrients may have relatively little effect on macrophyte growth. Barber (1991) reached exactly the same conclusion in a macrophyte modeling study on the Colorado River below the City of Austin.

If biological nutrient removal (BNR) were required for all four of the domestic treatment plants discharging to Lake Dunlap, the average annual cost would be in the range of $300,000 to $500,000. While nutrient removal effects would extend to the lakes below Dunlap to a degree, this is substantially more expensive than the other control mechanisms that are currently used. For example, a continuation of the current program of herbicide treatments on the hydro lakes is estimated to cost about $180,000 per year, periodic restocking with sterile grass carp about $15,000 per year and mechanical cutting about $60,000 to $100,000 per year. All of these cost estimates are based on recent history and can be expected to vary substantially year-to-year.

Since the effect of point source nutrient removal on rooted macrophyte levels is likely to be relatively small, BNR does not appear to be the preferred alternative from an economic perspective. However, it is frequently difficult to capture all nuances of a public issue in a financial balance sheet. All of the other less costly alternatives have some negative aspects which must be considered in the balancing and decisionmaking process. Where reductions in the point source nutrient load can be made in a cost-effective manner, they are desirable. Two specific actions, eliminating any remaining phosphates from detergents used in the area and irrigating with the effluent during dry weather, are recommended for further investigation.

Considering all of the methods, it was concluded that the only practical approach will be a management plan that employs all available tools to achieve cost-effective controls of nuisance aquatic plants. From these results, the following study recommendations are made:

1. Given the diverse nature of the alternatives and their consequences, and the variable nature of conditions in Lake Dunlap and the other hydro-lakes, it appears that the most desirable plan to manage aquatic plant problems will be an integrated combination of all the available alternatives. The options include: mechanical cutting, chemical treatment with herbicides, and biological controls such as sterile grass carp, water lettuce weevils, and replanting of native aquatic plants. A critical element of the integrated approach will be frequent monitoring of the degree of aquatic plant infestation so that response measures can be taken while the problem is relatively small and more easily managed.

2. As part of the integrated approach, the GBRA and NBU should initiate discussions with the City of New Braunfels and major detergent vendors to determine the best way to insure that any phosphorus input that can be easily avoided is removed from the system.

3. In the same spirit, the GBRA and the NBU should begin preliminary engineering to better quantify the cost of dry weather land application. If this can be achieved at relatively low cost, the GBRA and NBU should consider going forward with this option, recognizing that reductions in point source nutrient inputs will be helpful but are not likely to eliminate the aquatic plant problem by itself.

4. While mechanical cutting probably has only limited utility on Lake Dunlap and Lake McQueeney, it should be given further testing.

5. The management of vegetation in lakes is not unique to Lake Dunlap; it is similar to other water resource issues that must be addressed. Means for recovery of costs is a major issue for all management options.

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ACKNOWLEDGMENTS

James Arnst provided much of the background and history of macrophyte problems in the hydro lakes. He also provided valuable insight and comment on the early drafts of the document.

Mike McCall and Ed Oborny collected the water and sediment samples from Lake Dunlap, and Debbie Magin supervised their chemical analysis.

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1.0 INTRODUCTION

Lake Dunlap is the first of a series of low head, run-of-river hydroelectric reservoirs on the Guadalupe River. The dam forming Lake Dunlap and the hydroelectric generator was completed in 1928 by the Texas Power Corporation. In 1963 the Guadalupe-Blanco River Authority (GBRA) took over the dam and has continued to produce electricity for the region. Figure 1-1 shows the major waterways in the immediate vicinity of Lake Dunlap as well as the other reservoirs operated by the GBRA.

While the primary reason Lake Dunlap was constructed was the generation of low-cost electricity, over the years it has developed a number of other uses. First, a significant number of waterfront homes have been built around the lake, attracted by the visual amenity and by the proximity to recreational uses. Second, the lake has attracted a substantial amount of use for boating and fishing. Finally, the lake provides a convenient point for water diversion from the river. The fact that the lake is used extensively by the public means that when something inhibits that use significantly, there is an immediate public concern.

The lake has a history of nuisance plant problems. Most of the problems appear to be associated with aquatic macroscopic plants, as opposed to microscopic plankton. These macro plants are called macrophytes. A moderate amount of macrophytes are desirable as fish habitat, but high densities can restrict boating and other uses. Efforts to control macrophytes in Lake Dunlap have included mechanical cutting, herbicides, and adding fish (grass carp) that eat the macrophytes. Another method that has been considered in the past and discussed recently is restricting the concentration of nutrients, primarily phosphorus. The main focus of this study is on the nutrient control alternative, but the other methods are considered in parallel.

This report is divided into six sections. Section 2.0 (next section) reviews the history of the problem. It describes the history of plant problems that have occurred as well as the many studies that have been performed on the subject over the years. The third section follows on this history with a discussion of technical literature related to algal problems in lakes. The fourth section describes water and sediment measurements made in Lake Dunlap and major wastewater sources. Section five is a quantitative analysis of the system, drawing on the data obtained in earlier studies. It also includes use of a simplified numerical model of the system that is used to estimate the effect of point source nutrient reduction alternatives. In addition, other alternatives such as herbicide use, sterile grass carp and mechanical harvesting are compared. The final section addresses the overall situation and presents recommendations for further work.

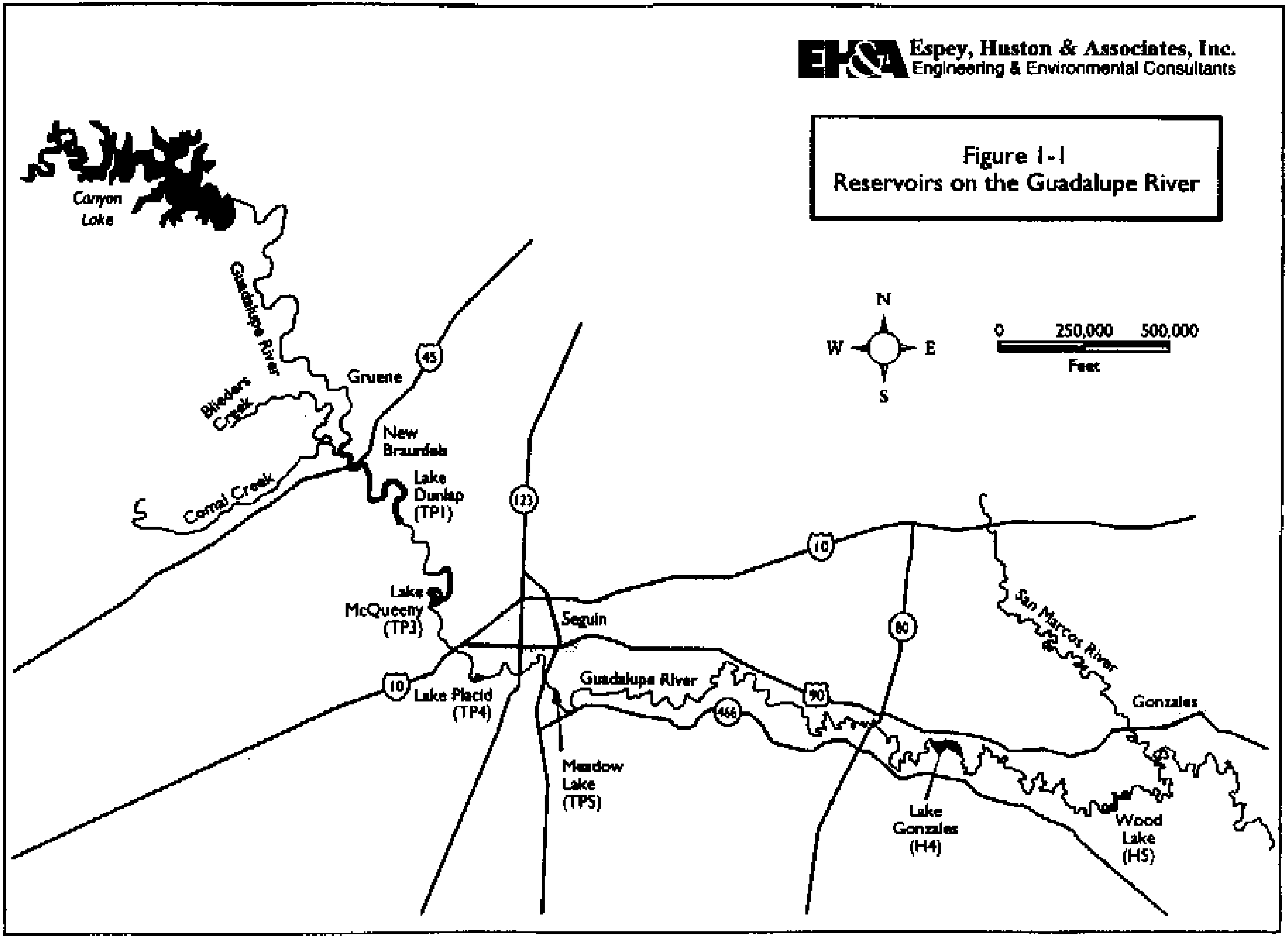


Figure 1-1
Reservoirs on the Guadalupe River

2.0 HISTORY OF PLANT PROBLEMS AND WATER QUALITY STUDIES

This section briefly reviews earlier information on aquatic plant concerns and studies of water quality that might relate to these concerns in Lake Dunlap. The section is broken into two major parts, one dealing with the local history of aquatic plant concerns and the other summarizing local water quality studies dealing with nutrients and plants. In reviewing the information, it is useful to consider historical river flow. Figure 2-1 is a plot of the Guadalupe River flows entering the lake and downstream of the lake from January 1, 1965 to mid-1998.

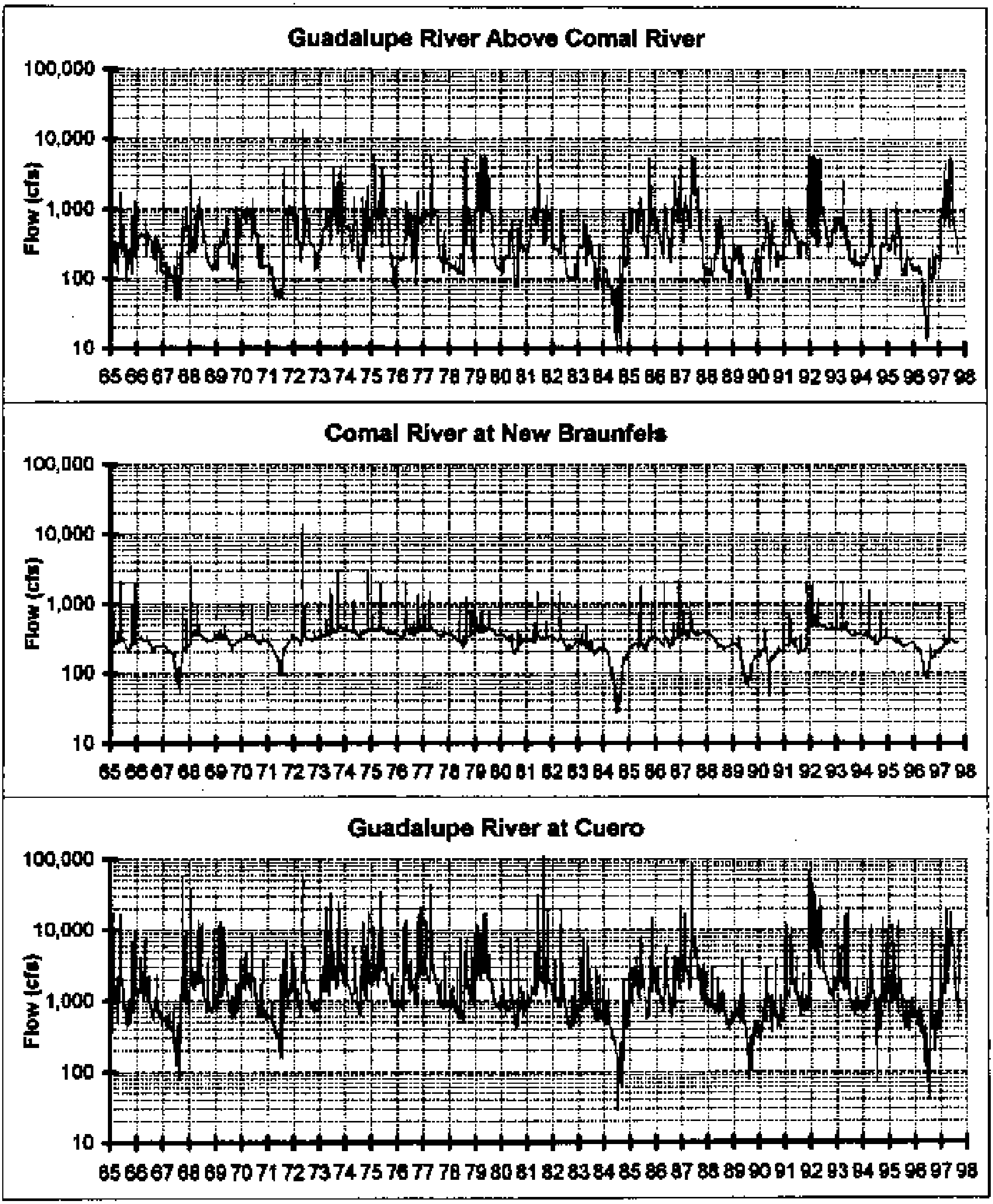
2.1 AQUATIC PLANT HISTORY

During the period 1965-1972, Lake Dunlap was substantially covered by water hyacinth (*Eichhornia crassipes*), a floating plant that exists in large mats with roots that can sometimes reach to the sediments. Efforts to remove the plants with drag wires and earth-moving machinery were largely ineffective. Attachment A contains copies of correspondence exchanged in the late 1960's relative to the topic. A high-flow period in May of 1972 removed most of the hyacinth, and the lake was clear for most of the 1970s. Referring to Figure 2-1, there were no low-flow periods between the summer of 1971 and 1984.

An indication that macrophytes are natural concerns is provided in the correspondence shown in Attachment B. This attachment contains letters in 1969 between the mayor of New Braunfels and the Executive Director of the Texas Water Quality Board concerning a new weedcutter used by the City to control weeds in Landa Park on the Comal River. Also noted are cutting efforts by a Comal County Recreational District and the Lower Colorado River Authority, operating a power plant below Landa Park. The major concern addressed in the correspondence is not the aquatic weeds themselves, but the effect of the cut weeds moving downstream and constituting a nuisance problem on Lake Dunlap. From this it is clear that macrophyte growth in the spring-fed Comal River has been common and a major concern for a substantial period of time.

In 1984 there was another low-flow period and a filamentous algae known as "Witches Hair" became dominant. It tended to form associations or "globs" that drifted with the wind on the water surface. It was noted that when ingested by an outboard engine cooling water pump, the algae was very effective in stopping the water flow.

FIGURE 2-1
FLOWS OBSERVED AT USGS GAGES



In the late 1980s and 1990, the dominant plant became the water lettuce (*Pistia stratioiles*). It also is free-floating and was moved in wind-driven rafts across the lake. The Waterlettuce was also effective in stopping boating. High flows in the winter of 1991-92 cleared out the lake. However, there is also file documentation in 1991 of a joint Texas Parks and Wildlife Department (TPWD) and Corps of Engineers release of 200 lettuce weevils (*Neohydronymous affinis*). This was an attempt at using a biological agent to control the macrophyte problem that was apparently successful. In June of 1998 the TPWD released 1,000 lettuce weevils in the H4 reservoir near Gonzales to control a water lettuce infestation in that reservoir.

Hydrilla was first discovered in Lake Dunlap during the summer of 1993. In the following two years, the TPWD applied herbicides in an attempt to control the hydrilla. Figure 2-2 is a map of the major bloom areas of Lake Dunlap in 1995 prepared from TPWD surveys. In 1996, the TPWD stocked the river with triploid (sterile) grass carp (*Ctenopharyngodon idella*) and also used herbicides. The combined effects of these two, plus high flows of 1997, have substantially put the hydrilla problem in remission.

Another possibly related concern was reported in 1996-97 dealing with taste and odor (T&O) problems at the Canyon Regional Water Authority's Water Treatment Plant (CRWA). The problems were reported between late April and the end of August 1996, during a time of low flows. Representatives of CRWA theorized that high levels of aquatic plant growth were the cause, possibly exacerbated by the hydrilla control efforts in May 1996.

From this brief review, it is clear that earlier plant problems have not been restricted to attached species that are able to obtain their nutrients from the sediment. Free floating plants as well as attached species have all produced problems. Another observation is that plant problems seem to be associated primarily with low-flow periods, which in turn suggests that nutrients could be a major triggering factor along with better water clarity and longer detention time. Clearly, low-flows are also essential to avoid washout of non-attached species.

2.2 WATER QUALITY STUDIES

The Lake Dunlap area of the Guadalupe River has to be one of the more heavily studied portions of the state. Attachment C contains short summaries of the seventeen studies located, along with relevant nutrient data provided only in these studies. Data that are already included in state, USGS, or GBRA monitoring data files were not tabulated.

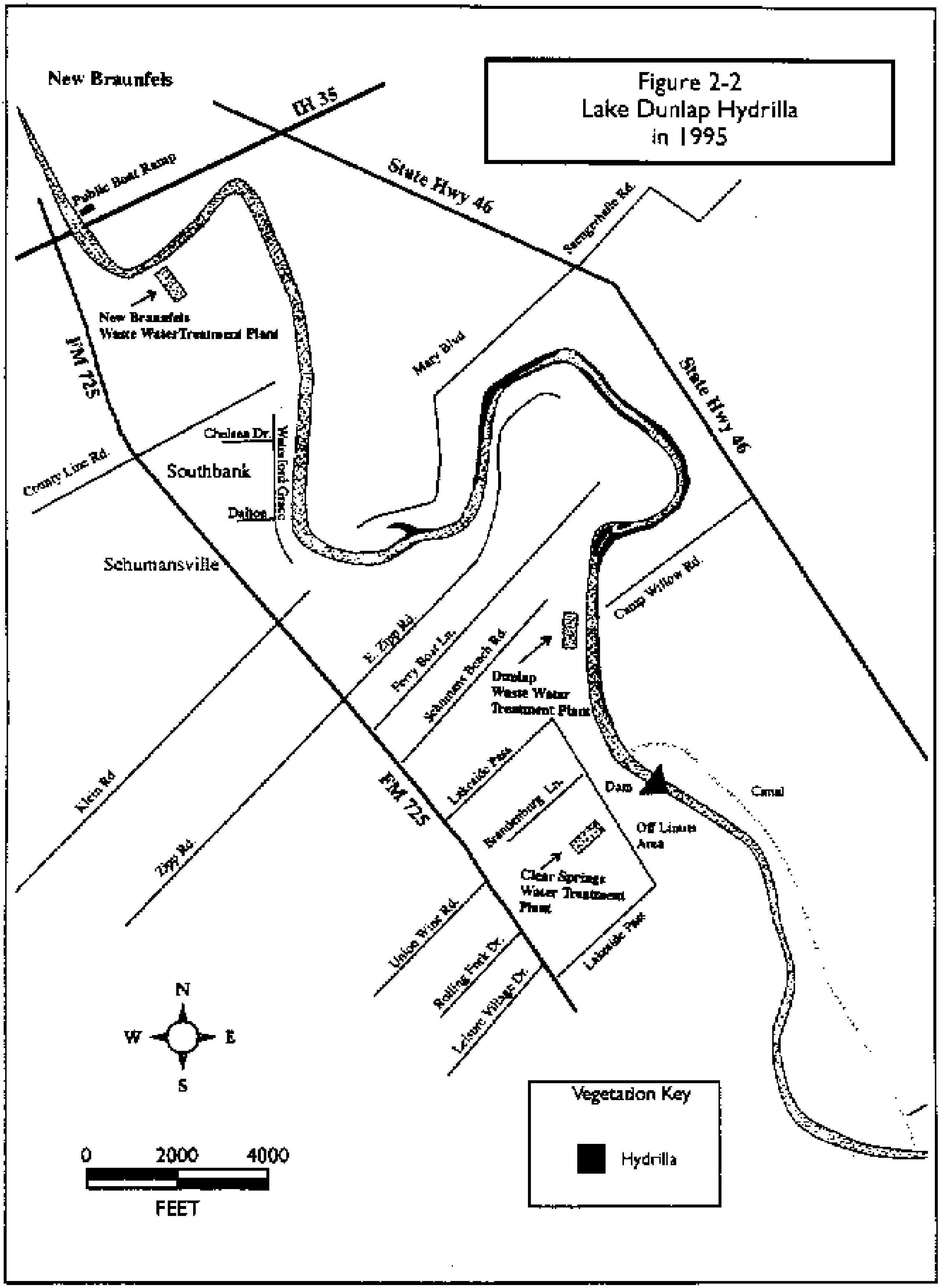


Figure 2-2
Lake Dunlap Hydrilla
in 1995

Most of the studies deal with general water quality in the river. However, a few were specifically oriented to evaluating nutrient removal as a method of controlling algae and macrophytes in Lake Dunlap. The conclusion of the latest evaluation of this topic (EH&A, 1981 and Glass Environmental Consultants, 1982) was that removal of phosphorus from point sources (specifically New Braunfels effluent) was likely to reduce aquatic plant levels but would be very costly. However, that study was performed almost twenty years ago. During that interval there has been significant growth in wastewater flows and the cost of phosphorus removal appears to be somewhat less than was the case in 1982.

Another major conclusion of the previous studies is that where nutrients exert a limiting effect on plant growth, the nutrient most likely to be limiting is phosphorus (P). The main reason is that nitrogen, particularly nitrate-N, exists in relatively high concentration (about 1 mg/L as N) in Comal Springs, while P tends to be relatively low, on the order of 0.01 mg/L. While P is most often in relatively low supply, there is still enough P in Comal Springs to support extensive plant growth. Also, while P generally is the nutrient that is least available, relatively high P concentrations exist in Canyon Lake releases during the summer. Under those conditions there can be an excess of all nutrients and it cannot be said that P will necessarily be limiting.

3.0 LITERATURE REVIEW FOR MACROPHYTES

Before addressing the alternatives for dealing with the plant problem on Lake Dunlap, it is worthwhile to review basic information on macrophytes. Most macrophytes are vascular plants with roots, stems, leaves and flowers. Many free-floating species such as duckweed and water hyacinth have roots hanging from the floating leaves. Macrophytes do not have woody stems but depend on buoyancy from air-filled leaves and stems. Aquatic plants can reproduce sexually and by several asexual methods and are able to rapidly colonize a site. The ability to rapidly reproduce and to quickly dominate a waterbody are major reasons why they are referred to as aquatic weeds.

Typically, macrophytes rooted in the sediment exist between the shoreline and a maximum depth generally limited by light availability. Light appears to be a key factor in the extent of macrophyte activity, with turbid lakes having relatively little activity. Macrophytes promote clear water by trapping particulate matter, which tends to further their spread.

Cooke et al. (1993) notes that excessive nutrient loading is not a direct cause of macrophyte problems. They note that high nutrient loads are more often associated with phytoplankton blooms, shading, and a reduction in macrophytes. Only free-floating forms like water hyacinths are noted to respond directly to higher water concentrations of nutrients.

Sediment type plays a major role with rooted macrophytes. Sediment can range from coarse gravels and sands, where water exchanges freely through the sediment, to very tight and organic clays, which allow little water exchange. In the case of coarse sediments, the nutrient content of the overlying water is essentially the same as the interstitial sediment waters. While the plant nutrient uptake may occur predominantly in the root zone, the nutrient content of the water is actually what is available for macrophyte growth. Fine sediments allow little water exchange but can be major reservoirs of nutrients, supporting abundant plant growth even when the water has insufficient nutrients to support normal growth.

Major control methods common in the literature include periodic draining to kill the plants, herbicides, organisms selected to eat the weeds (e.g., Grass Carp), sediment covers and water surface shading, machinery to harvest the weeds, and nutrient removal. Every lake situation is unique, and the plants that grow well in a particular year may well be different from those that proliferate in other years under different hydrologic and biologic conditions. Cooke et al. (1993) notes that "shallow lakes, ponds and reservoirs with nutrient-rich soils will support these plants. The desire to have "weed-free" lakes is both naïve and unreasonable" (p 266).

There are two fundamental questions to be addressed in the literature search:

1. What P concentrations in the water and sediment are low enough to yield significant reduction in macrophyte growth?

2. Are low P levels in the water sufficient to produce reduced growth if sediment sources of P are available?

At this time we have some evidence of macrophytes' ability to use P from both sediment and water, but quantitative values are limited. The following papers address the subject of water versus sediment source. The basic conclusion of these and other papers seems to be that rooted vegetation will obtain the bulk of its nutrient needs from the sediments, but is able to derive needed nutrients from the water under conditions where the sediments are relatively poor sources. Another aspect of this is that some sediments like sands or cobbles are in immediate communication with the overlying water. In this case the water can be a direct supplier of nutrients to the plant roots. With less permeable sediments, diffusion from the water is likely to be an insignificant factor. In many cases, such sediments tend to diffuse nutrients into the overlying water.

Rattray, M.R., C. Howard-Williams and J.M.A. Brown. 1991. Sediment and water as sources of nitrogen and phosphorus for submerged rooted aquatic macrophytes. Aquatic Botany. 40. 225-237.

In comparing growth response in nutrient-enriched sediment and water, the authors concluded that response was dependent on the availability of P in both the water and sediment. In field conditions the macrophytes always absorbed P from the sediments, but will absorb P from the water via the shoots if high enough concentrations are available.

Barko, J.W. and R. Michael Smart. 1986. Sediment-related mechanisms of growth limitation in submerged macrophytes. Ecology. 67(5). 1328-1340.

Experiments with *Myriophyllum spicatum* L. and *Hydrilla verticillata* (L.f.) demonstrated the role of sediment density and organic content in providing optimal growth conditions. They also demonstrated a positive effect of nutrient addition in water when the sediment growth conditions were less than optimal.

Burkholder, J.M. and R.G. Wetzel. 1990. Epiphytic alkaline phosphatase on natural and artificial plants in an oligotrophic lake: Re-evaluation of the role of macrophytes as a phosphorus source for epiphytes. Limnology and Oceanography 35(3) 736-747.

Measurements of epiphyte (attached slimes) activity were conducted in a P-limited lake. Epiphyte growth was monitored on real and artificial macrophytes, and it was found that the real macrophytes stimulated epiphyte growth significantly. This indicated that the macrophytes were a source of P throughout the growing season. Since the water was the same for both, the source of the P for the macrophytes and the epiphytes had to be the sediments.

Stephen, D., B. Moss, and G. Phillips. 1997. Do rooted macrophytes increase sediment phosphorus release? Hydrobiologicia. 342/343: 27-34.

Measurements were made of overlying water P concentrations from sediment cores with and without macrophytes. It was found that where differences occurred, the macrophytes increased the P release from the sediments.

Carignan, R. and J. Kalff. 1980. Phosphorus sources for aquatic weeds: Water or Sediments?. Science 207: 987-988.

Using 32P-labeled sediments, measurements were made on seven macrophyte species to determine if the P incorporated into the plants was from the water (without label) or the sediment. It was found that overall, 72% of the P in the plant tissue originated in the sediments.

Wright, R.M. and A.J. McDonnell. 1986. Macrophyte Growth in Shallow Streams: Field Investigations. ASCE Env. Vol 112. 953-966.

Field measurements are reported of macrophyte and periphytin growth in streams with varying degrees of nutrient enrichment. For two streams with similar P concentrations but different sediment conditions, a factor of two increase in macrophyte production was observed with higher sediment P levels. They also observed that water concentrations could affect sediment concentrations, and that higher water P concentrations produced higher macrophyte growth and standing crop levels.

Wright, R.M. and A.J. McDonnell. 1986. Macrophyte Growth in Shallow Streams: Biomass Model. ASCE Env. Vol 112. 966-982.

This paper presents a model of the macrophyte growth in the two stream reaches, one receiving and dominated by wastewater and the other with no apparent wastewater sources. The model only considered water concentrations of P and related a specific photosynthetic rate (day^{-1}) to the P concentrations. With a reduction in the photosynthetic rate based on lower P levels, the model indicated a reduction in macrophytes with a reduction in river water P concentrations. The range of P concentrations considered was 1.15 mg/L of soluble ortho-P down to 0.0075 mg/L.

4.0 LAKE DUNLAP SAMPLING

As a part of this study, a set of data was collected in Lake Dunlap on 10 September 1997. This section of the report describes the methods and results of that sampling.

The objective of the sampling was to obtain concurrent data on water and sediment conditions, during a time when aquatic plant growth would be a concern. The unusually high flows existing during most of 1997 meant that the effort had to be delayed until a time of the year when algal growth tends to be slower. Nevertheless, the data provides useful information on the overall system. The river flow on the day of sampling averaged 793 cfs, with 519 cfs from the Guadalupe and 274 from the Comal River.

A total of 9 lake stations, shown on Figure 4-1, were sampled. Each lake station involved a transect of the stream, where composite water and sediment samples were collected. The general pattern was to collect water and sediment samples at roughly 25%, mid-channel, and 75% of the way across each transect. The boat crew would then follow the same path with the boat engine idling, collecting depth observations every 5 seconds. They would then go back to the centerline to collect probe measurements. Water and sediment grab samples were composited in the boat to yield single samples for laboratory analysis.

This pattern had to be modified on several transects, where scouring of the bottom made it impossible to collect sediment at the usual locations. In these cases, sediment was collected from the part of the transect where it was possible. With station 9, above the Gruene WWTP, there was no sediment in the river to be sampled.

In addition to the water and sediment samples at the 9 stations, samples were collected from the effluent of the Lake Dunlap WWTP (LDWWTP) and the New Braunfels Utilities WWTP (NBUWWTP). The chemical characteristics of the water and sediment samples are tabulated in Tables 4-1 and 4-2.

Figure 4-2 shows the physical dimensions of the seven transects that could be sampled by boat. The lake maximum depth is nearly 20 ft deep near the dam, but most of the lake averages between 7 and 8 feet in depth. While the average depth remains fairly constant, the width becomes progressively smaller with distance upstream.

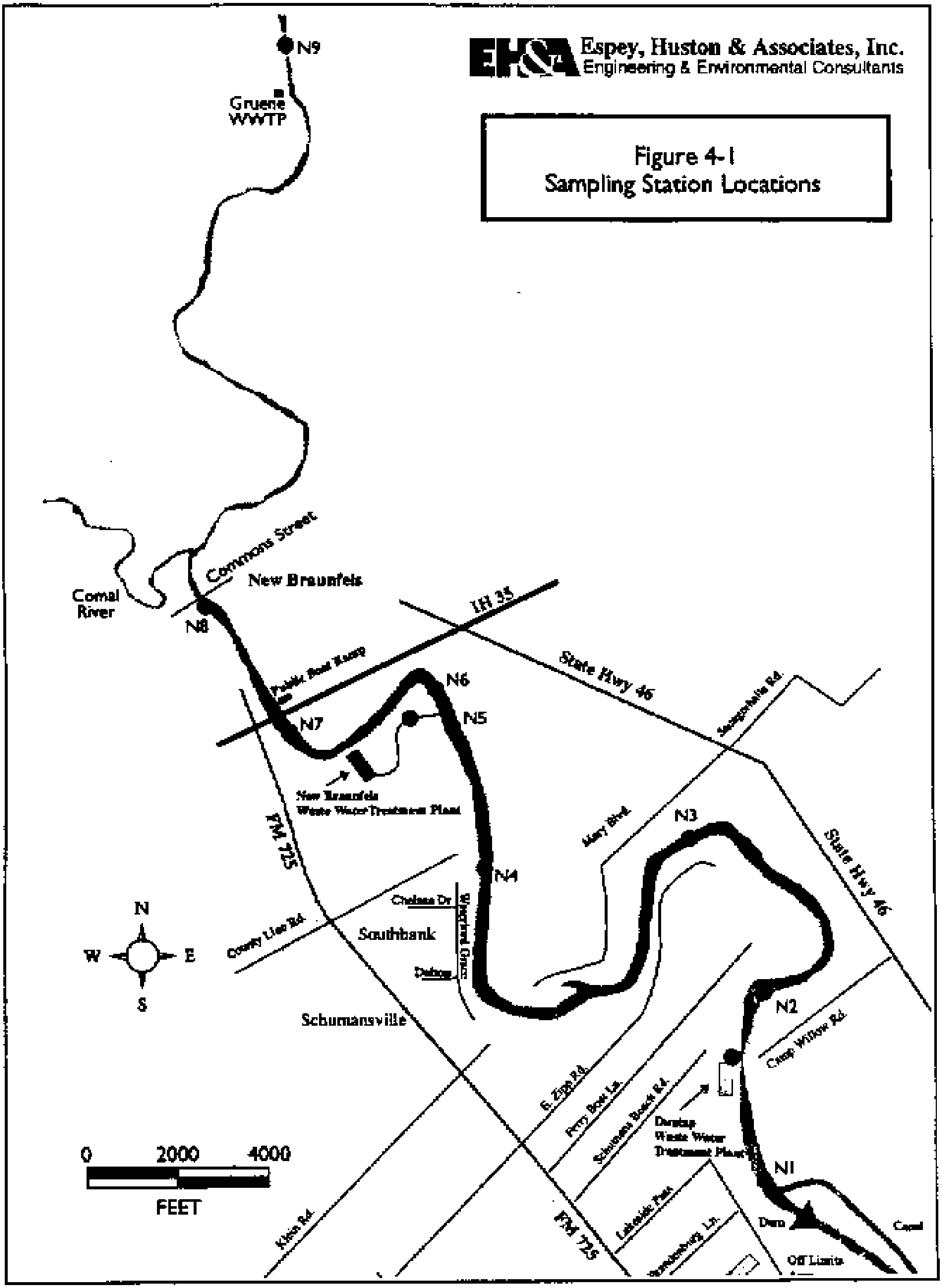


Figure 4-1
Sampling Station Locations

TABLE 4-1
WATER QUALITY DATA COLLECTED FROM LAKE DUNLAP ON 9/10/1997

Station	Conductivity (µmhos/cm)	DO (mg/L)	pH (SU)	Temperature (°C)
N9	400	9.28	7.97	25.8
N8	430	8.58	7.93	26.1
N7	440	8.82	7.72	25.3
N6	440	8.27	7.78	25.2
New B. WWTP	1,310	5.05	7.60	25.2
N5	450	7.92	7.82	25.4
N4	410	7.77	7.66	25.4
N3	420	7.73	7.73	25.8
N2	420	7.60	7.71	26.3
Dunlap WWTP				
N1	400	8.47	7.87	26.9

Station	NH3-N (mg/L)	NO2+NO3-N (mg/L)	TKN (mg/L)	Diss. PO4-P (mg/L)	TP (mg/L)
N9	0.05	0.47	0.69	0.02	0.08
N8	0.05	0.47	0.71	0.03	0.09
N7	0.04	0.92	0.56	0.02	0.09
N6	0.04	0.92	1.14	0.03	0.09
New B. WWTP	0.48	9.00	1.87	2.70	2.62
N5	0.05	1.15	0.80	0.08	0.14
N4	0.06	0.82	0.90	0.04	0.11
N3	0.06	0.77	0.69	0.05	0.10
N2	0.07	0.90	1.01	0.06	0.11
Dunlap WWTP	0.09	15.90	1.32	3.20	3.48
N1	0.06	0.84	0.77	0.06	0.11

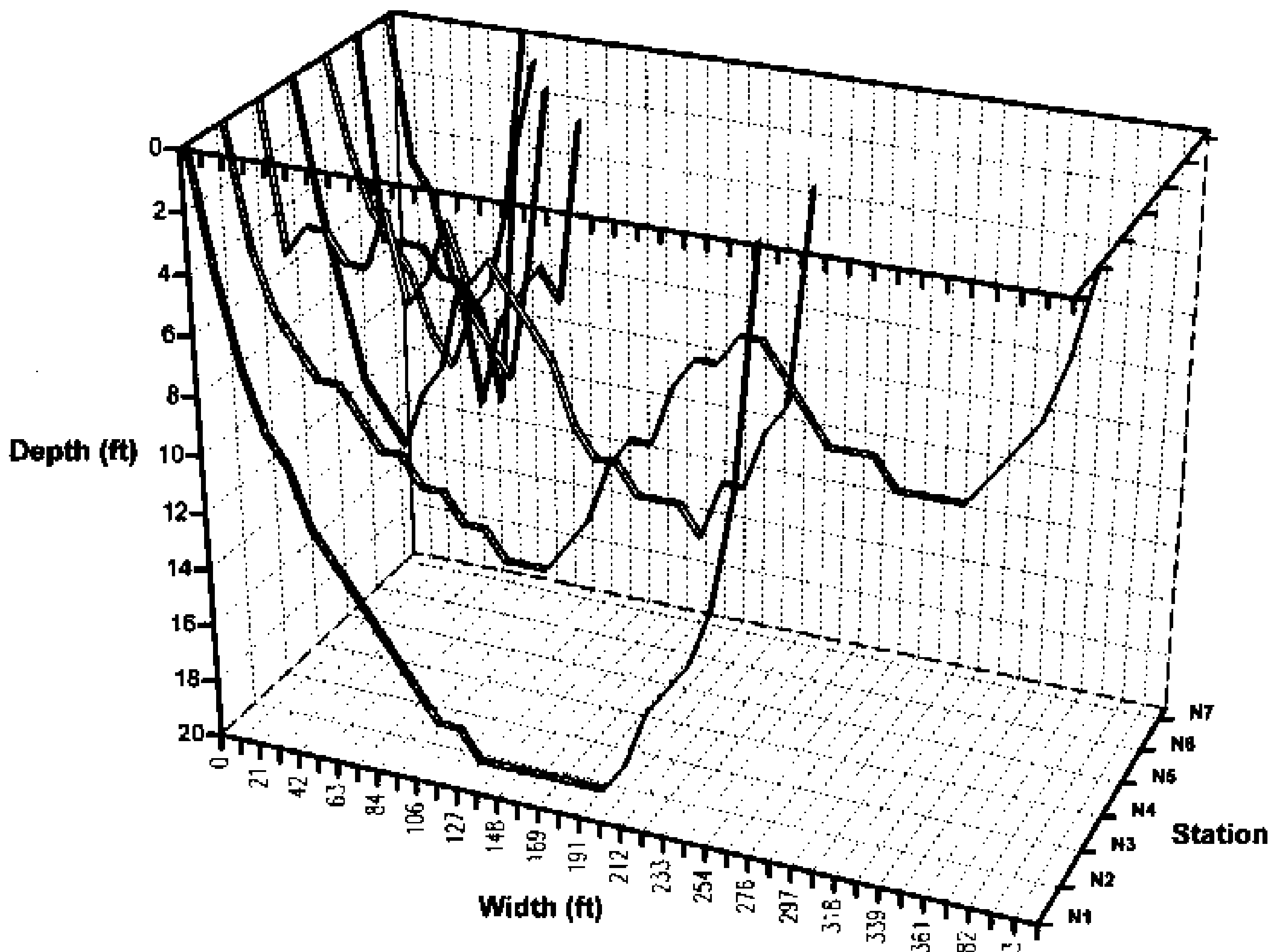
Station	COD (mg/L)	TOC (mg/L)	Total Solids (mg/L)	Total Vol. Solids (mg/L)	TSS (mg/L)	VSS (mg/L)
N9	24.0	3.7	315	< 1	2.6	< 1.0
N8	17.8	2.3	328	< 1	3.4	< 1.0
N7	24.0	2.3	348	< 1	2.2	< 1.0
N6	19.0	2.0	354	2	2.3	< 1.0
New B. WWTP	25.3	7.2	1,164	266	4.1	1.2
N5	10.2	1.8	364	12	2.3	< 1.0
N4	19.0	2.2	341	3	1.5	3.0
N3	29.1	2.2	355	19	5.6	< 1.0
N2	14.0	2.6	358	3	11.7	1.8
Dunlap WWTP	19.0	4.7	654	145	2.2	1.5
N1	21.5	2.8	356	6	6.6	1.5

TABLE 4-2
SEDIMENT QUALITY DATA COLLECTED FROM LAKE DUNLAP ON 9/10/1997

Station	COD (mg/kg)	TOC (mg/kg)	% Vol. Solids (%)	Sediment % Solids (%)	
N8	62,735	7,018	6	55.1	
N7	55,600	7,321	7	86.9	
N6	102,793	8,261	12	43.0	
N5	51,298	2,333	4	26.2	
N4	64,875	3,089	6	53.8	
N3	59,051	5,217	6	53.8	
N2	75,519	7,803	7	44.5	
N1	85,987	13,900	8	38.4	
Station	**NH3-N (mg/kg)**	**NO3-N (mg/kg)**	**TKN (mg/kg)**	**PO4-P (mg/kg)**	**TP (mg/kg)**
N8	188.0	0.23	1,404	3.0	281
N7	98.4	0.07	1,368	3.3	320
N6	152.0	0.03	1,682	5.0	322
N5	96.6	0.22	1,488	6.6	852
N4	105.0	0.08	1,390	4.0	334
N3	114.0	0.04	1,238	3.6	333
N2	172.0	0.04	1,933	4.9	412
N1	170.0	0.05	1,831	5.3	517

Note: TP & TKN were digested data, NO3-N, NH3-N and PO4-P were dissolved data.

FIGURE 4-2
CROSS SECTIONS OF SAMPLING LOCATIONS IN LAKE DUNLAP



Another longitudinal process in the lake is the change in sediment characteristics. Figure 4-3 shows the distribution of sands, silts and clays for each station. It can be seen that the upstream stations, which have a smaller cross-sectional area and thus higher velocity flows, have a higher proportion of coarse sediments (sand). With distance downstream the stations show progressively higher content of silt and clay sediment.

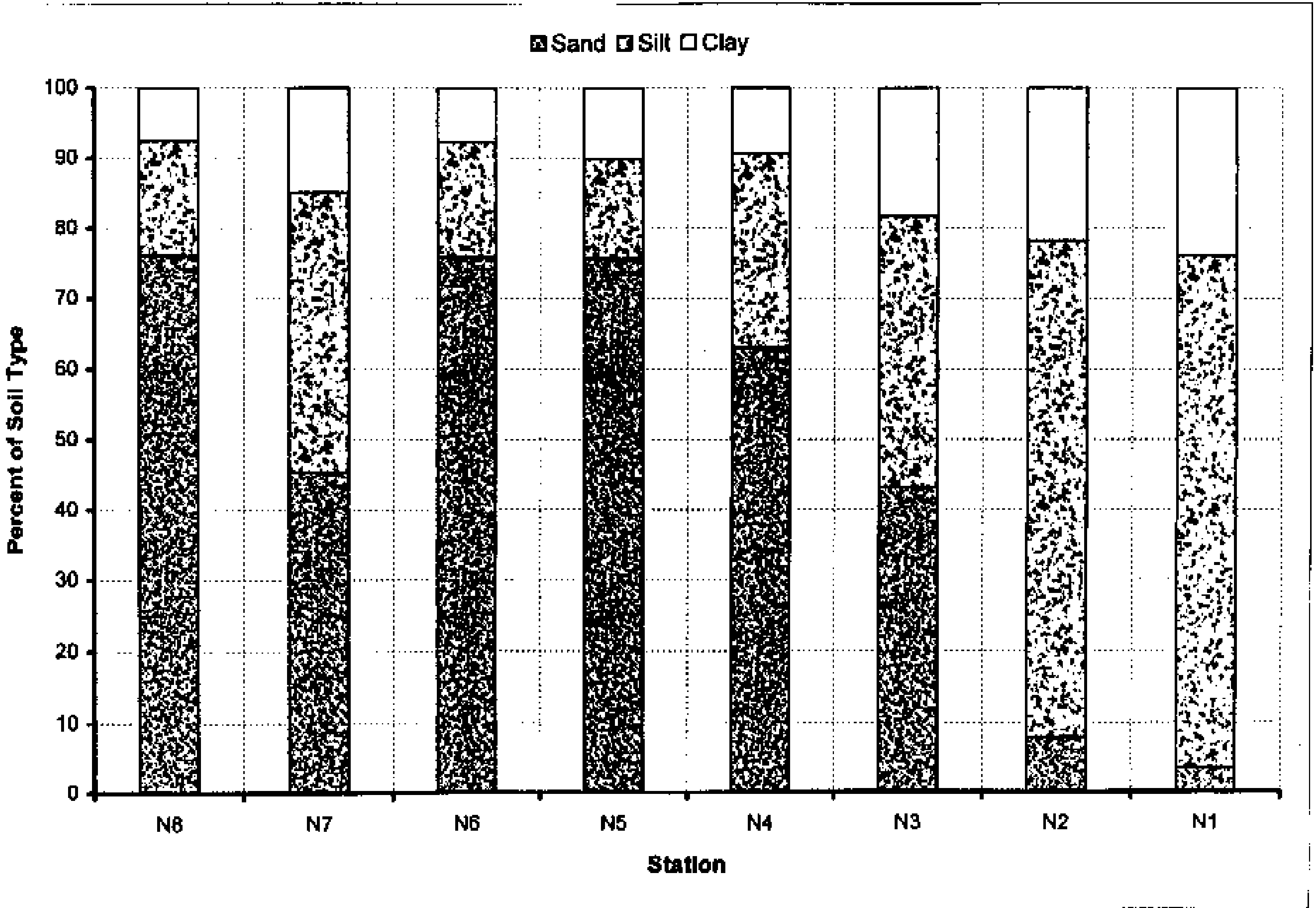
Figure 4-4 shows the parameters measured by probe in the lake and the two effluents. The difference between the NBUWWTP effluent and ambient lake data can be seen most strongly in the conductivity data.

Figure 4-5 shows data related to oxygen demand and solids content. The COD and TOC values from both plants appear to be almost as low as ambient levels. The total solids and volatile total solids are higher than ambient at the NBUWWTP, reflecting the same difference shown in the conductivity data. There are higher TSS levels at lake stations 1-3. These slightly elevated concentrations are not reflected in the volatile data, suggesting that the source is inorganic in nature.

Figure 4-6 shows the major nutrients. The nitrate-N and phosphorus levels of the effluents are substantially higher than ambient, as would be expected. The upstream total N concentration is about 2 mg/L, and the NBUWWTP effluent total N is about 11.3. With a ratio of the flows of about 176 to 1, the downstream total N concentration is essentially unchanged. For phosphorus, the upstream concentration is 0.09 mg/L and the NBUWWTP effluent is about 2.7 mg/L in this grab sample. The calculated increase in total P is from 0.09 to 0.105 mg/L, and the downstream stations in Table 4-1 reflect that change.

Figure 4-7 shows the sediment chemical data. Note that these figures do not have the wastewater samples, but the NBUWWTP effluent enters between stations 5 and 6. With these data it appears that the only indication of an effect from NBUWWTP is in the nitrate-N and phosphorus data. There appears to be an indication of higher P levels with distance downstream, possibly reflecting the higher proportion of fine sediments in the lower lake stations. Interestingly, the TOC in the sediment appears to be lowered markedly just downstream of the NBUWWTP discharge and only slowly returns to previous levels with distance downstream. The percent solids data drops sharply with distance downstream reflecting the higher moisture content of the finer sediments in the lower lake.

FIGURE 4-3
DISTRIBUTION OF SANDS, SILTS AND CLAYS FOR EACH SAMPLING STATION



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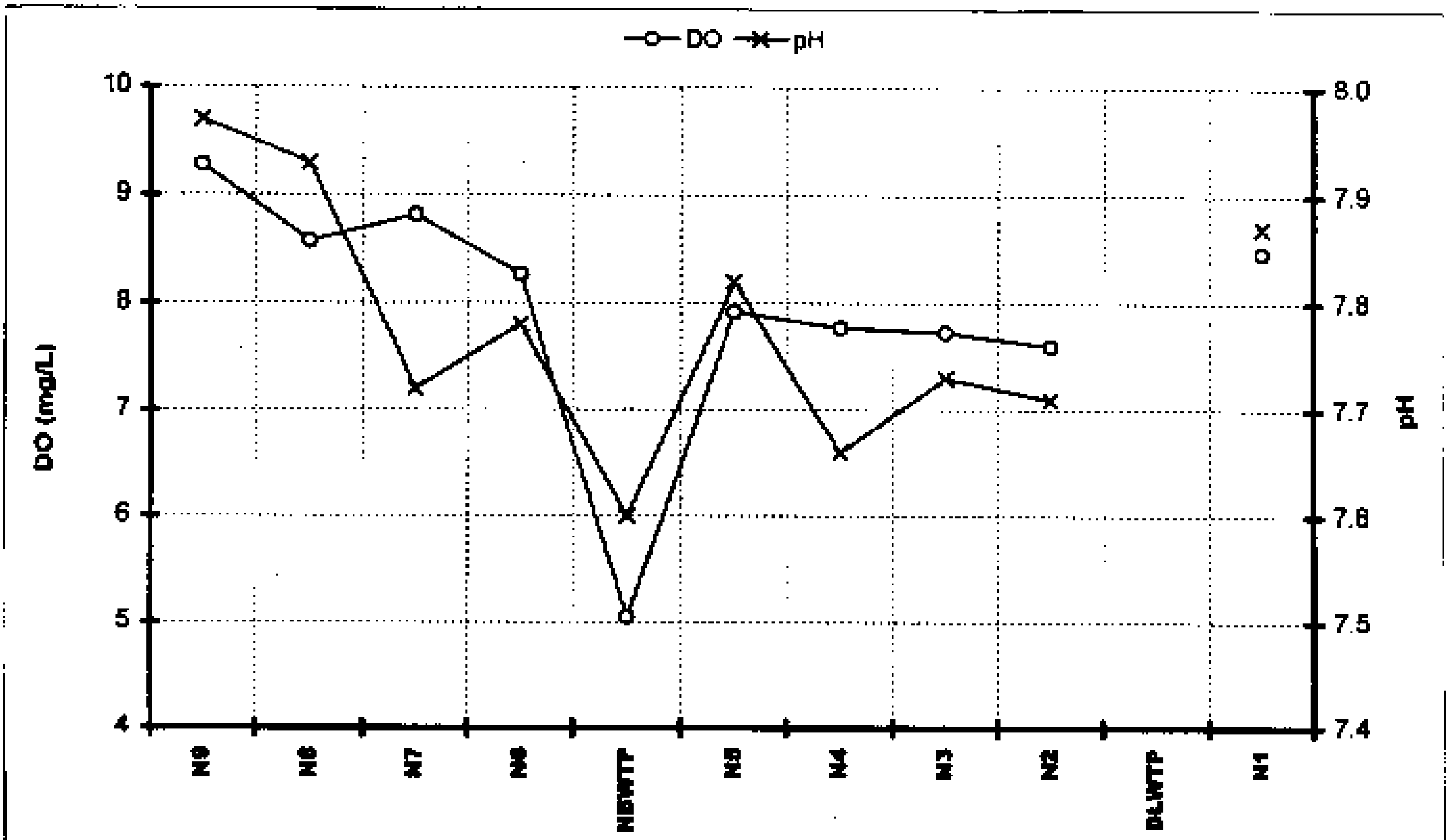
Espey, Huston & Associates, Inc.

FIGURE 4-4
PROBE WATER QUALITY DATA COLLECTED FROM LAKE DUNLAP ON 9/10/1997



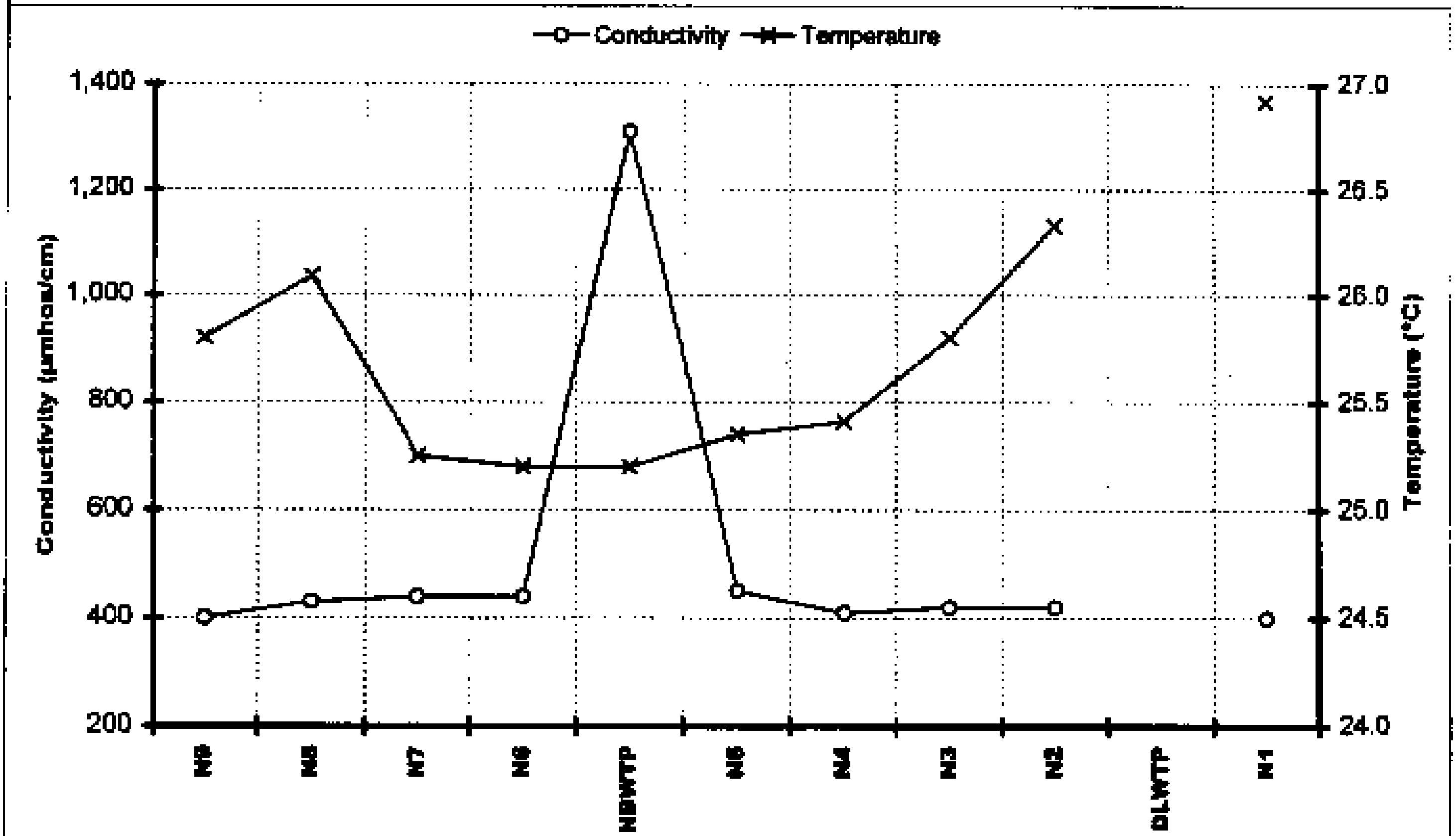


FIGURE 4-5
SOLIDS AND OXYGEN DEMAND DATA COLLECTED FROM LAKE DUNLAP ON 9/10/1997

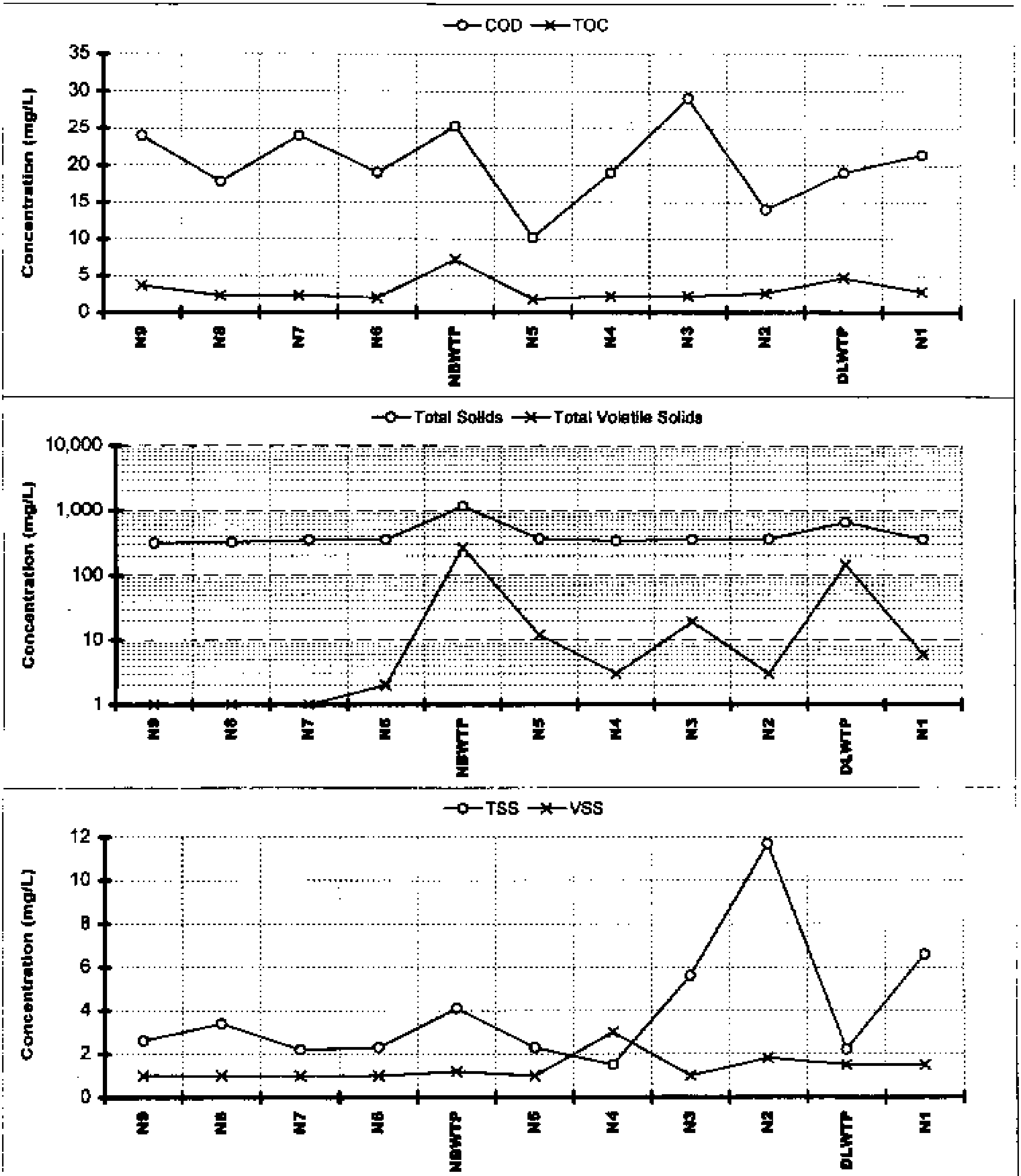


FIGURE 4-6
NUTRIENTS DATA COLLECTED FROM LAKE DUNLAP ON 9/10/1997

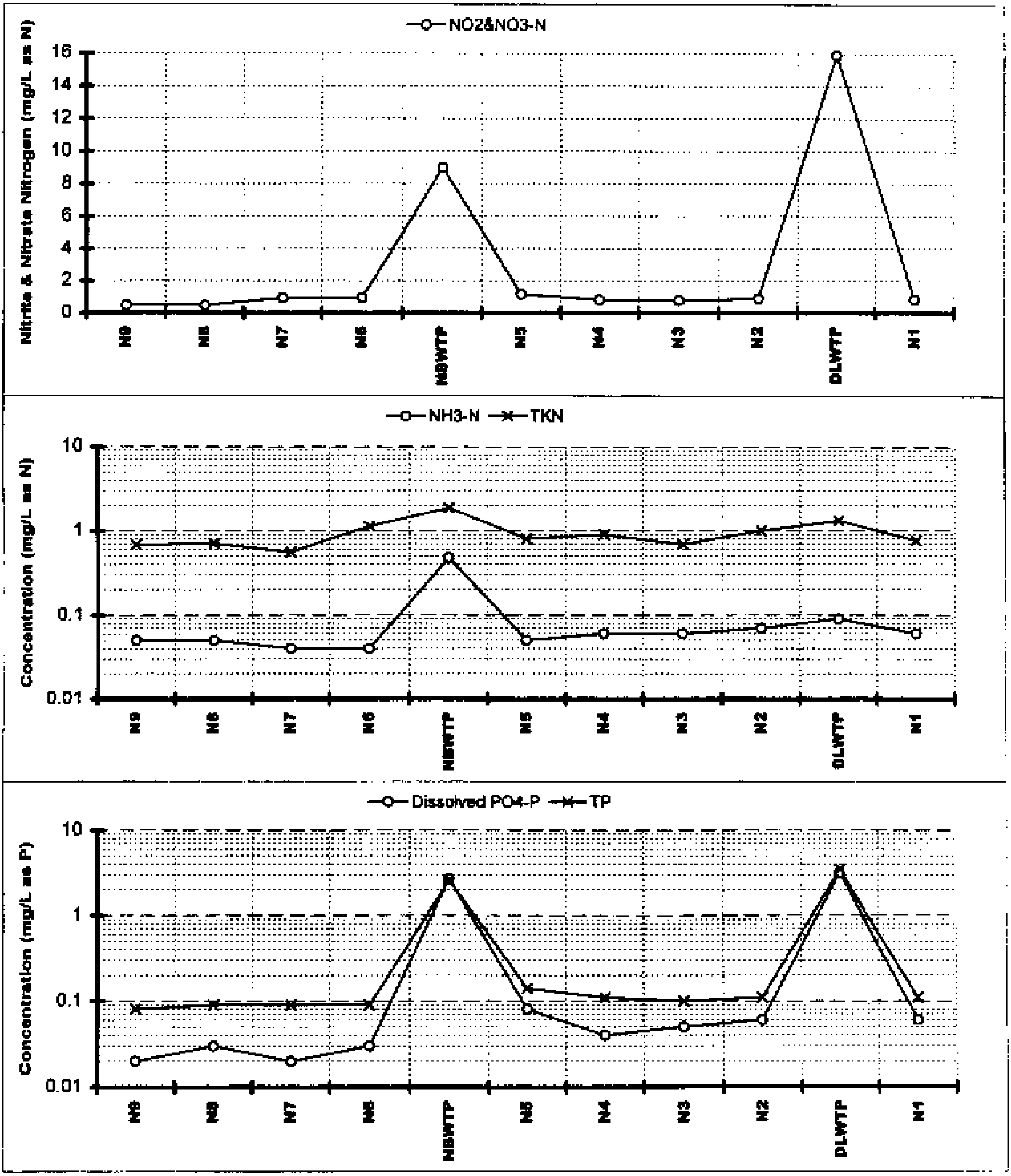
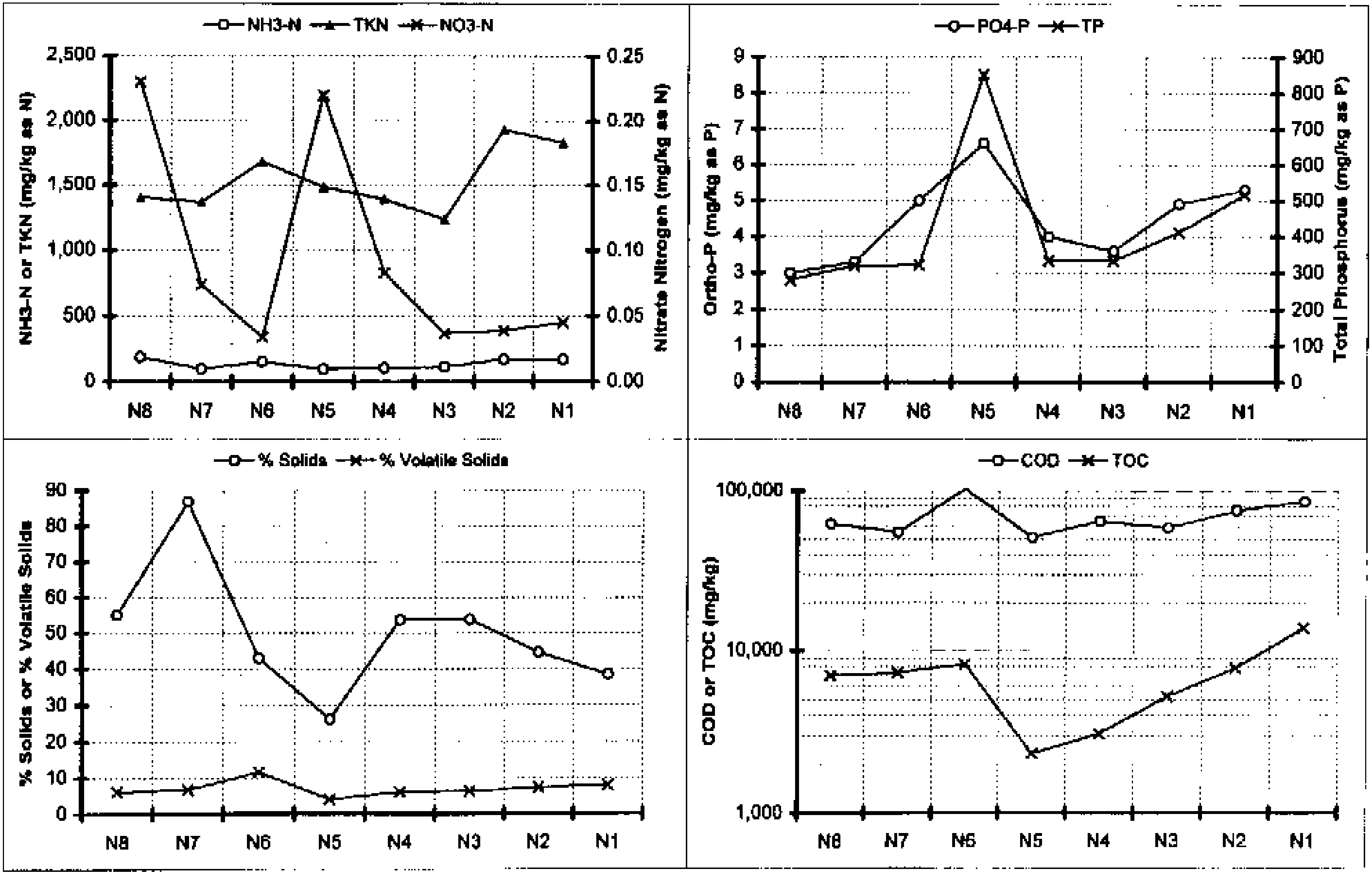


FIGURE 4-7
SEDIMENT QUALITY DATA COLLECTED FROM LAKE DUNLAP ON 9/10/1997



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5.0 ANALYSIS

This section of the report integrates information from various sources and provides a preliminary assessment of alternatives to manage or control problems associated with excess aquatic plant growth, primarily hydrilla, on Lake Dunlap. The alternatives considered include:

- Removal or reduction of phosphorus inputs from domestic wastewater point sources,
- Continued periodic treatment with herbicides,
- Periodic restocking of triploid grass carp,
- Mechanical cutting, and
- A combination of all of the above in an integrated approach.

Habitat manipulations such as drawing down the lake to expose the bottom and kill plants, and using bottom covers in specific areas to prevent plant roots from reaching the sediment may have utility in some situations but are not evaluated in this study.

5.1 POINT SOURCE PHOSPHORUS REMOVAL

This section is divided into two components. One is estimating the effect on aquatic plant growth of a given amount of point source P removal, and the other is estimating the cost of this removal by several mechanisms.

Any plant's basic requirements for growth include sunlight and sufficient inorganic elements to form new plant tissue through photosynthesis. The inorganic elements are called nutrients. If nutrients, particularly nitrogen and phosphorus, are at low concentrations, they can limit the rate of plant growth. However, if the nutrients exist at excess concentrations, adding or removing some of the nutrients will have little effect on plant growth. Estimating the effect of changes in phosphorus thus requires a quantitative understanding of background conditions and the effect of aquatic plant activity.

5.1.1 Estimating the Effect of Point Source P Reduction

New Braunfels Utilities (NBU) operates three WWTPs that discharge to the system; the South and North Kuehler plants together discharge 3 to 4 mgd on average, and the much smaller Gruene plant. The GBRA operates the relatively small Lake Dunlap plant. None of these plants are designed to remove P from the effluent. During times when the river flow is low, the treatment plants can contribute a significant percentage of the system P concentration. For example, with a river flow of 300 cfs and a combined background concentration of 0.01 mg/L of total-P, the combined effluent of about 5 cfs with a total-P of 5 mg/L constitutes less than 2% of the flow but over eight times the background P load. Under these circumstances the effluent can have a significant effect on the lake P concentration. However, when the background P concentration is higher, as it often is, or the flow larger, the relative impact of the point sources on lake P concentration can be markedly less.

It should be noted that the major WWTPs are not the only manmade source of phosphorus to the system. Other minor sources include waterfront septic systems along the lake and heavy swimming use. While these undoubtedly contribute some nutrients to the system, their net effect is not likely to be significant. A properly functioning septic tank and drain field will typically do at least as well as WWTPs in nutrient removal. The total wastewater flow from a few hundred waterfront septic systems, compared to tens of thousands of residents would be very difficult to detect.

The main question is determining what amount of reduction in aquatic plants might be achieved with a given reduction in point source phosphorus. As noted in Section 2.2, with the major input of nitrate-N from the Comal River, P is almost always available in relatively smaller amounts than N, and is thus the nutrient with the greatest likelihood of being a limiting factor for plant growth. The major question is whether there is already enough P available in the system to make reductions in point sources relatively unimportant.

The primary tool to address the question of the effect of point source nutrient reduction is a numerical model of aquatic plant growth. Such models typically consider the effects of N and P availability in water and sediment, temperature, light, residence time, and ecosystem interactions. Such models are a simplification of a very complex system designed to quantify the major components and help the decision making process. Because the real world is quite complex, involving many competing ecosystem components at each level, such numerical models require a large number of coefficients to represent even the simplified bulk processes of the model. These coefficients must be adjusted in the calibration process to make the numerical model properly represent key aspects of the prototype.

In the modeling work done in the late 1970s (see Appendix C for references and a brief summary), a state-of-the-art model (for its time) was employed. The model was named WREDUN, after Water Resources Engineers and DUNlap. The model was applied using calibration data obtained during 1977. It so happens that 1977 was a relatively wet year, with flow through Lake Dunlap staying above 1,000 cfs until well into August. The model calibration to this data was necessarily imprecise as there was little in the way of plant growth in the lake from which to gauge the model's response. Further, there were severe limitations on the quantity and quality of the calibration data that could be collected. For example, there was no independent data available to verify or check the model calibration. With the limited data available, calibration choices had to be made which had a major effect on the answers the model provided--the amount of reduction in aquatic plant growth for the P reduction alternatives considered.

While the conditions for this earlier study were far from ideal, the basic situation will always exist to some extent. It is very rare to have all the data one would like, and weather conditions can usually be depended upon to exhibit less than perfect cooperation. Judgements will always have to be made based on imperfect data, and such judgments can have important consequences. The model results, which were used in the decisionmaking at the time, do not seem unreasonable today; a reduction of NBUWWTP's P concentration from 5.1 to 0.5 mg/L would reduce peak algal concentrations by 20 to 40%. However, the absolute levels that the model was simulating were very low by historical standards.

For this analysis we have the benefit of 20-20 hindsight, but data that are only marginally better. Furthermore, this project does not have the resources to support a more refined modeling effort. All that can be done is to re-evaluate the situation with a simplified system, considering newer data and modeling information.

To represent the Lake Dunlap system, the major elements of the WREDUN model's equations for P uptake by algae were coded into a steady state spreadsheet model. Interactions involving nitrogen, light, temperature, settling, shading, etc. are ignored. All of these can be important in calibrating a model to specific aquatic plant levels and observed events, but are relatively unimportant in evaluating the effect of adjusting one parameter of interest, point source P inputs. The key parameter which defines the sensitivity of WREDUN and other plant growth models to changes in P inputs is the phosphorus half-saturation constant. This is the concentration at which the maximum plant growth rate is reduced by 50% because the P concentration in the water is low enough to restrict growth. In a full modeling study, the setting of this value must be done in concert with the overall calibration process, because it can have a major effect on the model's representation of plant growth.

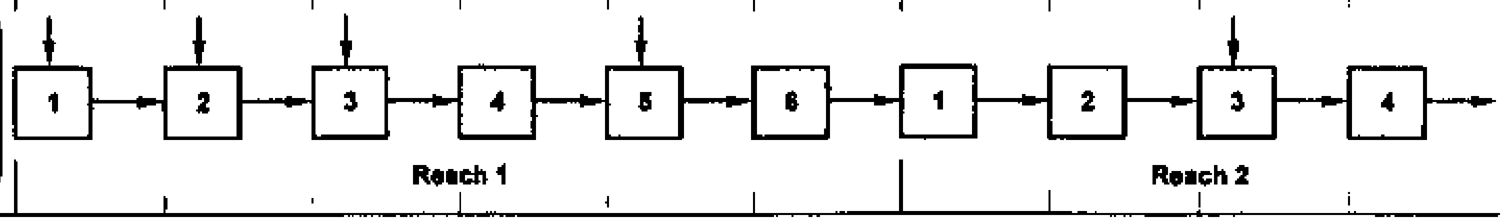
Table 5-1 shows the spreadsheet representation of the Lake Dunlap system using the calibration data available to the original study along with the calibration choices made at the time. The Guadalupe and Comal River input phosphorus concentrations were set at very low levels in the modeling study. Lake chlorophyll a values are very low, as are PO_4-P concentrations. The spreadsheet demonstrates an ability to approximate the 1977 field data. Next, the spreadsheet is adjusted to again match the field data but using a maximum growth rate and half saturation constant that appear to be more in the

TABLE 5-1

SIMPLIFIED PHOSPHORUS MODEL FOR LAKE DUNLAP - CALIBRATION USING 8/16/1977 DATA

I. Layout:										
Reach No.:	1	1	1	1	1	1	2	2	2	2
Element No.:	1	2	3	4	5	6	1	2	3	4
Length, Δx (miles):	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
River miles:	282	281	280	279	278	277	276	275	274	273
II. Given Hydraulic Data:										
Coef. for velocity, $a * 10^{5}$ =	26.67	26.67	26.67	26.67	26.67	26.67	8.33	8.33	8.33	8.33
Expo. for velocity, b =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Coef. for depth, α =	15	15	15	15	15	15	24	24	24	24
Expo. for depth, β =	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
III. Given Interaction Coefficients:										
Phos. half-sat. const., Kp (mg/L) =	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Alg. max. growth rate, μmax (1/day) =	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950
Algae respiration rate, ρ (1/day) =	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Algae mortality rate, m (1/day) =	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
Algae settling rate, σ (ft/day) =	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Frac. of P in alg., α_2 (mg P/mg Algae) =	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
IV. Given Inflow:										
Type:	Headwater	Tributary	WWTP		WWTP				WWTP	
Name:	Guadalupe River	Comal River	Mission Vall. Mill		NBU				GBRA Dunlap	
Flow (cfs) =	299.0	340.0	2.94		4.95				0.017	
PO4-P conc. (mg/L) =	0.0010	0.0040	0.3310		4.5500				0.1150	
Algae biomass conc. (mg/L) =	0.0185	0.0000	0.0000		0.0000				0.0000	

Assuming:
No nitrogen simulation
No organic detritus simulation
No light intensity simulation
No temperature simulation or correction
No DO simulation
No benthic simulation
No dispersion simulation



V. Calculated Flows & Concentrations:

Type:	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow
Flow (cfs) =	299.0	299.0	639.0	639.0	641.9	641.9	641.9	641.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9
PO4-P conc. (mg/L) =	0.0010	0.0010	0.0026	0.0026	0.0041	0.0041	0.0041	0.0041	0.0396	0.0396	0.0396	0.0396	0.0396	0.0396	0.0396	0.0395	0.0395	0.0394	0.0394	0.0393
Algae biomass conc. (mg/L) =	0.0185	0.0185	0.0077	0.0074	0.0074	0.0072	0.0072	0.0069	0.0069	0.0075	0.0075	0.0082	0.0082	0.0106	0.0106	0.0141	0.0141	0.0185	0.0185	0.0242
Chl_a (µg/L, 50 µg Ch_a/mg A used) =	0.9250	0.9250	0.3865	0.3710	0.3693	0.3580	0.3580	0.3469	0.3443	0.3762	0.3762	0.4111	0.4111	0.5389	0.5389	0.7063	0.7063	0.9254	0.9254	1.2120

VI. Calculated Hydraulic Parameters:

Velocity (ft/s) =	0.080	0.170	0.171	0.171	0.173	0.173	0.054	0.054	0.054	0.054
Depth (ft) =	15.0	15.0	15.0	15.0	15.0	15.0	24.0	24.0	24.0	24.0
Travel time (hours) =	18.4	8.6	8.6	8.6	8.5	8.5	27.2	27.2	27.2	27.2

mainstream of EPA compendium of modeling coefficients (EPA, 1985). Table 5-2 shows the calculations with only the half-saturation value lowered, resulting in a higher chlorophyll a, and 5-3 shows the calculations with the maximum growth rate reduced to match the field high-flow observations. Figure 5-1 shows the adjusted calibration to the 1977 data. The main effect of using a lower half saturation constant is to allow the modeled plants to continue to grow at substantially lower P concentrations than was the case in the original model calibration. We believe this lower half saturation concentration is more appropriate in that it tracks more closely values obtained in other model calibrations, and because it reflects the common observation of heavy aquatic plant growth in the Comal springs and river area, where P levels are rarely reported to be higher than 0.01 mg/L (USGS, 1994).

The next step in the analysis is to consider a range of Guadalupe and Comal river flows that are more representative of lower flow conditions that have been the major concern historically. Table 5-4 shows a new run with the river flow reduced to a level that is an average for the August to October 1996 period. The headwater PO_4-P concentration is set to 0.01 mg/L, representative of available low flow data. At the lower flow, model chlorophyll a is much higher: 15.3 ug/L instead of 1.2 ug/L. The effect of reducing the WWTP effluent P concentration to 0.5 mg/L can be seen in Table 5-5 and Figure 5-2. The peak chlorophyll a is reduced to 6.2 ug/L, a 60% reduction. This reduction is sensitive to the coefficients employed that have a substantial margin of error, and it would be less if river flows were higher. The result must be viewed as a preliminary estimate with much room for uncertainty. Note in comparing figures 5-1 and 5-2 that the scales are different. Note also that the algae (chlorophyll a) had not begun to experience nutrient limitation by the time the water leaves the dam. Additional algae and macrophyte growth and P uptake could be expected under this scenario further downstream. Another consideration is that background concentrations of P are frequently sufficient for extensive plant growth. The point source addition can stimulate plant growth to some degree, but is frequently not the decisive factor.

Another important observation is that this result deals only with plankton (chlorophyll a) and does not address rooted macrophytes such as hydrilla. The original study did quantify macrophytes, but had little in the way of calibration data to support the values presented. Furthermore, the study did not consider the sediments as a source of nutrients for macrophytes. A much better macrophyte simulation could be done today because more data are available, and there is a better understanding of macrophyte requirements, but the study resources do not allow the model calibration and development required to use the data. In the absence of better information, this analysis is limited to phytoplankton (chlorophyll a). However, the reader should recognize that rooted macrophytes have the ability to derive needed nutrients from the sediment, which means that reductions in the water concentration of nutrients may have

TABLE 5-2

SIMPLIFIED PHOSPHORUS MODEL FOR LAKE DUNLAP WITH UPDATED PHOSPHORUS HALF SATURATION CONSTANT

I. Layout:

Reach No.:	1	1	1	1	1	1	2	2	2	2
Element No.:	1	2	3	4	5	6	1	2	3	4
Length, Δx (miles):	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
River miles:	282	281	280	279	278	277	276	275	274	273

II. Given Hydraulic Data:

Coef. for velocity, a * 10^{-5} =	28.67	28.67	28.67	28.67	28.67	28.67	8.33	8.33	8.33	8.33
Expo. for velocity, b =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Coef. for depth, α =	15	15	15	15	15	15	24	24	24	24
Expo. for depth, β =	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

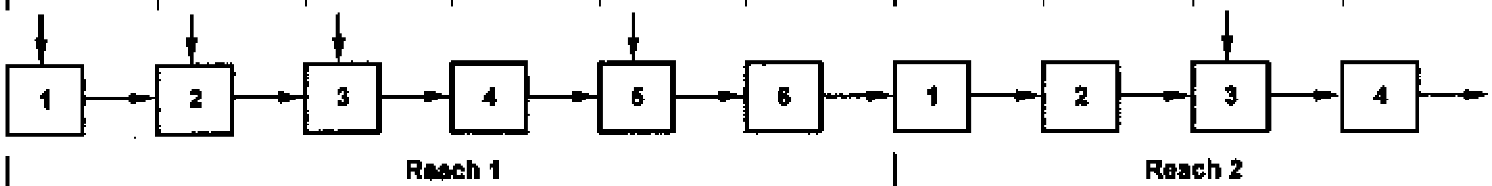
III. Given Interaction Coefficients:

Phos. half-sat. const., Kp (mg/L) =	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**
Alg. max. growth rate, µmax (1/day) =	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950
Algae respiration rate, ρ (1/day) =	0.035	0.035	0.035	0.035	0.035	0.035	0.036	0.036	0.036	0.036
Algae mortality rate, m (1/day) =	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
Algae settling rate, σ (ft/day) =	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Frac. of P in alg., a_p (mg P/mg Algae) =	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013

IV. Given Inflow:

Type:	Headwater	Tributary	WWTP		WWTP				WWTP	
Name:	Guadalupe River	Comal River	Mission Vall. Mill		NBU				GBRA Dunlap	
Flow (cfs) =	299.0	340.0	2.94		4.95				0.017	
PO4-P conc. (mg/L) =	0.0010	0.0040	0.3310		4.6500				0.1150	
Algae biomass conc. (mg/L) =	0.0185	0.0000	0.0000		0.0000				0.0000	

Assuming:
No nitrogen simulation
No organic detritus simulation
No light intensity simulation
No temperature simulation or correction
No DO simulation
No benthic simulation
No dispersion simulation



V. Calculated Flows & Concentrations:

Type:	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow
Flow (cfs) =	299.0	299.0	639.0	639.0	641.9	641.9	641.9	641.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9
PO4-P conc. (mg/L) =	0.0010	0.0010	0.0028	0.0028	0.0041	0.0041	0.0041	0.0041	0.0398	0.0398	0.0398	0.0396	0.0396	0.0394	0.0394	0.0392	0.0392	0.0388	0.0388	0.0381
Algae biomass conc. (mg/L) =	0.0185	0.0175	0.0082	0.0083	0.0083	0.0086	0.0086	0.0090	0.0089	0.0108	0.0108	0.0131	0.0131	0.0221	0.0221	0.0376	0.0376	0.0635	0.0635	0.1074
Chl_a (µg/L, 50 µg Ch_a/mg A used) =	0.9250	0.8740	0.4090	0.4144	0.4125	0.4298	0.4298	0.4477	0.4443	0.5388	0.5388	0.6533	0.6533	1.1071	1.1071	1.8754	1.8753	3.1748	3.1748	5.3690

VI. Calculated Hydraulic Parameters:

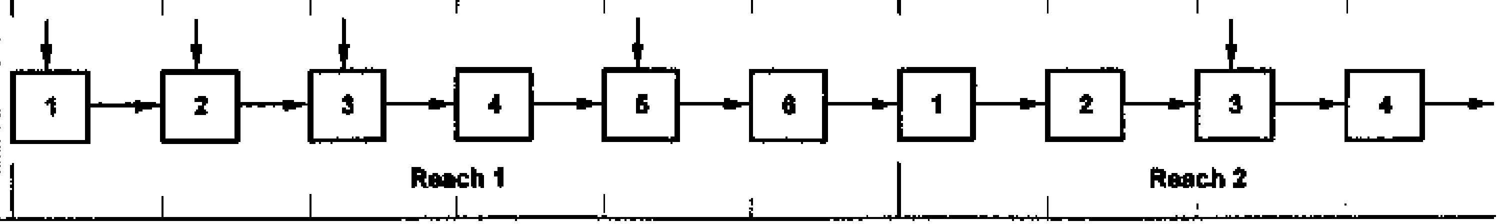
Velocity (ft/s) =	0.080	0.170	0.171	0.171	0.173	0.173	0.054	0.054	0.054	0.054
Depth (ft) =	15.0	15.0	15.0	15.0	15.0	15.0	24.0	24.0	24.0	24.0
Travel time (hours) =	18.4	8.6	8.6	8.6	8.5	8.5	27.2	27.2	27.2	27.2

TABLE 5-3

SIMPLIFIED PHOS. MODEL FOR LAKE DUNLAP WITH UPDATED PHOS. HALF SATURATION CONSTANT & MAX. GROWTH RATE

I. Layout:										
Reach No.:	1	1	1	1	1	1	2	2	2	2
Element No.:	1	2	3	4	5	6	1	2	3	4
Length, Δx (miles):	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
River miles:	282	281	280	279	278	277	276	275	274	273
II. Given Hydraulic Data:										
Coef. for velocity, $a \cdot 10^{-5}$ =	26.67	26.67	26.67	26.67	26.67	26.67	8.33	8.33	8.33	8.33
Expo. for velocity, b =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Coef. for depth, α =	15	15	15	15	15	15	24	24	24	24
Expo. for depth, β =	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
III. Given Interaction Coefficients:										
Phos. half-sat. const, Kp (mg/L) =	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Alg. max. growth rate, μ_{max} (1/day) =	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Algae respiration rate, ρ (1/day) =	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Algae mortality rate, m (1/day) =	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
Algae settling rate, σ (ft/day) =	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Frac. of P in alg., α_4 (mg P/mg Algae) =	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
IV. Given Inflow:										
Type:	Headwater	Tributary	WWTP		WWTP				WWTP	
Name:	Guadalupe River	Comal River	Mission Vall. Mill		NBU				GBRA Dunlap	
Flow (cfs) =	299.0	340.0	2.94		4.95				0.017	
PO4-P conc. (mg/L) =	0.0010	0.0040	0.3310		4.8600				0.1150	
Algae biomass conc. (mg/L) =	0.0185	0.0000	0.0000		0.0000				0.0000	

Assuming:
No nitrogen simulation
No organic detritus simulation
No light intensity simulation
No temperature simulation or correction
No DO simulation
No benthic simulation
No dispersion simulation



V. Calculated Flows & Concentrations:

Type:	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow
Flow (cfs) =	299.0	299.0	639.0	639.0	641.9	641.9	641.9	641.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9	646.9
PO4-P conc. (mg/L) =	0.0010	0.0010	0.0026	0.0026	0.0041	0.0041	0.0041	0.0041	0.0398	0.0398	0.0398	0.0398	0.0398	0.0396	0.0396	0.0395	0.0395	0.0394	0.0394	0.0393
Algae biomass conc. (mg/L) =	0.0185	0.0169	0.0079	0.0078	0.0077	0.0077	0.0077	0.0076	0.0076	0.0082	0.0082	0.0089	0.0089	0.0115	0.0115	0.0148	0.0148	0.0191	0.0191	0.0245
Chl_a (µg/L, 50 µg Ch_a/mg A used) =	0.9250	0.8460	0.3954	0.3875	0.3858	0.3840	0.3840	0.3822	0.3793	0.4116	0.4116	0.4467	0.4467	0.5751	0.5751	0.7403	0.7403	0.9529	0.9529	1.2282

VI. Calculated Hydraulic Parameters:

Velocity (ft/s) =	0.080	0.170	0.171	0.171	0.173	0.173	0.054	0.054	0.054	0.054
Depth (ft) =	15.0	15.0	15.0	15.0	15.0	15.0	24.0	24.0	24.0	24.0
Travel time (hours) =	18.4	8.6	8.6	8.6	8.5	8.5	27.2	27.2	27.2	27.2

FIGURE 5-1
SIMULATION RESULTS UNDER HIGH FLOW CONDITIONS

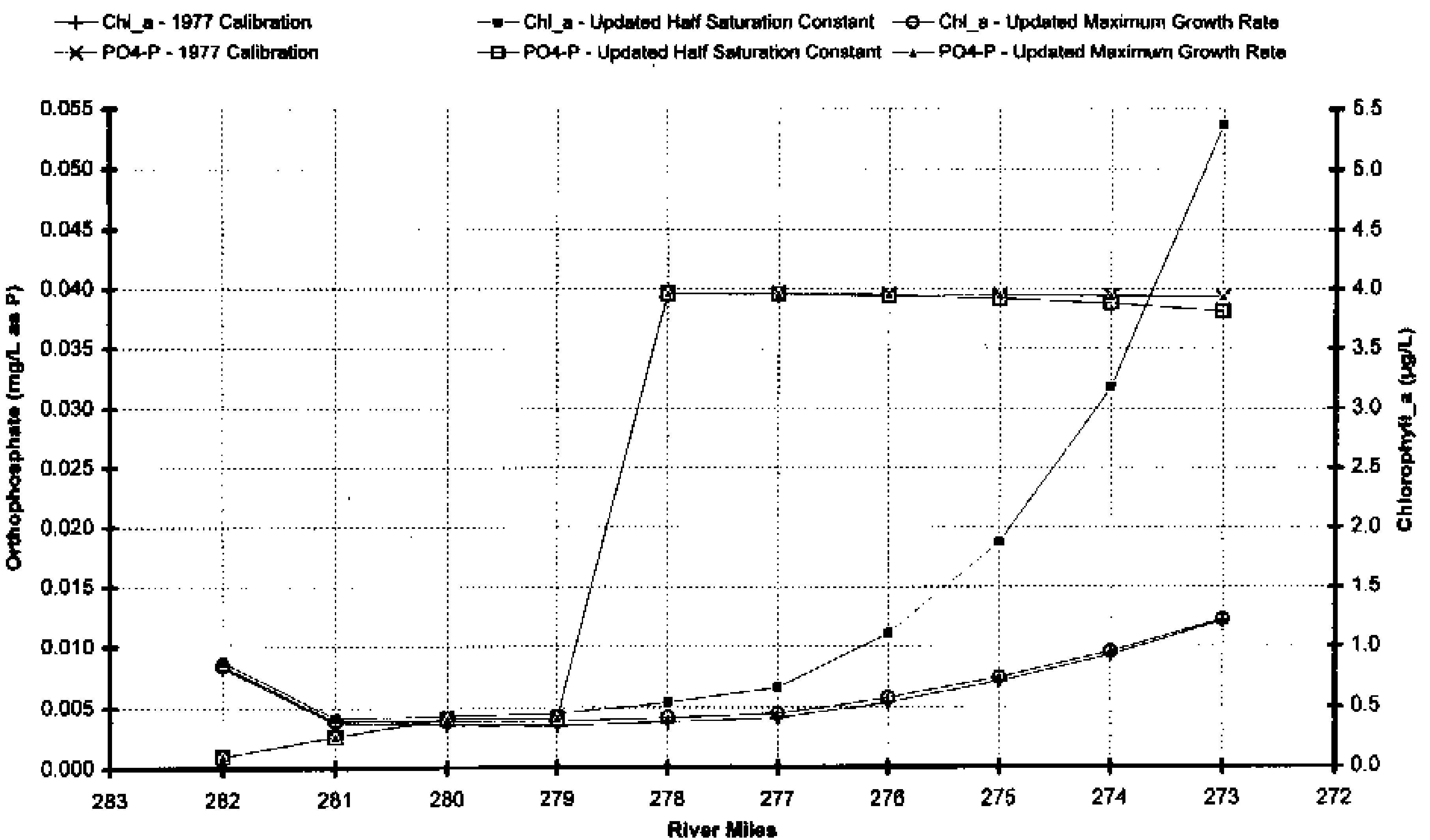
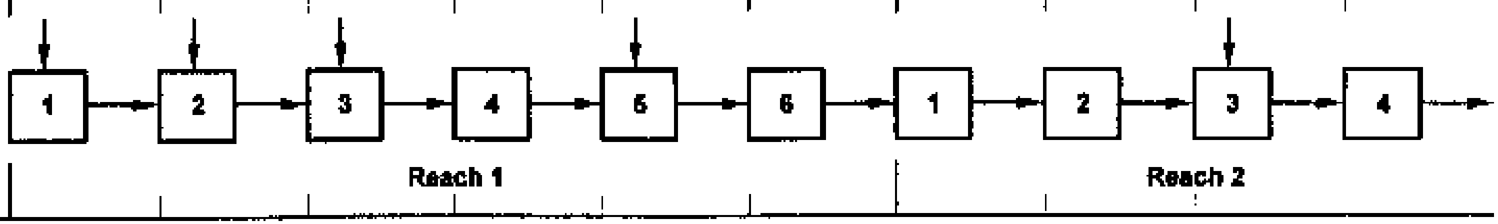


TABLE 5-4

SIMPLIFIED PHOS. MODEL FOR LAKE DUNLAP - SIMULATION OF LOW FLOW CONDITIONS DURING AUG - OCT 1995

I. Layout:										
Reach No.:	1	1	1	1	1	1	2	2	2	2
Element No.:	1	2	3	4	5	6	1	2	3	4
Length, Δx (miles):	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
River miles:	282	281	280	279	278	277	276	275	274	273
II. Given Hydraulic Data:										
Coef. for velocity, $a * 10^5$ =	26.67	26.67	26.67	26.67	26.67	26.67	8.33	8.33	8.33	8.33
Expo. for velocity, b =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Coef. for depth, α =	15	15	15	15	15	15	24	24	24	24
Expo. for depth, β =	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
III. Given Interaction Coefficients:										
Phos. half-sat. const., Kp (mg/L) =	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Alg. max. growth rate, μmax (1/day) =	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
Algae respiration rate, ρ (1/day) =	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Algae mortality rate, m (1/day) =	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
Algae settling rate, σ (ft/day) =	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Frac. of P in alg., a_4 (mg P/mg Algae) =	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
IV. Given Inflow:										
Type:	Headwater	Tributary	WWTP		WWTP				WWTP	
Name:	Guadalupe River	Comal River	Mission Vall. Mill		NBU				GBRA Dunlap	
Flow (cfs) =	84.5	140.7	2.94		4.95				0.017	
PO4-P conc. (mg/L) =	0.0100	0.0100	0.3310		4.6500				0.1150	
Algae biomass conc. (mg/L) =	0.0185	0.0000	0.0000		0.0000				0.0000	

Assuming:
No nitrogen simulation
No organic detritus simulation
No light intensity simulation
No temperature simulation or correction
No DO simulation
No benthic simulation
No dispersion simulation



V. Calculated Flows & Concentrations:

Type:	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow
Flow (cfs) =	84.5	84.6	225.2	225.2	228.2	228.2	228.2	228.2	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1
PO4-P conc. (mg/L) =	0.0100	0.0099	0.0099	0.0098	0.0141	0.0140	0.0140	0.0140	0.1124	0.1124	0.1124	0.1123	0.1123	0.1119	0.1119	0.1113	0.1113	0.1099	0.1099	0.1072
Algae biomass conc. (mg/L) =	0.0185	0.0231	0.0087	0.0095	0.0093	0.0106	0.0106	0.0120	0.0118	0.0153	0.0153	0.0198	0.0198	0.0393	0.0393	0.0779	0.0779	0.1547	0.1547	0.3067
Chl_a (ug/L, 50 μg Ch_a/mg A used) =	0.925	1.155	0.433	0.474	0.467	0.530	0.530	0.601	0.589	0.763	0.763	0.988	0.988	1.963	1.963	3.897	3.896	7.733	7.733	15.337

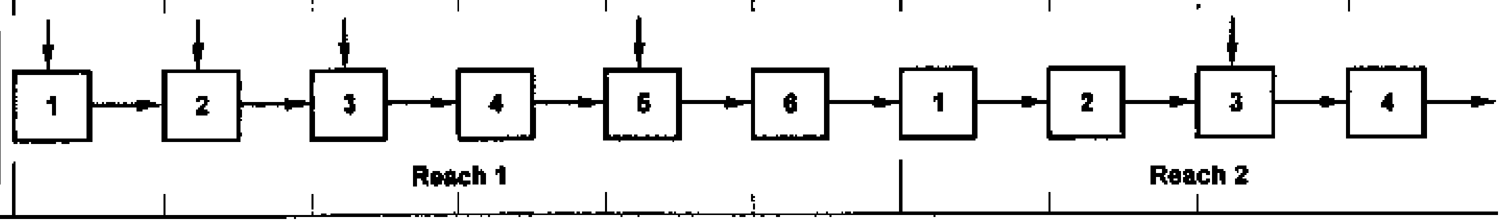
VI. Calculated Hydraulic Parameters:

Velocity (ft/s) =	0.023	0.060	0.061	0.061	0.062	0.062	0.019	0.019	0.019	0.019
Depth (ft) =	15.0	15.0	15.0	15.0	15.0	15.0	24.0	24.0	24.0	24.0
Travel time (hours) =	65.1	24.4	24.1	24.1	23.6	23.6	75.5	75.5	75.5	75.5

TABLE 5-5
SIMPLIFIED PHOS. MODEL FOR LAKE DUNLAP - SIMULATION OF POINT SOURCE PHOS. REDUCTION EFFECTS

I. Layout:										
Reach No.:	1	1	1	1	1	1	2	2	2	2
Element No.:	1	2	3	4	5	6	1	2	3	4
Length, Δx (miles):	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
River miles:	282	281	280	279	278	277	276	275	274	273
II. Given Hydraulic Data:										
Coef. for velocity, a * 10^{-5} =	26.67	26.67	26.67	26.67	26.67	26.67	8.33	8.33	8.33	8.33
Expo. for velocity, b =	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Coef. for depth, α =	15	15	15	15	15	15	24	24	24	24
Expo. for depth, β =	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
III. Given Interaction Coefficients:										
Phos. half-sat. const., Kp (mg/L) =	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Alg. max. growth rate, μmax (1/day) =	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600
Algae respiration rate, ρ (1/day) =	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Algae mortality rate, m (1/day) =	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
Algae settling rate, σ (ft/day) =	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Frac. of P in alg., a_p (mg P/mg Algae) =	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
IV. Given Inflow:										
Type:	Headwater	Tributary	WWTP		WWTP				WWTP	
Name:	Guadalupe River	Comal River	Mission Vall. Mill		NBU				GBRA Dunlap	
Flow (cfs) =	84.5	140.7	2.94		4.95				0.017	
PO4-P conc. (mg/L) =	0.0100	0.0140	0.3310		0.5000				0.5000	
Algae biomass conc. (mg/L) =	0.0185	0.0000	0.0000		0.0000				0.0000	

Assuming:
No nitrogen simulation
No organic detritus simulation
No light intensity simulation
No temperature simulation or correction
No DO simulation
No benthic simulation
No dispersion simulation

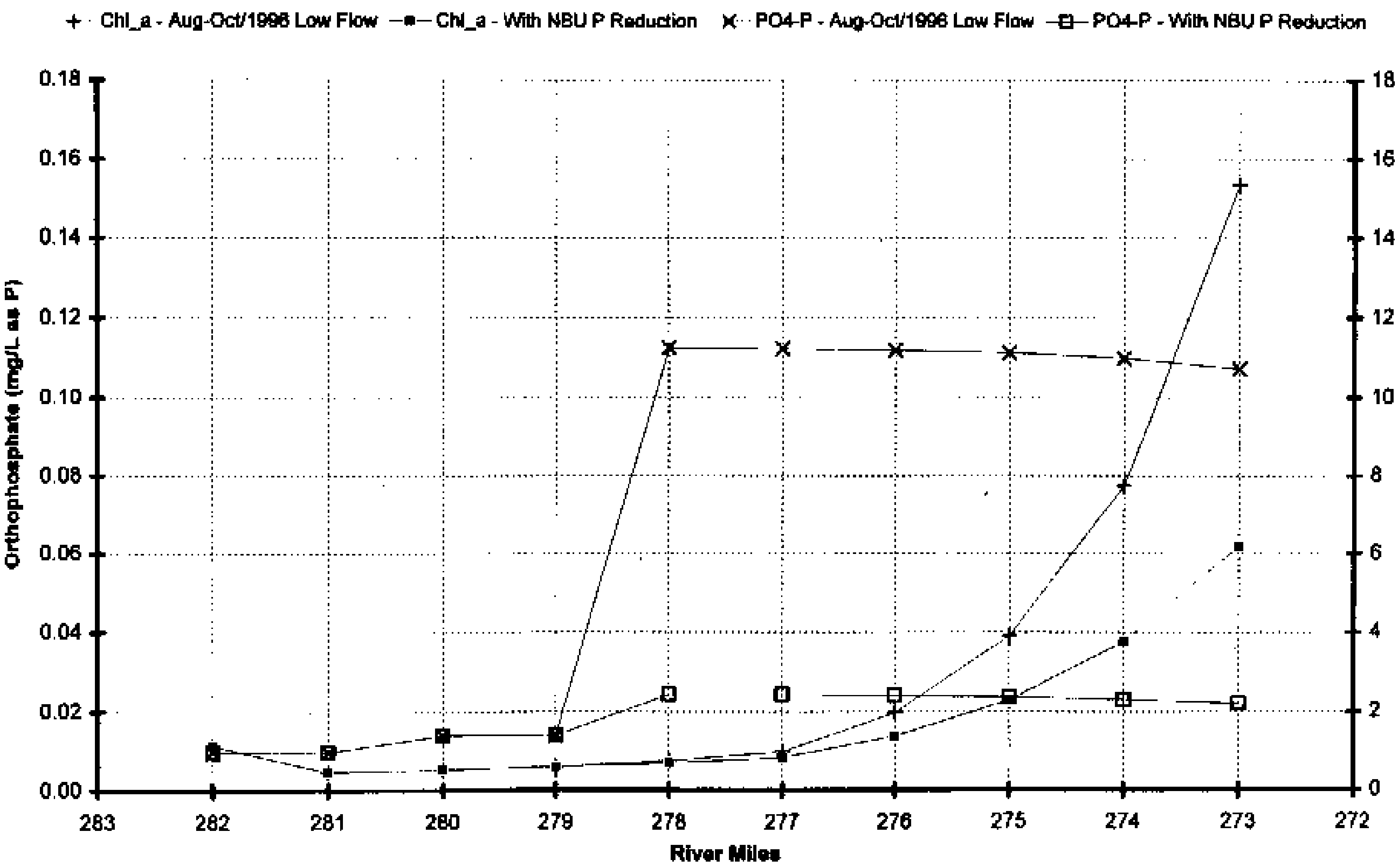


V. Calculated Flows & Concentrations:

Type:	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow	Well Mixed	Outflow
Flow (cfs) =	84.5	84.5	225.2	225.2	228.2	228.2	228.2	228.2	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1	233.1
PO4-P conc. (mg/L) =	0.0100	0.0099	0.0099	0.0099	0.0141	0.0140	0.0140	0.0140	0.0243	0.0243	0.0243	0.0242	0.0242	0.0240	0.0240	0.0236	0.0237	0.0231	0.0231	0.0221
Algae biomass conc. (mg/L) =	0.0185	0.0231	0.0087	0.0095	0.0093	0.0106	0.0106	0.0120	0.0118	0.0140	0.0140	0.0167	0.0167	0.0277	0.0277	0.0458	0.0457	0.0754	0.0754	0.1235
Chl_a (μg/L, 50 μg Chl_a/mg A used) =	0.925	1.155	0.433	0.474	0.467	0.530	0.530	0.601	0.589	0.702	0.702	0.837	0.837	1.385	1.385	2.288	2.287	3.768	3.768	6.174

VI. Calculated Hydraulic Parameters:										
Velocity (ft/s) =	0.023	0.060	0.061	0.061	0.062	0.062	0.019	0.019	0.019	0.019
Depth (ft) =	15.0	15.0	15.0	15.0	15.0	15.0	24.0	24.0	24.0	24.0
Travel time (hours) =	66.1	24.4	24.1	24.1	23.6	23.6	75.5	75.5	75.5	75.5

FIGURE 5-2
SIMULATION RESULTS UNDER LOW FLOW CONDITIONS



Po4mod1.xlc 6/19/98 11:02 AM YCS

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relatively little effect on macrophyte growth. Barber (1991) reached exactly the same conclusion in a macrophyte modeling study on the Colorado River below the City of Austin.

5.1.2 Estimating the Cost of Point Source P Reduction

When point source nutrient removal was considered in the 1977-82 era, the primary alternatives evaluated were chemical addition (lime, alum or ferric chloride). These methods are effective, but relatively costly, both in terms of initial cost and in terms of O&M costs for chemicals and the cost of additional sludge disposal. The cost estimated in 1982 to achieve 0.5 mg/L effluent P concentration was about $2,000,000 in capital costs and between $126,000 and $782,000 per year in operating and maintenance costs (GBRA and Glass Environmental Consultants, 1982). That could amount to almost a million per year in annualized 1982 dollars, or several million per year in inflation-adjusted 1998 dollars. This relatively high cost of nutrient removal appears to have been a significant factor in the decision to take no action on point source nutrient removal at that time.

Since that time there has been a great deal of work on biological nutrient removal (BNR). In very brief terms, nitrogen is removed by first oxidizing organic and ammonia forms of nitrogen to nitrate and then reducing this to nitrogen gas in an anoxic zone of a treatment plant. Phosphorus is removed by process modifications that increase the P content of the sludge, sometimes combined with chemical addition for effluent polishing. The main advantage of BNR over chemical methods is that chemical and excess sludge treatment costs are affected to a much smaller extent.

While BNR is widely used on the East Coast of the US and other countries, it is not common in Texas. However, there is some experience in the local area. For approximately ten years the City of Kerrville has operated a WWTP for P removal. They have been achieving an effluent limit of 1.0 mg/L all the time and 0.5 total mg P/L when the Guadalupe River flow drops below 50 cfs. Harder et al. (1998) provides details on the Kerrville program and success with methods to reduce chemical additions. The City of Austin performed a retrofit of one train on the South Austin Regional WWTP to achieve BNR. While the City had some development problems, they were able to achieve reliably an effluent P level of less than 1 mg/L at the end of their evaluation project. Additional facilities in the area include the City of San Marcos and the City of Cedar Park. All of this local experience can provide very useful insight into the likely cost and effectiveness of BNR, should it be considered. For this preliminary analysis, discussions suggest that the two larger NBUWWTPs could be modified to achieve P removal similar to Kerrville's for a capital cost on the order of $2 million and annual additional costs for chemicals, power and sludge of on the order of $200,000. Depending on interest rates and substantial margin of uncertainty, this would be an annual average cost of $300,000 to $400,000. The smaller NBU

Gruene plant and the GBRA Lake Dunlap plant would incur smaller but still substantial costs. To include these plants, the upper limit of the annual cost estimate is increased to $500,000. This cost can be expected to reduce planktonic algae levels in Lake Dunlap as well as the downstream lakes when the river flows are low to moderate, and may also produce smaller reductions in macrophytes.

On the subject of P removal, one item that should be considered is a ban on phosphate detergents. The City of Austin (Bhattarai, pers. com. 1998) instituted such a ban in 1991, and over the course of a year noted a 25% to 30% reduction in treatment plant effluent P concentrations. A desirable aspect of this is that there was a very small cost involved. Some reductions in phosphates in laundry products has undoubtedly occurred from voluntary actions by manufacturers over the years, and the amount of additional reduction that could be obtained in the New Braunfels area would have to be evaluated.

Another alternative for point source P reduction that should be given further consideration is dry-weather land application. Under this concept, the WWTPs would obtain relations with sufficient nearby land to allow all of the effluent to be used for irrigation when the need is greatest, during the growing season when there is no major rain. This would remove essentially all of the point source P during times when it would have the biggest effect on the lake. During rainy periods or when river flows are high, and during the winter when plant growth is slow, the treatment plants could discharge under the provisions of their current permits.

The major cost for this alternative would be the pumping and distribution system for the effluent. Operating the irrigation system and complying with the regulations for land application would require additional specialized labor. The amount of land needed, the pumping distances involved, and effects on water rights issues would have to be determined in additional studies. It is not clear whether the effluent could be sold to landowners desiring irrigation or whether there would be a cost for disposal. This would have to be determined in negotiations. Because of the above uncertainties, it is not possible to assign a cost for dry-weather land application, other than to note that it is likely to be substantially less costly than BNR.

5.2 HERBICIDE TREATMENT

This alternative essentially represents a continuation of present actions. For many years the TPWD has treated several of the Guadalupe River hydro lakes to control nuisance plants. The following is a tabulation of the TPWD activity during the period late 1995 to 1997.

Date	Lake	Species	Acreage	Herbicide
9/95	H-4	Waterhyacinth	2	Weedar 64
3/96	McQueeney	Hydrilla	305	Sonar SRP
5/96	Dunlap	Hydrilla	105	Aquathol-k
5/96	McQueeney	Hydrilla	103	Aquathol-k
6/96	Placid	Hydrilla	3.7	Aquathol-k
6/96	Dunlap	Waterhyacinth	1	Weedar 64
6/96	Placid	Waterhyacinth	4	Weedar 64
6/96	H-4	Waterhyacinth	4.5	Weedar 64
8/96	H-4	Waterhyacinth	8	Weedar 64
8/96	H-4	Waterhyacinth	11	Weedar 64
6/97	H-4	Waterhyacinth	11	Weedar 64
7/97	H-4	Waterhyacinth	8	Weedar 64
8/97	H-4	Waterhyacinth	4	Weedar 64

The historical application frequency has varied substantially. The above table begins in the fall of 1995. Herbicide applications had been made on Lake Dunlap in the spring of 1995, and also 1994, but these are not included in the above table. The TPWD performed all of these herbicide treatments. Costs for the herbicide itself range from $210 to over $1,000 per acre, depending on the chemical used and the application rate (Harvey, TPWD, 1998). During 1996, the cost for the herbicide itself was $25,000 on Lake Dunlap and $165,000 for Lake McQueeney. These direct herbicide costs were paid by the Friends of Lake McQueeney, the Preserve Lake Dunlap Association, and the GBRA.

All the costs associated with application were provided by TPWD. However, the TPWD is making plans to charge the full costs including the administrative and overhead costs of the herbicide program. In short, the cost of herbicide use, which up till now has been partially supported by TPWD, will increase.

For estimation purposes, we will assume the overall cost is approximately $500 per acre. If that figure is correct, the cost of the 1996 treatment on Lake Dunlap would have been over $50,000, and the 400 acres treated on Lake McQueeney would be about $200,000. Costs for Lake Placid and H-4 would be approximately $30,000.

Assuming that treatment will continue to be needed in the spring or early summer when river flows are low to moderate (i.e. say 2 out of 3 years), a rough estimate can be developed. Taking two thirds of the 1996 cost, the annual average cost for this alternative for all the lakes in the system would be on the order of $180,000 per year.

In addition to being a substantial cost, herbicide use can generate a measure of public concern. Proper application requires a great deal of care and effort to provide notice of the event and to coordinate with the public. Also, there needs to be careful monitoring of the technical literature on herbicide effects to be in a position to render informed technical opinions on public health and safety issues.

5.3 TRIPLOID GRASS CARP

Grass carp (*Ctenopharyngodon idella*) have long been known to feed on macrophytes and be effective in controlling plant levels. However, they are not native to the area and can cause problems if allowed to proliferate without proper controls. To address that concern, all grass carp added to Texas waterways are required by TPWD to be sterile. The technical term is triploid.

One technical question was whether grass carp would remain in the hydro-lakes. To address that question, the TPWD performed a study where it released 25 radio tagged triploid grass carp in each of five hydro-lakes in the system in the spring of 1995. In January of 1996, follow-up tracking (Prentice, 1998) indicated all 25 of the carp were still accounted for in Lake Dunlap. In February 1997, the number had declined to 18, and by May of 1998 there were only 2 remaining radio tagged fish. The bulk of the reduction occurred during the spring and summer of 1997, a time when river flows were unusually high.

In June of 1996 this effort was expanded to include 10,000 fish being released, with 5,000 each in Lake Dunlap and McQueeney. It can be presumed that roughly the same percentage (2/25 or 8%) of these fish remain in Lake Dunlap following the high flows in 1997.

The cost for the initial radio-tagging effort was approximately $81,000. The expanded program to stock the two lakes with triploid carp cost $78,750. The expanded stocking effort was paid for by Friends of Lake McQueeney, Preserve Lake Dunlap Association, GBRA, Comal and Guadalupe County Commissioners Court, NBU, and the Corps of Engineers Aquatic Weed Control Program, with labor and equipment provided by the TPWD. A full evaluation of the effectiveness of this effort is difficult. The high river flows in 1997 apparently washed out most of the carp as well as the hydrilla. While it may be assumed that the grass carp are effective and will stay in their assigned lakes during low to moderate flows, it appears that restocking would be needed every two to three years. A rough estimate of annual average costs for macrophyte control with triploid grass carp for Lake Dunlap would be $15,000 per year.

The stocking of Lake Dunlap (and other lakes) with triploid grass carp can be expected to be effective against macrophytes, but will have no effect on planktonic algae. Another concern might be that grass carp would overgraze vegetation, reducing the cover available for more desirable sport fish. Perhaps the biggest concern is the possible effects on the estuarine areas where most of the carp are ultimately transported.

5.4 MECHANICAL HARVESTING

Operating a mechanical harvester to control macrophytes is not a new idea. One was used in Landa Park in the late 1960s, and it was the major control mechanism for decades in Aquarena Springs, similar to Comal Springs. Except for these, the use of harvesters has not been common in the area, but recent developments have renewed interest. Specifically, the LCRA has worked with the Tennessee Valley Authority (TVA) on testing a portable harvester on Lake Bastrop in June of 1998. Also, in June of 1998 the GBRA announced they were seeking to negotiate an agreement with LCRA, TPWD, Friends of Lake McQueeney, Sportsman Conservationists of Texas and Angler's Group to share in the cost of testing a mechanical vegetation harvester.

One of the concerns with mechanical harvesting is disposal of the cut material. There are two basic alternatives, removal of the cuttings or leaving the cut material in the water. Leaving the material in the water is the least costly approach. However, in some cases the pieces can become a major source of organic matter returned to the lake where it will decay and recycle the nutrients. This can pose an oxygen demand problem as well as an aesthetic concern. In addition, with some plant species such as hydrilla the pieces can form new plants, resulting in further spread of the problem. The particular machine lent to the LCRA by the TVA cuts plants into smaller pieces that can sink to the bottom. LCRA is performing tests for these effects on Lake Bastrop.

Removal of the cuttings is desirable in avoiding these problems. However, the cost of hauling the cuttings out of a lake and disposal at a suitable location can be substantial.

The U.S. Army Corps of Engineers' Lake Seminole Hydrilla Action Plan (USCE, Mobile District, 1998) investigated the cost of mechanical harvesting at Lake Seminole. Their intent was to use a combination of several methods to combat hydrilla. The Corps noted that control of aquatic weeds could be obtained, to a limited extent, using a mechanical harvester. However, the Corps notes that equipment cost is quite high and its operating parameters severely limit the extent of acreage that can be controlled as well as areas of operation. They note that current use of a harvester by TVA is limited to cutting 20-40 foot wide boat lanes from public access points to open channels.

The Corps estimates the total initial investment in the mechanical harvester at $130,000. Following is a summary of their cost analysis.

> "The mechanical harvester has an 8-foot swath width (6-foot effective swath assuming a 25% overlap) and cuts the weeds off 3-5 feet below the surface. The harvester has a cutting speed of 1.0 mile per hour and will average 2 hours of cutting time per 8-hour day (25% efficiency coefficient because of transport time from one area to another). This combination of effective swath width, speed and efficiency will result in only 0.182 acres being harvested per hour. Also, harvester does not operate efficiently in and around docks or piers; or in areas where underwater obstructions are prevalent. For these reasons, it is estimated that the harvester can cover roughly 100 acres per year during its July - September operating season. To date, use of the harvester has been limited to clearing boat lanes in public use areas.
>
> The costs associated with the operation of a mechanical harvester can be characterized as a high fixed-to-variable cost ratio, essentially the exact opposite of the chemical applicator. This would result in a continual decline of per acre costs as acreage is expanded. However, since the coverage is limited to roughly 100 acres per year, significant efficiencies associated with the use of this equipment are not physically attainable. Harvester costs decline from just over $3,000 per acre (20 acres annually) to just over $1,000 per acre (75 acres annually). Costs decline still further to $832 per acre if 100 acres are harvested. Any changes in operating procedures that result in greater speed or reduce the travel time between weed infestations would significantly improve the economics associated with the harvester."

If a harvester were dedicated to the hydro-lakes area, there would be a reported capital cost of about $130,000. Assuming a ten-year useful life, 10% of capital cost per year in operation and maintenance, and operation only during the summer with a crew of two full-time staff used only during the summer, an annual average cost of about $60,000 to $100,000 is estimated. However, given the variable nature of the need, it may not be cost-effective to own and operate a harvester for the hydro-lakes. If a contractor provides harvesting services on an as-needed basis, the cost per acre harvested could be higher but the overall long-term cost might well be lower. The testing program with LCRA and TPWD described above will provide improved operational and cost data to better evaluate this alternative.

5.5 INTEGRATED MANAGEMENT

With many situations and possible tools, it is clear that no single method is likely to be optimal under all circumstances. The ideal approach is thus one that employs all available resources to achieve the highest degree of control at the lowest public cost.

There is little doubt that measures including some level of nutrient source management, herbicide application, triploid grass carp stocking and mechanical harvesting can all play a useful role. One additional measure may be selective plantings of native macrophytes which do not have as high a potential to achieve rapid growth and harmful levels as do hydrilla and water hyacinth. Under certain circumstances such native macrophytes might prevent harmful species from becoming dominant and doing damage to the lake resources. Another example is selective use of biological agents such as the lettuce weevil to control water lettuce.

A key element to a successful integrated management program is continuous monitoring of the aquatic plant situation so that early warning of a problem is available. Early warning allows response measures to be taken before the major impact has occurred. This should substantially reduce the cost of treatment actions, and also minimize the adverse effects on lake usage.

6.0 SUMMARY AND RECOMMENDATIONS

Aquatic plants have been documented as major concerns in Lake Dunlap since at least the 1960s, and were probably a problem from time to time since the lake was created in 1928. Over the years there have been a number of studies of the problem, but recent efforts to control harmful macrophyte infestations have focused primarily on herbicides and triploid grass carp. More recently there has been heightened attention arising from concerns over continued herbicide use and the effectiveness of other options. This study was conceived as part of the Texas Clean Rivers Program to evaluate available data and alternatives.

The primary emphasis of the study has been on revisiting the alternative of point source nutrient reduction. This had been examined almost twenty years earlier, but no action was taken at that time. In the meantime, a number of other alternatives including herbicides, sterile grass carp and mechanical harvesting were either being used or actively considered. This study reexamined point source nutrient removal in a preliminary manner, and put that alternative as well as the others mentioned on a roughly equal basis for comparison.

The major findings of the study are:

1. Removal of phosphorus from point sources down to the 0.5 mg/L level would reduce to some degree but not eliminate excessive algae and macrophyte growth. Whether the reduction in macrophyte density would be significant or not is problematical given the relatively high background concentration of phosphorus and ability of the major plant species of concern, hydrilla, to take its nutrients from the sediment. The annualized cost for just the two major NBU WWTPs would be on the order of $300,000 to $400,000 per year. Additional costs would be required for the smaller WWTPs operated by the GBRA and NBU. More accurate estimates of the amount of reduction under given conditions could be developed, but such work would depend on having additional phosphorus data (with lower detection limits) as well as more complete observations of plant and macrophyte concentrations.

2. A smaller reduction in point source P load might be achieved at very low cost by banning higher phosphate detergents from use in the area. The City of Austin took this step in 1991, and city staff (Bhattarai, 1998) reported a 25% to 30% reduction in the total P effluent concentration. Because of voluntary reductions in phosphates from various manufacturers over time, the amount of reduction possible in New

Braunfels may be much smaller. Nevertheless, this is a low-cost action that should be given further consideration, as it would be desirable to have in place if nutrient removal at the treatment plants were ever initiated.

3. Another alternative that needs further evaluation is dry weather effluent irrigation. Because open land appears to be available in reasonable proximity to the major WWTPs, this could be at least as effective as biological nutrient removal but considerably less costly.

4. The other alternatives considered, herbicides, sterile grass carp, and mechanical harvesting all appear to be more effective and less costly than direct point source P removal on an annual basis. However, they all carry with them some negative aspects. Each is limited to the specific lake of application, while nutrient removal benefits all downstream lakes to some degree.

From these findings, the following study recommendations are:

1. Given the diverse nature of the alternatives and their consequences, and the variable nature of conditions in Lake Dunlap and the other hydro-lakes, it appears that the most desirable plan to manage aquatic plant problems will be an integrated combination of all the available alternatives. The options include: mechanical cutting, chemical treatment with herbicides, and biological controls such as sterile grass carp, water lettuce weevils, and replanting of native aquatic plants. A critical element of the integrated approach will be frequent monitoring of the degree of aquatic plant infestation so that response measures can be taken while the problem is relatively small and more easily managed.

2. As part of the integrated approach, the GBRA and NBU should initiate discussions with the City of New Braunfels and major detergent vendors to determine the best way to insure that any phosphorus input that can be easily avoided is removed from the system.

3. In the same spirit, the GBRA and the NBU should begin preliminary engineering to better quantify the cost of dry weather land application. If this can be achieved at relatively low cost, the GBRA and NBU should consider going forward with this

option, recognizing that reductions in point source nutrient inputs will be helpful but are not likely to eliminate the aquatic plant problem by itself.

4. While mechanical cutting probably has only limited utility on Lake Dunlap and Lake McQueeney, it should be given further testing.

5. The management of vegetation in lakes is not unique to Lake Dunlap; it is similar to other water resource issues that must be addressed. Means for recovery of costs is a major issue for all management options.

7.0 REFERENCES

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ATTACHMENT A

CORRESPONDENCE RELATED TO AQUATIC PLANTS

O. C. FISHER
21ST DIST., TEXAS

RECEIVED
AUG 25 1969
G. B. R. A.
GENERAL OFFICE

Congress of the United States
House of Representatives
Washington, D.C. 20515

August 18, 1969

Mr. George E. Novotny, C.L.U.
165 S. Seguin Avenue
New Braunfels, Texas 78130

Dear Mr. Novotny:

In response to your letter of August 13, I am pleased to assure you that I will certainly do all that I can to assist the property owners on Lake Dunlap with the weed and hyacinthus problem. I would appreciate very much your mentioning to Mr. Robert Vahrenkamp that I am interested and ask him to let me know what I can do.

With best regards, I remain

Sincerely,

O. C. Fisher

1ST NATIONAL BANK of New Braunfels P.O. DRAWER 251 NEW BRAUNFELS TEXAS 78130

JOSEPH FAUST
PRESIDENT

RECEIVED
AUG 20 1969
G. B. R. A.
GENERAL OFFICE

August 19, 1969

Mr. R. H. Vahrenkamp
General Manager
Guadalupe-Blanco River Authority
Post Office Box 271
Seguin, Texas 78155

Dear Porky:

I read with much interest the notice to the property owners on McQueeney of the Authority's notice to lower the level of their lake today. We have the daily opportunity of working on our banks so I guess we are really better off then they are.

In all seriousness, you mentioned water quality, and we on Dunlap are faced with a much more serious condition then the daily change in the water level in that we are experiencing an infestation of aquatic plants which I am sure will spread to the entire chain of lakes if something is not done.

There have been a number of Dunlap property owners who have expressed grave concern regarding this condition and some thought has been given to the possibility of forming a water recreation district with powers of taxation which would work with the Authority in preserving a very fine lake which we all enjoy so much. I would very much appreciate your views on this and any suggestions you might have.

If you would care to make an on the spot inspection some afternoon after three my boat is at your disposal and we might even find suitable liquid refreshments available.

Very truly yours,

Joseph Faust

JF/cs

B

JAMES R. NOWLIN
475 MILAM BLDG.
SAN ANTONIO, TEXAS 78205

HOUSE OF REPRESENTATIVES
AUSTIN

COMMITTEES:
VICE CHAIRMAN:
YOUTH
MEMBER:
CONSTITUTIONAL AMENDMENTS
PRIVILEGES, SUFFRAGE AND ELECTIONS
JUDICIARY
MENTAL HEALTH AND MENTAL RETARDATION

October 7, 1969

Mr. Howard B. Boswell, Executive Director
Texas Water Development Board
301 West 2nd Street
Austin, Texas

Dear Mr. Boswell:

I have been contacted recently by a good friend and constituent and also a member of our San Antonio City Council, Mr. Ed Hill, regarding problems which he has encountered on property he owns on the Guadalupe River just outside of New Braunfels, Texas, and near Lake Dunlap. Councilman Hill stated that the cutting of grass and weeds, probably on or near the Landa Park Golf Course, consistently causes a backup of grass and other foreign materials along and adjacent to the docks and boat houses down river on the Guadalupe. If your office has any jurisdiction in this matter, I would appreciate an inquiry into it or your advice as to the proper board or agency to which I should refer Councilman Hill's complaint.

Thank you for your assistance in this matter. With kindest personal regards, I am

Sincerely,

James R. Nowlin
James R. Nowlin

JRN:tg

RECEIVED
OCT 8 1969
TEXAS WATER
DEVELOPMENT BOARD

The City of
New Braunfels

POST OFFICE BOX 644 NEW BRAUNFELS, TEXAS

October 30, 1969

Mr. Hugh C. Yantis, Jr.
Executive Director
Texas Water Quality Board
1108 Lavaca Street
Austin, Texas 78701

Dear Mr. Yantis:

Thank you for your letter dated October 21st, 1969. We are aware that weeds being cut in Landa Park by the City and other agencies have caused some problems in the Guadalupe and Comal below their source. However, we did not realize that these cuttings which escape us are causing a pollution problem, as much as they are a nuisance to property owners and tourist facilities.

The City has taken quite extensive steps to eliminate the weed problem. We have just this past spring purchased a new aquatic weedcutter at a cost of $27,000.00 which is designed to cut and harvest all weeds as they are cut, and it is doing a good job. Our main problem lies with a subdivision known as Landa Park Estates who govern a portion of the Comal River and cut their own weeds and do not collect them. This agency controlling that portion of the river is known as the Comal County Water Recreational District #1.

At this time, some weeds are also escaping the Lower Colorado River Authority Plant below Landa Park. Mr. Oliver Haas, Manager of the local LCRA Plant, and I have discussed the problem and he has assured me that they are working on a system to collect all cuttings missed by our present machinery. The Landa Park Manager and I are working with the Comal County Water Recreational District #1 to eliminate their problem at the same time.

I am sure that the situation will be much improved by next spring. Please keep us informed of any complaints you may receive and we will continually try to improve on our facility. I would like to invite you, at your convenience, to come to New Braunfels and inspect the situation with me.

Sincerely yours,

Jack Ohlrich, Mayor

JO/jr
cc: Honorable James R. Nowlin, San Antonio, Texas 78205
Mr. Howard D. Boswell, Austin, Texas 78701
Mr. Robert Vahrenkamp, Seguin, Texas 78155

ATTACHMENT B

CORRESPONDENCE RELATED TO MECHANICAL HARVESTING OF AQUATIC PLANTS

TEXAS WATER QUALITY BOARD

1108 LAVACA ST. 475-2651
AUSTIN, TEXAS 78701

November 25, 1969

Honorable Jack Ohlrich, Mayor
City of New Braunfels
P. O. Box 644
New Braunfels, Texas

Dear Mayor Ohlrich:

I certainly appreciate your letter of October 30, 1969, providing to me the information requested in my letter of October 21, 1969, relative to the nuisance problem in the Guadalupe River below Landa Park caused by the escape of aquatic weeds cut from the river in the park area. I certainly appreciate the steps taken by the city in controlling this problem and hope that the city's new aquatic weed cutter functions as planned. I note that in addition to the city, the Lower Colorado River Authority and the Comal County Water Recreation District #1 both cut weeds in the river and that you have or propose to discuss the nuisance problem and its solution with both parties. In this connection, I am asking our district representative, Mr. Tim Morris, to call on you at his next opportunity to see if he can be of assistance in this effort.

I certainly appreciate your offer to carry me on an inspection trip to view this problem and the solutions being put into effect. Due to the press of other matters, however, I will be unable to accept your very fine invitation.

Very truly yours,

Hugh C. Yantis, Jr.
Executive Director

ccs: The Honorable James R. Nowlin
Guadalupe-Blanco River Authority
Lower Colorado River Authority
Mr. J. R. Singleton, E.D., Texas Parks & Wildlife Dept.
Mr. Howard B. Boswell, Texas Water Development Board

ATTACHMENT C

SUMMARIES OF STUDIES OF NUTRIENTS AND AQUATIC PLANTS ON LAKE DUNLAP

LITERATURE REVIEW AND SUMMARY
LAKE DUNLAP NUTRIENT AND EUTROPHICATION CONCERNS

The Lake Dunlap reach of the Guadalupe River has been studied extensively over the years in relation to nutrients and eutrophication concerns. The following literature review provides a brief summary of the reports and studies prepared for Lake Dunlap, as well as those for this reach of the Guadalupe River. It is arranged chronologically, and attempts to include all major studies. However, in view of the large number of years that have passed, it is recognized that some important work may have been overlooked.

In addition to the brief summary of the work performed, any data collected that is not part of some other database, is presented in tabular form as an attachment.

Hannan, Herbert H. and Willard C. Young. 1970. Physiochemical Limnology of the Guadalupe River, Texas. Texas Water Quality Board, Grant No. 373.

This study, from February 1969 to January 1970, included taking water samples from 16 stations along the Guadalupe River downstream of the confluence with the Comal River, to point 20 m above the dam in Lake Wood. Several limnological parameters were analyzed, including nutrient concentrations.

Throughout the study period, Hannan and Young, found that the concentration of Nitrate-N ranged from 0.02 mg/L to 0.43 mg/L. Below the confluence with the Comal River and below wastewater treatment plant outfalls in New Braunfels and Mission Valley had concentrations above 0.20 mg/L. This increase in concentration was attributed to low flow conditions and natural springs that feed the Comal River. Nitrate-N was greater than 0.01 mg/L and less than 0.02 mg/L for the remaining stations. The TKN concentration ranged from 0.30 mg/L to 0.60 mg/L, with higher concentrations correlated with increased chlorophyll a. Sewage effluents entering the river increased ammonia-N concentration in the river, however this was quickly assimilated.

Hannan and Young stated that based on this study it appears that the river is assimilating phosphorus as it travels downstream of the sewage treatment plants. Above the New Braunfels treatment plant, mean total phosphate-P concentrations were 0.05 mg/L or less. However below the treatment plant the mean concentration was greater than 0.5 mg/L. Mean concentrations below the Sequin treatment plant were also higher than upstream, at 0.08 mg/L or greater. Hannan and Young deduced that sewage treatment plants were an obvious source in the study area.

In comparing sources of nitrate-N and phosphate-P, Hannan and Young reported that while phosphate-P was associated with sewage outfalls, nitrate-N was not. They also determined that retention in reservoirs reduced the concentration of nitrate-N and that phosphate-P was the most critical parameter in addressing eutrophication.

Mayhew, Joe J. 1970. Nitrogen and Phosphorus Dynamics in a 153 Kilometer Stretch of the Guadalupe River, Texas. M.S. thesis, Southwest Texas State University, San Marcos, Texas. 147 pp.

Southwest Texas State University. 1970. (in TWQB Report No. 31990, Brandes and Andrews, 1977)

H.H. Hannan, W.C. Long and J.J. Mayhew conducted studies on Lake Dunlap indicating that nitrogen over the limiting nutrient. Southwest Texas State University conducted a study from February 1969 to January 1970 at three stations, one located just below the Comal and Guadalupe River confluence, one between the New Braunfels STP and Mission Valley Mills effluent, and the last upstream between dam below Lake Dunlap.

Total nitrogen increased to 1.37 mg/L below the point source discharges (Station 2) and decreased upstream of the dam below Lake Dunlap. Total phosphorus concentrations were as high as of 0.08 mg/L between the confluence and the treatment plant discharges which was attributed to point and nonpoint sources of phosphorus. However, the primary source was the New Braunfels STP. Phosphorus levels were suspected to remain constant from the treatment plant discharge points to the station upstream from the dam, suggesting the P uptake is insignificant or being offset by other sources.

The trophic state of the reservoir was also represented through biological considerations. The diversity, extent and rate of growth of algal and aquatic plants are related to the eutrophication process. A table is included in the report that summarizes available information on aquatic vegetation in the vicinity of Lake Dunlap. The information above can be found in, Data Report for Lake Dunlap Eutrophication Study, submitted to the Texas Water Quality Board in April 1977.

Forrest and Cotton, Inc. 1970. Water Quality Management Study: Guadalupe River Basin.

Report No.1, Survey of Existing Water Quality. Guadalupe-Blanco River Authority and Upper Guadalupe River Authority.

The purpose of this study was to assist the Texas Water Quality Board (TWQB) in reviewing current water quality standards and establishing future standards as well as providing a source of information for quality management programs. The parameters of primary concern were DO, pH, temperature, and Cl, however, other parameters were analyzed and discussed briefly.

Some nutrient analyses were made in the Seguin-New Braunfels segment on June 16 and 18 and August 19, 1969; however, not all sites were analyzed for all nutrient parameters. Nitrate concentrations at stations at or just below the confluence with the Guadalupe River were as high as 1.15 mg/L with other values of 1.12 and 1.09 mg/L in this area on July 16. (Nitrate-N concentrations in Lake Dunlap as well as other NB and Sequin locations ranged from 0.1 mg/L to 1.27 mg/L on sampled dates.) Orthophosphate levels ranged from trace to 1.18 mg/L just above the confluence of the Comal River on August 19. This was noted to be 39 times higher than orthophosphate found in unpolluted waters. In the area of Lake Dunlap, concentrations on June 16 were in the range of 0.29 mg/L. Just below Lake Dunlap, the concentration of orthophosphate was 6.61 mg/L on this same day.

Nitrogen concentrations were noted to be high enough to indicate nutrient concern in all segments. Total phosphate was in the range of 0.24 mg/L on July 16th and 0.36 on August 19th in the Lake Dunlap area. These data and other parameter data are included in tabular form by segment, Victoria, Kerrville, and Seguin-New Braunfels in the appendices. The sampling data for those stations in the Lake Dunlap area are included as an attachment in tabular form.

Water Quality Management Study - Supplement 1 Report A: Influence of Canyon Reservoir on the Water Quality of the Guadalupe River, conducted by GBRA and UGRA for Texas Water Quality Board. August 1971.

A profile of the physicochemical conditions in Canyon Lake, upstream of the reservoir and in the tailrace of the Canyon Dam were presented. Samples were collected at four sites, one station upstream from the flood control level of Guadalupe River, two stations within the reservoir and one station in the tailrace of the dam. There were several other locations between stations that were sampled intermittently. These stations were sampled from November 1969 to January 1971. Nitrogen was determined in March and August 1970 and January 1971, with P determined in August 1970 and July 1971. Samples were collected once on each date.

Several nitrogen parameters were analyzed including Nitrate, nitrite, and ammonia-N and TKN. Both spring fed rivers, San Marcos and Comal, had higher inorganic nitrate-N concentrations. Nitrate-N concentrations in the Guadalupe River were at least twice that of the reservoir. Nitrate levels peaked in March 1970 while the lowest concentrations were obtained in January 1971. Concentrations of Nitrate-N above the dam in Guadalupe River never exceeded .002 mg/L; therefore water entering reservoir is relatively pollutant free. Nitrate-N ranged from .001 mg/L upstream from dam to .009 mg/L at 100 m out from the control tower of the dam. Ammonia-N ranged from 0 to 0.16 mg/L and was only found occasionally in trace amounts entering the reservoir. TKN was only slightly greater in the reservoir than in the upstream river.

Phosphorus in the study was at elevations less than other ecosystems with the exception of Lake Waco. Lake Dunlap had higher phosphate-P concentrations than the Canyon Reservoir. Total phosphate-P in the study was 0.03 mg/L with most forms less the 0.025 mg/L.

Brandes, J. Robert and Howard O. Andrews. 1977. Data Report: Lake Dunlap Eutrophication Study. Texas Water Quality Board No. 31990. Austin, Texas

A Data Report for Lake Dunlap Eutrophication Study was prepared by Robert J. Brandes and Howard Andrews and submitted to the TWQB in April 1977. The purpose of this data report was to develop and calibrate a mathematical lake eutrophication model. Lake Dunlap was selected as the test site and a monthly water sampling program was initiated.

The report included a discussion of the geography of the Lake Dunlap area and a discussion of pollutant sources. In the immediate vicinity of Lake Dunlap, there are four wastewater discharges, New Braunfels WWTP, two Mission Valley mill discharges and GBRA River bend WWTP, with New Braunfels and Mission Valley Mills discharges being the most significant. A copy of the data tables, USGS Seasonal Water Quality Data for Lake Dunlap and Annual USGS Water Quality Data for Lake Dunlap, are included as attachments.

New Braunfels was noted to be the most significant source of nutrients to the Lake Dunlap area, discharging an average of 19.0 mg/L total nitrogen and 6.4 mg/L of total phosphorus during the last five years (1972-76). In addition, Total N concentrations of Mission Valley Mills, 6.6 mg/L, was also considered a significant source of nutrients. A discussion of nonpoint source input was also included. Point source discharges account for 58% of the phosphorus inputs and only 12% of total nitrogen loads. The Comal River is responsible for over half of the nitrogen loading in the Guadalupe River. Nonpoint sources had little effect on the lake as a whole. It was concluded that Lake Dunlap is a sink for nitrogen and loses phosphorus.

Numerous water quality sources were available to this study and summaries of some of these sources were included in tabular form. The TWQB conducted a study from 1971 to 1977, which included nutrient data. Based on these data, the average concentration of total nitrogen in the Comal River was 1.93 mg/L (more than twice the concentrations in the Guadalupe River). However, ammonia-N concentrations were the same for both rivers. Average total-P values were low at 0.01 mg/L, however Comal River averaged 0.05 mg/L This was unexplained.

The USGS also conducted a water quality study for the Lake Dunlap segment from 1968 to 1976, which is discussed in the report. Total nitrogen averaged 1.17 mg/L, with a reduction occurring from the aforementioned study at a station located above the Comal and Guadalupe River Confluence. This was attributed to nutrient uptake by aquatic vegetation (and settling).

Total phosphorus averaged 0.08 mg/L for Lake Dunlap in the study. This was four times the concentration below the confluence, and the main source was suspected to be the New Braunfels wastewater treatment plant.

URS/Forrest and Cotton, Inc. 1978. Interim Report Number I: Guadalupe Basin Water Quality Management Plan. Guadalupe-Blanco River Authority No. F0065.

Interim Report #1, Guadalupe Basin Water Quality Management Plan, prepared by URS/ Forest and Cotton, Inc. for GBRA in February 1978, developed water quality management subplans in order to meet national goal of "fishable, swimmable", by 1983.

Several steps were mentioned in order to develop and implement these subplans. Waste load projections from both point and nonpoint sources were analyzed for each segment of the Guadalupe River Basin. Next a waste load analysis was preformed. Finally, alternative plans were proposed complete with design of cost analysis, water rights and impacts. One of the planning priorities was segment 1804, segment of Guadalupe River below San Marcos confluence and confluence with Comal River. The problem noted in this segment was eutrophication within river channel impoundment.

The report summarizes loading to Lake Dunlap and Lake McQueeny for point and nonpoint sources. Structural requirements and management requirements for Lake Dunlap were discussed including sewage collection at New Braunfels and sewage treatment and collection at Lake Dunlap and Lake Placid. Two alternatives were presented for regional wastewater collection systems as opposed to septic tank systems located along Lake Dunlap. These alternatives, costs and impacts were also discussed.

URS/Forrest and Cotton, Inc. 1978. Basic Data Report Volume I: Guadalupe Basin Water Quality Management Plan. Guadalupe-Blanco River Authority No. F0064.

In Volume I of the Guadalupe Basin Water Quality Management Plan, information was included on wastewater treatment facilities, existing water quality, land use and population including projections of economic growth, population and land use patterns. A nutrient section was included in the Water Quality Assessment chapter. The three nutrient parameters discussed were ammonia-N, Nitrate-N and phosphorus.

NH_3-N concentrations were similar throughout the basin with areas ranging from 0.10 mg/L in most stream segments, to 0.99 mg/L at the San Antonio River confluence. Nitrate-N annual average concentrations ranged from 0.08 mg/L to 2.10 mg/L, with the highest concentration (4.70 mg/L) occurring on the Comal River. Most stations had maximum concentrations below 1.60 mg/L.

TP annual average ranges from 0.01 mg/L to 0.68 mg/L with most stations at about 0.01 mg/L. The higher TP concentrations were primarily found in the Guadalupe River tidal, the San Antonio River confluence and San Marcos River confluence. Other parameters were discussed including temperature, metals, bacteria, DO, TDS, chlorides and sulfates.

Guadalupe-Blanco River Authority. 1978. Final Report: Data Gathering 1977-1978, Lake Dunlap, Comal and Guadalupe Counties, Texas.. Texas Department of Water Resources.

The report prepared by GBRA for the Texas Department of Water Resources in November of 1978, included detailed descriptions of sampling sites, collection and analytical methods, a brief review of data of certain parameters and all data collected during the study period. Data gathering was begun in April 1977 and concluded in March 1978. Eleven stations were located along Lake Dunlap from upstream of the Comal River confluence with Guadalupe River to the timber bridge over the powerhouse canal. In addition, three stations were sampled including those located at the New Braunfels wastewater treatment plant, Dunlap wastewater treatment plant and the Mission Valley Mills plant. Other stations included Blieders Creek, Dry Comal Creek and Blinking Light Creek. All stations were sampled within a four-hour time span.

Nitrate-N above the confluence of the Comal River contained an average concentration of 0.7 mg/L. However, the nitrate-N levels in Comal River were nearly three times as high at 1.8 mg/L. This is characteristic of water from the Edwards Aquifer. Below the confluence, the Nitrate-N value averages 11 mg/L. There was a slow decrease in nitrate values at river flows downstream. In areas of high residential development, there was a summertime decrease in nitrate-N which was attributed to algal uptake. Ammonia-N levels were associated with wastewater treatment plant discharges. Above these point discharge concentration levels were 0.02 mg/L and 0.01 mg/L for the Guadalupe and Comal River respectively. However, below the New Braunfels WWTP, the ammonia concentrations increased to 0.09 mg/L. Nitrate-N levels were present in very small concentrations with no downstream or seasonal patterns.

Total-P and other phosphorus concentrations increased as water flowed into the main lake. At the station below the New Braunfels WWTP, average surface concentrations were 0.025 mg/L ortho-P and 0.051 mg/L total P, with bottom concentrations of 0.095 mg/L ortho-P and 0.140 mg/L Total P. Main lake stations had an average P concentration from 0.30 to 0.54 mg/L orthophosphate and 0.068 to 0.049 mg/L total P. Nitrate-N, total-P and ortho-P data tables for Lake Dunlap are included as an attachment following the literature review. The New Braunfels effluent phosphorus content was reported to be in excess of 2,000 times the stream concentration.

Appendices include complete sampling data for each station. Other parameters discussed in the paper include primary productivity, conductivity, temperature, secchi disc, alkalinity, and organic nitrogen.

Brandes, J. Robert and Aaron B. Stein. 1979. WREDUN Model Documentation Report with Lake Dunlap Application. Texas Department of Water Resources No. 31990. Austin, Texas.

Brandes and Stein developed a water quality model, called WREDUN, to simulate the behavior of the hydrologic and water quality components of the system. WREDUN was developed to indicate the response of Lake Dunlap to changes in nutrient loading hydrology and meteorology. The model includes both phytoplankton (chlorophyll a) and macrophytes in the simulations. In order to format and calibrate the WREDUN model, a comprehensive data collection program was conducted on Lake Dunlap by GBRA from April 1977 to March 1978. These system inputs are included as an attachment in tabular form. Model and prototype values were compared in order to fine-tune the model.

The model was calibrated to conditions in 1977, when flows were moderately high. A sensitivity analysis was performed, but there was no evaluation of nutrient reduction alternatives in this report.

Guadalupe-Blanco River Authority. 1981. Working Paper Lake Dunlap Study. Texas Department of Water Resources.

In the working paper of the Lake Dunlap study, the basic information on the watershed was reviewed. The major problem was noted to be eutrophication, and excessive levels of both algae and macrophytes. Analysis of the data suggested that phosphorus was most often the limiting nutrient. The paper identified 9 alternative methods to control eutrophication, and recommended several for further study: selective withdrawal from Canyon during the summer, reduction in P from New Braunfels WWTP, a combination of the first two, plus nonpoint source analysis. The paper also recommended computer modeling to evaluate the effectiveness of each alternative.

Espey, Huston & Associates, Inc. (EH&A). 1981. Interim Report: Task 1804.312: Projected Water Quality Lake Dunlap Study. EH&A Document No. 81538. Austin, Texas.

The report analyzed alternative measures and feasibility for reduction of nutrient loads of Lake Dunlap. Several methods were proposed to control eutrophication including destratification and/or selected withdrawal from Canyon Reservoir, nutrient reduction from New Braunfels STP effluent, a combination of these two methods and control of nonpoint sources either simply or in combination with the above methods. The WREDUN model was used to determine the effectiveness of each alternative. This model had been calibrated using data collected by GBRA from April 1977 to March 1978.

The results from the modeled alternatives showed that point source phosphorus controls substantially affected levels of orthophosphorus in Lake Dunlap. The most effective alternative was combining New Braunfels STP phosphorus discharge controls and controlling N and P discharge from Canyon Reservoir. However, phosphorus control of just the New

Braunfels STP was also considered effective. The 2nd and 3rd most effective strategies, respectively, were reductions in effluent phosphorus discharges from the New Braunfels STP to 2 mg/L or to 0.05 mg/L. All of the effective strategies included phosphorus control, and no nitrogen control strategies alone were considered effective. Although the most effective case included nitrogen and phosphorus control, this was primarily due to phosphorus control of New Braunfels STP. The model also showed that limiting orthophosphate-P and to some extent nitrate-N levels in Lake Dunlap, would reduce macrophyte and algae production.

Glass Environmental Consultants. 1982. Interim Report: Lake Dunlap Study, Impacts of Alternate Control Strategies. Guadalupe-Blanco River Authority No. GO108.

An analysis of the socio-economic impacts of implementing the four control cases that were presented in the 1981 EH&A analysis was included in the Interim Report. This report described the facilities that would be required to implement the four most effective alternates, their feasibility and impacts. It concluded that reducing nitrogen and phosphorus in the discharge from the Canyon Reservoir, and the controlling N and P in the stormwater runoff from the New Braunfels area was not economically feasible with available technology. The needed control strategies would be expensive and the controls used for treating urban runoff are typically not very good at removing N and P. Based on this, the report eliminated strategies that included controlling N and P in urban runoff or from the Canyon Reservoir. The two control strategies that were considered required reduction in ortho-P discharged from New Braunfels WWTP to either 0.5 mg/L or 2 mg/L ortho-P. Both of these cases would incur significant costs, with reduction to 0.5 mg/L as P being 10 times more expensive based on construction, chemical and power costs.

Reducing ortho-P to 2 mg/L would require more man-hours and would make WWTP operation more complex. Although this control strategy would initially reduce the rate of algal and macrophyte growth in Lake Dunlap, by the year 2000, growth rates would be approaching levels experienced in 1981. On the other hand, reducing ortho-P to 0.5 mg/L, in effluent from two major STP's in New Braunfels would significantly reduce algal and macrophyte growth through the year 2000 (except for peak in July). If no action were taken then only a 5% increase in algal concentration in July was projected to occur by the year 2000.

Ottmers, Donald D. 1987. Intensive Survey of the Comal River Segment 1811. Texas Water Commission, IS 87-08.

An Intensive Survey of the Comal River, Segment 1811, was conducted in July 1987 by Mr. Donald D.Ottmers of the Texas Water Commission. The Comal River is spring fed and flows through the city of New Braunfels. Nine stations were sampled from the headwaters of the Comal River to just before the confluence with the Guadalupe River. Sampling spanned a two day time period, July 8th and 9th and several parameters were analyzed including nutrients.

Ammonia-N was found at levels less than 0.02 mg/L, with the exception of Prince Solms park which had levels as high as 0.03 mg/L. Nitrate-N, naturally found in spring water, was detected all along the river ranging from 1.59 mg/L to 1.76 mg/L. Ortho-P concentrations were less than 0.01 mg/L along the river. This data are included in tabular form as an attachment. Based on this data, Ottmers concluded that phosphorus was limiting algal growth in the Comal River.

Guadalupe-Blanco River Authority and the Upper-Guadalupe River Authority. 1992. Clean Rivers Program Regional Assessment of Water Quality: Guadalupe River Basin and the Lavaca-Guadalupe Coastal Basin.

The 1992 Regional Assessment of Water Quality identified and documented specific water quality conditions for the Guadalupe River Basin and the Lavaca-Guadalupe Coastal Basin. Existing water quality data from the TNRCC, GBRA and UGRA were included and reviewed in this summary. Nutrient parameters of interest included total phosphorus, total Kjeldahl nitrogen, ammonia-N and nitrate-N.

The averages for total P, NH_3-N and NO_3-N for the Guadalupe River at Lake Dunlap were 0.093, 0.081 and 0.761 mg/L, respectively. No samples were analyzed for TKN reported in the survey. Likewise, although UGRA and GBRA data provided evidence of development, the effects of development appeared to be small. The UGRA sampling program was begun in 1984, while GBRA sampling program was begun in 1987. The averages for total P and NO_3-N in the Lake Dunlap area (A.C.'s place) were 0.096 and 1.36, respectively. No samples were analyzed for TKN or NH3-N as reported in the summary of GBRA and UGRA data. Summaries of the GBRA and TNRCC data are included in the literature review.

Water quality parameters varied substantially, with standard deviations approximately equal to means, and the ranges much larger than standard deviations in some cases. Differences in water quality parameters were discussed in this summary, and the effect of flow was investigated. It was concluded that flow was an important determinant of variation for several water quality parameters.

Other topics in this summary included permitted municipal and industrial wastewater activities, inventory of water rights and an assessment of nonpoint source water quality assessments. A complete annotated bibliography was also included from the GBRA and TWC libraries of studies performed in the basin.

Guadalupe-Blanco River Authority and the Upper Guadalupe River Authority. 1994. Clean Rivers Program Water Quality Assessment Guadalupe River Basin and the Lavaca-Guadalupe Coastal Basin. Texas Natural Resource Conservation Commission, 14215/940813.

Data included in this assessment were collected over a two-year span from 1993 to 1994. A requirement of the Clean River Program was to assess water quality for each basin in order to identify concerns. These concerns were identified based on screening criteria, which were set conservatively by TNRCC.

Parameters of concern for the Guadalupe Basin, based on data from all segments, were nutrients, dissolved solids and metals. Nutrients were a concern at the Guadalupe River tidal, below the confluence with San Marcos, on and below the Comal River, on the upper and lower San Marcos River and at Plum Creek. Nutrients were also found to be a possible concern at Canyon Lake, at Johnson Creek and at the north and south fork of the Guadalupe River. Focusing on nutrient concerns the assessment then analyzed each segment of the river. Segments below the confluence with the San Antonio River had higher concentrations of nutrients. Nitrate-N had a mean average concentration of 1.695 mg/L, and a nitrite-N average mean concentration of 1.967 mg/L. Total –P and ortho-P were also a concern, with average mean concentrations of 0.495 mg/L and 0.394 mg/L respectively. Segment 1804 of the Guadalupe River, which includes the cities of New Braunfels and Sequin, also had nutrient levels of concern. Nitrate-N had a mean average concentration of 1.741 mg/L in this segment. The Comal River also had a high mean average concentration of Nitrate-N at 1.504 mg/L. Nutrient levels continued to be high throughout the length of the Guadalupe River.

In assessing causes for the high levels of nutrients, it was first noted that one segment contains both the San Marcos River confluence and the San Antonio River confluence. The San Antonio River was higher in dissolved solids, nutrients and indicator bacteria than the Guadalupe River; therefore it is expected that those parameters would have higher concentrations in this stretch than in other reaches. The segment of the river below the confluence with the Comal River had nutrient concerns that were nitrogen related. This is a natural situation for this basin due to spring flow, which is high in nitrates.

Guadalupe-Blanco River Authority and the Upper Guadalupe River Authority. 1995. Clean Rivers Program End-Of-Year Report, FY-94-95. Texas Natural Resource Conservation Commission.

The Clean Rivers Program End of the Year Report, FY-94-95, prepared by the GBRA and the UGRA, addresses problems which have been dealt with since the publication of the 1994 water quality assessment. The specific purpose of one of those task was dealing with Hydrilla bloom of small hydro lakes along the Guadalupe River, which have caused restrictions in lake access, swimming and boating.

Lake McQueeny and Lake Dunlap are two such lakes. Both of these lakes have had herbicide endothall applied to control hydrilla growth. This herbicide, Aquathol K, was also used in May 1994 and successfully controlled about 90% of the hydrilla. Other options such as the use of grass carp have also been addressed to control hydrilla vegetation. However, there is a major concern of the ability to contain the carp within the area needing treatment. This was a summary of information taken from the Clean Rivers Program End of the Year Report, FY-94-95.

Brown, P.F. 1996. Influences of Flow and Basin Morphometry on Nutrient Dynamics in a series of Texas Reservoirs. Masters Thesis. Southwest Texas State University, Department of Biology.

Lakes Dunlap and McQueeny were sampled for nutrients, turbidity, alkalinity, and chlorophyll a, twice per month from May through December 1992. Both surface and bottom samples were collected from five stations in each lake plus the Canyon and Comal River discharges. During this period, flows from Canyon were some of the highest on record. Data were analyzed both spatially and temporally. It was found that with the high flows and short residence times, chlorophyll a remained very low throughout the year. Late in the year when Canyon releases dropped to more typical levels did the Comal River and New Braunfel wastewater effluent begin to have a significant effect. The study provides a valuable pool of high quality nutrient data from all the major sources.

Table IX (Cont.)

Seguin--New Braunfels Segment: Sampling Set No. II (Cont.)

Station Number	6	7	8	9	10	11	12	13	14
River Mile	259.4	264.9	269.9	272.0	277.4	277.8	278.9	279.8	280.3
Sampling Date (1969)	8/19	8/19	8/19	8/19	8/19	8/19	8/19	8/19	8/19
Sampling Time	1600	1450	1415	1215	1140	1050	1005	0920	0830
Temperature (°C)	33	32	31	31	30	30	29	29	28
pH	8.3	8.25	8.0	8.2	8.15	8.15	8.1	8.1	8.15
BOD_5 (mg/l)	4.4	3.4	< 2	--	< 2	< 2	< 2	< 2	< 2
BOD_{20} (mg/l)	--	--	--	--	--	< 2	< 2	< 2	--
Total-PO_4 (mg/l)	--	.16	.40	--	--	.36	.42	.24	.30
Ortho-PO_4 (mg/l)*	--	trace	.72	--	--	trace	9.6	ND	1.18
Organic-N (mg/l)	--	.63	.45	--	--	.38	1.05	.20	.31
Ammonia-N (mg/l)	--	0	0	--	--	0	0	0	0
Nitrite-N (mg/l)	--	trace	trace	--	--	.01	.01	trace	trace
Nitrate-N (mg/l)	--	.28	--	--	--	.97	.91	.91	.56
Alk (mg/l as Ca CO_3)	--	--	--	--	--	224	220	--	194
Hardness (mg/l as Ca CO_3)	--	--	--	--	--	175	220	--	212
SO_4 (mg/l)	--	--	--	--	--	18.0	20.0	--	--
Fe (mg/l)	trace	trace	trace	trace	trace	trace	trace	trace	trace
Dissolved Oxygen (mg/l)	7.7	8.1	7.1	8.2	5.9	5.6	7.3	6.8	7.1

Forrest and Cotton, Inc. 1970. Water Quality Management Study: Guadalupe River Basin. Report No.1, Survey of Existing Water Quality. Guadalupe-Blanco River Authority and Upper Guadalupe River Authority.

Station Number	6	7	8	9	10	11	12	13	14
Vol. Susp. Solids (mg/l)	--	--	--	--	--	605	320	--	--
Chlorides (mg/l)	--	--	--	--	--	30	29	--	25
Chlorophyll (mg/l)	--	.31	.34	--	--	--	--	.11	.11
Total Coliforms (No/l)	--	200	3800	--	--	--	--	1000	200
Fecal Coliforms (No/l)	--	80	40	--	--	0	7000		200
Light Penetration (In.)	--	--	24	--	--	--	--	66	42
Calcium (mg/l as $CaCO_3$)	--	--	--	--	--	125	161	--	125
Flow (cfs)	346	346	346	346	346	346	346	135	135

Table IX (Cont.)

Seguin-New Braunfels Segment, Sampling Set No. I (Cont.)

Station Number	8	9	10	11	12	13	14
River Mile	270.0	270.8	277.7	277.9	278.9	279.4	280.8
Sampling Date (1969)	6/16	6/16	6/16	6/16	6/16	6/16	6/16
Sampling Time	1810	1410	1320	1250	1200	1105	1025
Temperature (°C)	27	27	25.5	25	25	25	23
pH	7.3	8.0	7.9	7.8	7.95	7.9	7.8
BOD_5 (mg/l)	< 2	< 2	< 2	< 2	2.5	< 2	< 2
COD (mg/l)	--	--	--	11.7	15.6	--	--
Total-PO_4 (mg/l)	.05	--	--	.24	.24	.24	--
Ortho-PO_4 (mg/l)	.61	--	--	.29	.19	.05	0
Organic-N (mg/l)	.26	--	--	.07	0	.07	--
Ammonia-N (mg/l)	0	--	--	0	0	0	--
Nitrite-N (mg/l)	.01	--	--	.01	.01	.01	0
Nitrate-N (mg/l)	.42	--	--	1.15	1.12	1.09	.65
Alk (mg/l as $CaCO_3$)	--	--	--	240	230	--	216
Hardness (mg/l as $CaCO_3$)	--	--	--	180	153	--	150
SO_4 (mg/l)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.0
F[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Dissolved Oxygen (mg/l)	8.3	8.7	8.1	8.1	8.3	8.7	8.5
Conductivity (micromhos/cm)	--	--	--	534	538	--	502
Susp. Solids (mg/l)	--	--	--	6.2	5.5	--	11.2
Vol. Susp. Solids (mg/l)	--	--	--	3.7	2.8	--	3.7
Chlorophyll (mg/l)	--	--	--	--	--	.009	--
Total Coliforms (No./l)	--	--	--	--	320	--	180
Light Penetration (in.)	--	--	--	--	--	72	30
Flow (cfs)	633	633	633	633	633	334	334

Forrest and Cotton, Inc. 1970. Water Quality Management Study: Guadalupe River Basin. Report No. I, Survey of Existing Water Quality. Guadalupe-Blanco River Authority and Upper Guadalupe River Authority.

* ND--None detected

Table IV-4

SUMMARY OF ANNUAL USGS WATER QUALITY DATA FOR LAKE DUNLAP, R.M. 272 (1968 - 1976)[1]

	1968	1969	1970	1971	1972	1973	1974	1975	1976	Ave.
Nitrogen (mg/l)										
NO_3 + NO_2-N	0.85	0.78	0.87	0.88	0.90	0.82	0.84	0.87	0.72	0.84
NH_3-N	-	-	-	-	-	0.07	0.13	0.05	0.07	0.09
TKN-N	-	-	-	-	-	0.27	0.37	0.31	0.34	0.33
Total-N	1.19	1.12	1.21	1.22	1.24	1.09	1.21	1.18	1.06	1.17
Phosphorus (mg/l)										
Inorganic-P[2]	0.03	0.06	0.08	0.09	0.06	0.03	0.05	0.03	0.04	0.05
Total-P	0.05	0.10	0.12	0.14	0.10	0.05	0.08	0.04	0.06	0.08
BOD_5 (mg/l)	1.4	1.5	1.9	1.7	1.5	1.0	1.5	1.0	0.8	1.4
Dissolved Oxygen (mg/l)	7.6	10.7	10.1	7.6	9.6	11.5	9.1	9.0	9.3	9.4
Temperature (°C)	22.0	23.0	22.4	22.4	23.9	21.1	21.1	19.3	21.4	21.8

[1]Calendar years (5 to 9 observations per year)

[2]Estimated from SWTSU data

Brandes, J. Robert and Howard O. Andrews. 1977. Data Report: Lake Dunlap Eutrophication Study. Texas Water Quality Board No. 31990. Austin, Texas

Table IV-5

SUMMARY OF SEASONAL USGS WATER QUALITY DATA FOR LAKE DUNLAP R.M. 273 (1968 - 1976)[1]

	Winter	Spring	Summer	Fall
Nitrogen (mg/l)				
$NO_2 + NO_3$-N	1.05	0.87	0.66	0.81
NH_3-N	0.06	0.09	0.08	0.06
TKN-N	0.30	0.38	0.33	0.29
Total-N	1.35	1.25	0.99	1.10
Total P (mg/l)	0.09	0.08	0.08	0.09
BOD_5 (mg/l)	0.85	1.25	1.80	0.91
Dissolved Oxygen (mg/l)				
Concentration	9.1	9.2	9.7	9.2
% Saturation	94	103	117	107
Temperature (°C)	17.2	21.3	25.5	23.5

[1]Calendar years, seasons defined as follows: Winter = Dec., Jan., Feb.
Spring = Mar., Apr., May
Summer = Jun., Jul., Aug.
Fall = Sept., Oct., Nov.

Brandes, J. Robert and Howard O. Andrews. 1977. Data Report: Lake Dunlap Eutrophication Study. Texas Water Quality Board No. 31990. Austin, Texas

Table 10. Nitrate-Nitrogen Values, Lake Dunlap Area, 1977-1978.

Values are in mg/l N

Station	1977											1978	
	4/28	5/24	6/6	7/7	7/18	8/15	8/25	9/24	10/29	11/19	12/17	1/26	3/11
1	035	050	065	058	0660	0596	0750	0667	078	0894	0662	0961	076
2	165	1,196	1870	164	1,580	1821	3990	1,787	230	0975	1,322	1,327	1,25
3T	045	140	0993	096	1,024	1,227	1375	1507	123	0,589	1,203	1,224	1,15
3B	---		098	096	1,024	1,238	1405	1536	124	0,312	1,212	1,233	1,14
4T	047	175	0999	097	1,010	1,225	1404	1566	124	0,371	1,214	1,235	1,14
4B	---	099	0995	098	1,020	1,242	1413	1586	125	0,289	1,226	1,245	1,19
5T	---	093	0990	098	1,019	1,235	139	1,042	126	0,512	1,222	1,248	1,14
5B	---	098	0993	098	1,024	1,243	1401	1622	126	0,204	1,222	1,249	1,14
6T	059	000	1000	098	1,008	1,229	1375	1627	126	0,077	1,227	1,241	1,14
6B	---	---	1,000	098	1,006	1,296	1395	1646	127	0,663	1,237	1,239	1,14
7T	055	085	0990	095	0990	1,197	1,321	1642	127	0,280	1,254	1,241	1,12
7B	---	---	0986	096	0990	1,198	1363	1675	127	0,398	1,255	1,240	1,14
8T	047	091	1000	097	1,000	1,213	1,304	1705	1,267	0,195	1,226	1,232	1,14
8B	---	---	0990	097	0978	1,225	1,335	1,224	1,257	0,454	1,227	1,232	105
9T	045	091	0970	092	0980	0,703	0699	1059	1,248	0,115	1,231	1,227	1,11
9B	---	---	0970	093	0978	0803	0842	1,069	1,217	0,408	1,242	1,242	1,11
10T	049	088	0970	094	0960	0822	0799	0999	1,256	0,174	1,228	1,244	1,12
10B	---	---	0979	096	0978	1115	0815	1,248	1256	0,059	1,236	1,252	099
11	045	0938	0976	095	0976	1,022	0982	1,190	1,285	0,065	1,243	1,253	1,12
12	170	402	3845	386	3495	7593	6058	6959	1015	9767	9,513	152	670
13	1074	1945	2195	1,22	3348	47,275	507	53242	6700	44195	43280	45856	58.
14	019	030	0017	---	0,700	0628	0690	1,091	031	1,19	372	0,108	061
BLC	---	---	2,365	2,32	2624	---	---	---	---	---	---	---	---
DC	---	---	1,596	1,02	0952	---	---	---	---	---	---	---	---
BD	---	---	0976	094	0984	---	---	---	---	---	---	---	---

Guadalupe-Blanco River Authority. 1978. Final Report: Data Gathering 1977-1978, Lake Dunlap, Comal and Guadalupe Counties, Texas.. Texas Department of Water Resources.

Table 6. Ortho Phosphorus Values, Lake Dunlap Area, 1977–1978.

All Values are mg/l P

Station	1977 4/28	1977 5/24	1977 6/6	1977 7/7	1977 7/18	1977 8/15	1977 8/25	1977 9/24	1977 10/29	1977 12/17	1978 1/26	1978 3/11
1	0012	002	001	0015	0024	0001	0007	0013	0018	0010	0020	0016
2	0008	0005	0013	0008	0018	0004	0006	0016	0017	0012	0022	0008
3T	0013	005	0009	0007	0136	0005	0021	0019	0026	0015	0022	0010
3B			0016	0007	0026	0013	0022	0026	0101	0015	0035	0205
4T	0009	008	0009	0016	0024	0011	0019	-----	0030	0024	0025	0022
4B	----	010	0017	0004	0168	0006	0017	0027	0012	0105	0041	0529
5T	----	000	0011	0021	0151	0030	0042	0080	0010	0048	0073	0048
5B	----	001	0015	0013	0037	0023	0043	0071	0013	0046	0075	0051
6T	0014	005	0021	0022	0163	----	0065	0084	0042	0050	0063	0062
6B	----	----	0023	0017	0044	0057	0067	0260	0045	0054	0060	0135
7T	0010	013	0023	0023	0239	----	0061	0095	0035	0050	0071	0047
7B	----	----	0027	0026	0058	0040	0064	0087	0045	0050	0079	0047
8T	0010	010	0022	0021	0301	0038	0053	0084	0043	0042	0035	0073
8B	----	----	0027	0027	0069	0092	0057	0080	0043	0044	0056	0046
9T	0009	010	0023	0024	0042	<0001	<0001	0052	0035	0050	0068	0047
9B	----	----	0027	0166	0045	<0001	<0001	0098	0039	0050	0065	0047
10T	0016	010	0024	0025	0039	<0001	<0001	0065	0032	0055	0071	0048
10B	----	----	0030	0033	0042	0024	0083	0072	0037	0057	0075	0050
11	0013	020	0008	0015	0051	0020	0021	0043	0045	0054	0063	0053
12	----	----	----	140	535	465	310	4225	445	496	481	497
13	0266	<0001	----	0090	0113	0115	0228	0135	0691	0996	0252	0248
14	006	018	----	----	0210	0331	207	094	0268	127	037	079
BLC			0013	0008	0034							
DC			0015	0013	0024							
BC			0020	0027	0045							

Guadalupe-Blanco River Authority. 1978. Final Report: Data Gathering 1977-1978, Lake Dunlap, Comal and Guadalupe Counties, Texas.. Texas Department of Water Resources

Table 7. Total Phosphorus, Lake Dunlap Area, 1977-1978

Station	1977									1978	
	6/6	7/7	7/18	8/15	8/25	9/24	10/29	11/19	12/17	1/25	3/11
1	0052	0103	0041	0008	0014	100	0027	0045	0034	0032	0047
2	0038	0073	0030	0010	0008	0085	0034	0062	0035	0048	0035
3T	0065	0079		0005	0030	1850	0031	0057	0035	0041	0025
3B	0035	0098	0032	0020	0038	0455	0027	0071	0035	0038	0180
4T	0044	0089	0098	0052	0027	0200	0032	0144	0047	0030	0040
4B	0035	2260		0110	0030	0240	0030	0109	0123	0061	0495
5T	0664	0119	0066	0020	0048	0545	0037	0109	0083	0083	0639
5B	0037	0137	0061	0010	0050	0595	0063	0092	0085	0078	0071
6T	0046	0111		0031	0080	0590	0060	0096	0074	0069	0185
6B	0060	0127	0048	0090	0079	2235	0074	0134	0082	0068	0135
7T	0042	0109	0066	0040	0059	0500	0062	0103	0087	0074	0060
7B	0047	0127	0051	0040	0059	0600	0080	0150	0069	0080	0088
8T	0060	0142		0028	0050	0425	0050	0155	0067	0067	0088
8B	0049	0130	0054	0169	0065	0420	0081	0254	0064	0068	0056
9T	0048	0099	0171	----	0058	0525	0051	0124	0064	0064	0070
9B	0070	0271	0060	0053	0073	1075	0057	0127	0099	0070	0293
10T	0059	0100	0069	0049	0050	0440	0056	0108	0085	0072	0056
10B	0068	0128	0027	0031	0136	0480	0072	0142	0078	0093	0061
11	0053	0113	0094	0030	0048	0635	0051	0108	0085	0070	0099
12		581	460	509	525	5430	491	552	549	591	543
13	0085	0201	0139	0140	0237	0233	0712	0623	135	0280	0246
14	0315	---	0330	0454	211	158	0580	094	157	040	133
BLC	0048	0119	0062								
DC	0031	0115	0040								
BD	0039	0116	0032								

Guadalupe-Blanco River Authority. 1978. Final Report: Data Gathering 1977-1978, Lake Dunlap, Comal and Guadalupe Counties, Texas.. Texas Department of Water Resources.

TABLE VIII-4
LAKE DUNLAP SYSTEM INPUTS
POINT SOURCES

	Flow cfs	Temp °C	DO mg/l	BOD mg/l	Cons. Minerals #1	#2	#3	Detritus mg/l	Noncons. mg/l	NH3-N mg/l	NO2-N mg/l	NO3-N mg/l	PO4-P mg/l	COLI MPN/100 ml	ALGAE #1 mg/l	#2 mg/l
Simulation Day: 0 Date: 4/25/77																
Comal River	478.000	18.00	8.90	.13	0.0	0.0	0.0	4.40	0.0	.0263	.0040	1.690	.008	0.0	0.0	0.0
Mission Valley Mills	3.143	1.00	.36	.20	0.0	0.0	0.0	57.80	0.0	.4600	.0130	.190	.060	0.0	0.0	0.0
New Braunfels STP	4.950	22.00	6.45	1.00	0.0	0.0	0.0	15.70	0.0	17.2000	.3650	1.730	5.630	0.0	0.0	0.0
GBRA River Bend STP	.007	22.00	6.20	.07	0.0	0.0	0.0	4.60	0.0	.0483	.0433	16.740	.264	0.0	0.0	0.0
Simulation Day: 70 Date: 7/7/77																
Comal River	385.000	27.00	8.50	.83	0.0	0.0	0.0	2.20	0.0	.0023	.0013	1.643	.008	0.0	0.0	0.0
Mission Valley Mills	3.384	26.50	.35	.26	0.0	0.0	0.0	21.43	0.0	.3643	.0925	.013	.180	0.0	0.0	0.0
New Braunfels STP	4.950	25.80	6.45	2.23	0.0	0.0	0.0	3.43	0.0	10.5530	.0730	3.860	1.430	0.0	0.0	0.0
GBRA River Bend STP	.014	22.00	6.20	2.23	0.0	0.0	0.0	5.43	0.0	.0530	.1030	1.220	.090	0.0	0.0	0.0
Simulation Day: 109 Date: 8/16/77																
Comal River	340.000	24.00	7.50	.61	0.0	0.0	0.0	2.23	0.0	.0016	.0000	1.820	.004	0.0	0.0	0.0
Mission Valley Mills	2.840	26.50	.35	.03	0.0	0.0	0.0	12.82	0.0	1.9000	.0663	.628	.331	0.0	0.0	0.0
New Braunfels STP	4.950	25.80	6.48	4.96	0.0	0.0	0.0	12.20	0.0	11.7500	.0068	7.593	4.680	0.0	0.0	0.0
GBRA River Bend STP	.017	22.00	6.20	2.23	0.0	0.0	0.0	.98	0.0	1.9000	.1430	47.260	.115	0.0	0.0	0.0

Brandes, J. Robert and Aaron B. Stein. 1979. WREDUN Model Documentation Report with Lake Dunlap Application. Texas Department of Water Resources No. 31990. Austin, Texas.

TABLE I-2

WATER QUALITY DATA - PRINCIPAL INFLOW SOURCES AFFECTING LAKE DUNLAP

Source	Total Nitrogen (mg/l)[1]	Total Phosphorus (mg/l)[1]	Nitrogen Loading Pounds/Day		Phosphorus Loading Pounds/Day	
			Summer[2]	Annual[2]	Summer[2]	Annual[2]
Guadalupe River above Confluence with Comal River	0.82	0.01[3]	2,069	1,795	25[4]	22
Comal River (Prior to mixing with Guadalupe River)	1.93	0.05	2,872	3,111	74	81
New Braunfels Sewage Treatment Plant	19.0	6.4	522	522	176	176
West Point Pepperell	6.6	0.4	132	132	8	8
G-BRA River Bend Sewage Treatment Plant	---	0.4	---	---	0.09	0.09

1 Source WRE (1978)

2 Based on flows shown in Table I-1 and concentrations shown in Table I-2.

3 Value has been as high as 0.05 mg/l in summer.

4 Could be as high as 126 pounds per day in summer.

Guadalupe-Blanco River Authority. 1981. Working Paper Lake Dunlap Study. Texas Department of Water Resources.

TABLE 4

Laboratory Measurements

Parameter (*)	Stations A	B	C	D	E	F	G	H	I
$CBOD_5$	1	1	1	0.5	0.5	0.5	0.5	1	1
f-$CBOD_5$	1	1	1	0.5	0.5	0.5	0.5	1	1
$CBOD_{20}$	1.5	1.5	1	1	1	1.5	1	2	3
f-$CBOD_{20}$	1	1	0.5	1	1	1	1	1	1
TOC	<1	<1	<1	<1	2	<1	<1	<1	<1
TSS	8	<5	<5	<5	6	<5	<5	<5	<5
VSS	2	<5	<5	<5	1	<5	<5	<5	<5
Kjel-N	0.2	0.1	0.2	<0.1	0.3	0.1	0.1	0.1	0.2
NH_3-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03
NO_3-N	1.59	1.59	1.68	1.58	0.77	1.74	1.74	1.76	1.4
NO_2-N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
O-PO_4	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
T-PO_4	0.02	0.02	0.01	0.02	0.04	0.01	0.01	<0.01	<0.01
Cl	15	15	15	16	33	15	15	15	15
SO_4	26	28	26	26	76	26	26	27	27
TR	239	238	277	260	412	224	266	246	310
Cond. µmhos/cm	578	568	576	576	810	572	578	576	592
pH Units	7.7	7.8	7.5	7.5	7.7	7.5	7.4	7.5	7.8

Ottmers, Donald D. 1987. Intensive Survey of the Comal River Segment 1811. Texas Water Commission, IS 87-08.

J. Brown, 1996

APPENDIX B. Surface soluble reactive phosphorus (SRP) (ug L^{-1}), nitrate nitrogen (NO_3+NO_2-N) (ug L^{-1}), and ammonium (NH_4-N) (ug L^{-1}) for all sites on Lake Dunlap and Lake McQueeney reservoirs.

SRP DATE	CD	COM	D5	D4	D3	D2	D1	M5	M4	M3	M2	M1	MD
05/16/92	4	7	15	16	17	24	31	31	32	32	34	23	30
05/29/92	0	3	10	6	10	13	17	18	19	18	19	28	21
06/14/92	0	3	7	6	10	11	12	13	13	14	16	16	15
06/28/92	48	22	8	3	28	55	59	68	73	67	NA	52	66
07/11/92	3	14	8	9	12	18	16	17	17	17	14	12	17
07/26/92	2	4	10	9	13	20	18	16	19	17	2	3	12
08/09/92	1	0	5	10	18	29	22	22	24	25	7	8	16
08/23/92	2	0	5	5	12	10	12	12	13	15	12	11	12
09/06/92	2	3	9	8	20	11	9	9	6	5	2	2	6
09/27/92	3	2	14	18	27	30	26	27	23	20	16	19	21
10/11/92	0	1	10	8	18	34	30	28	18	11	20	15	12
11/15/92	1	4	15	22	40			29	30	29	29	30	30
12/14/92	3	4	15	14	23	32	32	30	28	24	24	27	21
NO_3-NO_2-N													
05/16/92	786	831	1138	1138	1128	1128	1093	1061	1073	1103	1153	988	1012
05/29/92	NA	818	875	869	850	852	830	858	839	853	864	840	837
06/14/92	763	668	778	783	811	795	773	772	784	791	793	793	799
06/28/92	551	573	1004	895	976	995	995	1155	1108	1088	NA	1017	1081
07/11/92	588	628	1056	1022	1030	1013	979	1024	1003	1018	942	912	1004
07/26/92	537	517	922	938	923	950	966	967	999	994	792	807	925
08/09/92	279	451	1031	1040	1040	944	961	967	1003	958	769	823	932
08/23/92	209	422	1079	1062	1100	986	1002	1018	1045	1028	1004	1005	994
09/06/92	132	428	1038	1055	1050	1018	979	982	990	998	879	826	963
09/27/92	41	486	1142	1151	1165	1341	112	1141	1157	1145	1112	1121	1093
10/11/92	67	658	1358	1350	1368	1364	1387	1358	1346	1339	1267	1236	1263
11/15/92	272	591	1415	1408	1417	NA	NA	1373	1394	1421	1376	1327	1339
12/14/92	301	511	1105	1084	1117	1109	1076	1088	1063	1099	1081	1078	1076
NH_4-N													
05/16/92	4	8	13	15	10	10	6	3	5	16	6	15	3
06/28/92	40	12	24	217	30	23	178	51	53	56	NA	30	43
07/11/92	19	32	7	5	29	58	56	42	46	46	42	29	45
07/26/92	43	25	0	0	15	41	0	56	28	54	19	8	48
08/09/92	87	7	8	9	41	78	58	56	52	59	35	27	37
08/23/92	130	14	10	8	65	73	61	43	62	33	55	45	55
09/06/92	286	42	11	12	128	144	115	120	88	87	30	34	86
09/27/92	363	28	13	14	153	208	355	5	196	187	92	NA	119
10/11/92	485	40	34	93	47	8	49	108	1	12	110	0	20
11/15/92	15	8	5	0	83	NA	NA	87	88	77	31	36	29
12/14/92	21	9	2	5	15	83	26	26	22	30	29	31	32

APPENDIX C. Bottom soluble reactive phosphorus (SRP) ($\mu g\ L^{-1}$), nitrate nitrogen (NO_3+NO_2-N) ($\mu g\ L^{-1}$), and ammonium (NH_4-N) ($\mu g\ L^{-1}$) for all sites on Lake Dunlap and Lake McQueeney reservoirs.

SRP				SITE				
DATE	D4	D3	D2	D1	M4	M3	M2	M1
05/16/92		21	35				37	36
06/28/92	64		65	70	66			
07/11/92		19	17	21	17	18		
07/26/92			22	18	16	16	6	19
08/09/92				25				22
08/23/92		13	11	14				14
09/06/92			12	12			11	8
09/27/92			31	27	22		22	21
10/11/92				33				14
11/15/92				28				30
12/14/92				32				24
NO_3-NO_2-N								
05/16/92		1141	1051				1086	1064
06/28/92	1026		1070	1066	1077			
07/11/92		1008	986	994	1016	1037		
07/26/92			950	965	993	980	832	968
08/09/92				963				944
08/23/92		1037	993	971				979
09/06/92			1039	1012			1008	958
09/27/92			1133	1119			1137	1047
10/11/92				1392				1302
11/15/92				1341				1335
12/14/92				1079				1059
NH_4-N								
05/16/92		9	14				5	8
06/28/92								
07/11/92	233		5	60	63			
07/26/92			56	51	53		38	
08/09/92				96			57	
08/23/92			67	68				48
09/06/92			147	127			111	81
09/27/92			343	250	197		89	61
10/11/92				47				25
11/15/92				100				36
12/14/92				32				31

APPENDIX D. Surface chlorophyll *a* (ug L^{-1}) for sites on Lake Dunlap and Lake McQueeney reservoirs.

						SITE						
DATE	COM	D6	D4	D3	D2	D1	M5	M4	M3	M2	M1	MD
05/29/92	3.7	0	3.3	3	2.7	2.4	1.4	1.2	1.9	1.1	1.8	1.6
08/09/92	0	1.1	0	0.2	0.5	2.4	0	0.3	0.7	1.6	3.1	1.9
08/23/92	1.2	0.3	0.8	1.3	0	4.4	3.9	3.1	3.2	2.5	5.2	3.2
09/06/92	0.7	1.2	1	0.3	0.2	2.1	2.4	3.1	3.4	6.6	13.7	2.9
09/27/92	0.3	1.6	1.2	0	0.2	0.5	1.4	2.1	2.9	4.7	11.8	3.2
10/11/92	1.9	1.1	0.8	0.3	0.7	2.6	1.9	4.8	2.1	2.7	4	2.4
11/15/92	0	0.5	0.1	0	0.9	0	1.5	0.5	0	1.4	0	2.2