Las Vegas Valley Water Quality Program

Program Management Consultant Brown and Caldwell • Culp/Wesner/Culp

March 8, 1982

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300 South Fourth Street
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017-683-99

Attention: Mr. Lewis H. Dodgion, State of Nevada
Mr. Ashley Hall, City of Las Vegas
Mr. Richard E. Reavis, Environmental Protection Agency
Mr. Bruce W. Spaulding, Clark County

Subject: Draft Water Quality Standards Study Report

Gentlemen:

We are pleased to submit for your review this draft report for the Water Quality Standards Study (WQSS). The report has been prepared in accordance with the work plan for Contract 6 approved by the Water Quality Study Board (WQSB) on March 21, 1980. The report contains recommendations on beneficial uses for Las Vegas Wash and Lake Mead, water quality criteria necessary to support those uses, and allowable waste loads (TMDLs) at Northshore Road to assure that the criteria are met. As specified in the Consent Decree, work is now needed under the Phase II Treatment Facilities Study, or some comparable study, to translate the allowable loads into effluent limitations for the wastewater treatment plants.

This report utilizes the various interim reports prepared by the Program Management Consultant and incorporates many of the comments that have been made by program participants in the technical meetings that have occurred over the past two years. The Technical Advisory Board members have reviewed drafts of the major technical chapters, although they have not reviewed the complete draft report. We strongly recommend that the WQSB authorize a procedure by which technical review comments on this draft WQSS report can be obtained from all parties, so the report can be finalized.

For your convenience, Chapter 1 is a report summary which provides an overview of the study and its findings.

Very truly yours,

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FOREWORD

The Water Quality Standards Study is one of several studies set forth in the Consent Decree. Portions of the program, including the Phase II Treatment Facilities Study, have not been completed or authorized. Thus, we believe it is critical that the limits of this report, as established in the work plan approved by the Water Quality Study Board, be clearly stated at the outset. The report contains recommendations on beneficial uses for Las Vegas Wash and Lake Mead, water quality criteria necessary to support those uses and allowable waste loads (TMDLs) at Northshore Road to assure that the criteria are met. This report does not develop effluent limitations for the treatment plants and, thus, cannot be used to completely determine whether effluent limitations of 30/30/1 are compatible with the recommended water quality criteria.

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CHAPTER 1

SUMMARY

In a report of this magnitude, a summary is desirable to provide an overview of the study and its findings. The following sections briefly describe the important points of each chapter of the report. Conclusions that are listed at the end of each major chapter are also contained in a single summary table in this chapter.

INTRODUCTION

The Las Vegas Valley Water Quality Program is a study of water quality and wastewater treatment facilities in the Las Vegas area. The program is the result of a Consent Decree in a litigation action filed by the Cities of Las Vegas and North Las Vegas in July 1978. The suit was filed against the U.S. Environmental Protection Agency (EPA), the State of Nevada, and Clark County, and requested that water quality standards for Las Vegas Wash and Lake Mead be reevaluated. The Consent Decree identified a series of studies that was to be conducted, one of which is the Water Quality Standards Study (WQSS). Several of the other studies have been completed, including the Phase I Treatment Facilities Study, the User Charge Study, and initial portions of the Phase II Treatment Facilities Study (TFS-II). Significant portions of TFS-II have not yet been conducted.

The objective of the combined WQSS/TFS-II process is to provide the basis upon which the Nevada Environmental Commission can make determinations required by Section 303 of the Clean

Water Act related to beneficial uses, water quality criteria, allowable waste loads, and treatment plant effluent limitations. The work that has been conducted to date in WQSS provides an adequate basis to develop many recommendations related to beneficial uses and the water quality criteria necessary to support those uses, and those recommendations are presented in this report. However, treatment plant effluent limitations cannot be defined until the remainder of TFS-II is completed.

PHYSICAL SETTING

The WQSS addresses water quality conditions in Las Vegas Wash and Lake Mead. Lake Mead was formed in 1935 by construction of Hoover Dam on the Colorado River at the junction of the states of Nevada, Arizona, and California. Las Vegas Wash is the chief drainage channel of the 1,600 square-mile Las Vegas Valley drainage basin and drains to the Las Vegas Bay in Boulder Basin on Lake Mead. The Las Vegas Valley has a population of about 500,000, lies in Clark County, Nevada, and contains the cities of Las Vegas, North Las Vegas, Henderson, and Boulder City. The local economy is highly dependent upon tourism and the recreational aspects of the area. Lake Mead is a major tourist attraction, attracting about four million visitors each year for swimming, boating, water skiing, fishing, and camping.

The Las Vegas Valley may be classified as a high desert region. Summers provide typical desert weather of hot, dry days with maximum temperatures normally above 100°F. Winters are relatively mild with average maximum temperatures of 55° to 65°F and average minimum temperatures of about 35°F. During the fall and spring, maximum temperatures of about 70° to 90°F and minimum temperatures of 45° to 65°F normally occur. Low humidity and abundant sunshine produce rapid evaporation which

averages over 100 inches per year. Precipitation averages about 4 inches per year, about half of which occurs during the summer when warm, moist tropical air predominates weather conditions. The area is essentially surrounded on all sides by mountains. From the mountains, alluvial aprons have formed extending into the basin lowlands. Four principal aquifers lie under the valley. The lower aquifers contain good quality water; however, the near-surface aquifer contains poor quality water due to natural salt buildup as well as man-made causes such as landscape irrigation, septic tanks, sewage effluent disposal, and irrigation with sewage effluent. The near-surface aquifer surfaces in the Las Vegas Wash.

The Las Vegas Wash originates in the Spring Mountains approximately 45 kilometers (km) north of the City of Las Vegas and is an intermittent stream from its origin to the City of Las Vegas wastewater treatment plant. From the treatment plant, the wash is a perennial stream fed by treated wastewater effluent from the City of Las Vegas and Clark County Sanitation District treatment plants, surfacing groundwater, and surface water runoff. The wash flows a distance of about 18 km between the City treatment plant and Las Vegas Bay and can be characterized by four distinct regions: an extensive tule and cattail marsh with a swift-moving channel; a series of ponds; a tule and cattail marsh; and a channelized fast-flowing stream bordered by steep canyons. Erosion in both the upper and lower wash has resulted in drainage of large areas of marshland and creation of channels.

During the WQSS, Lake Mead had an average elevation of about 366 meters (1,200 feet), was about 170 meters (560 feet) deep, contained about 31 km^3 (25,000,000 acre-feet) of water, extended about 161 km (100 miles) upstream, and had a surface

area of about 600 km^2 (230 square miles). The lake has an annual inflow of about 9,200,000 acre-feet from the Colorado River. Water is discharged from Lake Mead through Hoover Dam, additional water is withdrawn from Boulder Basin for municipal and industrial supply, and significant quantities of water are lost to evaporation. Las Vegas Bay, one of the primary areas of investigation in the WQSS, is a wedge-shaped, flooded canyon embayment in Boulder Basin. The bay is about 10.5 km (6.5 miles) long, 5.6 km (3.5 miles) across, and has a maximum depth of about 116 meters (380 feet). Bonelli Bay, adjacent to Virgin Basin, was selected as the background area for comparison of water quality data. Although smaller in size, its configuration is similar to Las Vegas Bay.

BENEFICIAL USES

The currently designated beneficial uses of Las Vegas Wash are aesthetics and recreation, irrigation, stock watering, fish, and wildlife. Current aesthetic and recreational uses include bird watching, hiking, and hunting. Most aesthetic and recreational use of the wash occurs in the marsh and ponded areas near Pabco Road. Plans to develop the wash into a wetlands park are currently under consideration. The wetlands park plan includes development of a wetlands interpretive center; increased marsh acreage; construction of ponds for waterfowl use; and construction of observation blinds, boardwalks, and trails. In the lower wash, the erosion would be controlled by construction of a dam across the wash. The wash provides a diverse habitat for a wide range of mammals, reptiles, and birds. The wash does not provide a diverse habitat for fish. At present, mosquito fish are the only fish populating the wash to a significant degree. Wash water is not used for irrigation presently; however, use of wash water for irrigation of a park is planned. No significant stock watering with wash water is currently conducted.

Beneficial uses of Lake Mead include recreation and aesthetics, water supply, fish and wildlife, and hydropower. All forms of water-oriented recreation are enjoyed in Lake Mead, including swimming, sunbathing, water-contact sports, boating, fishing, and aesthetic enjoyment. The lake attracts about four million visitors each year. The largest uses are swimming and water skiing, which predominate during the summer recreational season. Fishing is nearly as large a use as water-contact sports, and is more constant throughout the year. Lake Mead supplies the majority of water used for public supply in the region with nearly 130,000 acre-feet of water withdrawn from Boulder Basin annually for this purpose. The lake supports a substantial fishery consisting of striped and largemouth bass, threadfin shad, catfish, and carp. Largemouth and striped bass are the most popular game fish; however, the largemouth bass population has steadily decreased since 1963. Striped bass catches have dramatically increased in recent years, but the quality of striped bass has decreased.

In the early planning for WQSS, several approaches were considered for developing appropriate water quality criteria necessary to support beneficial uses. User surveys to determine public perceptions and to quantify water quality impacts were considered, but that approach was not approved. The approach that was adopted by the Water Quality Study Board (WQSB) consisted of scientific evaluation of data collected in WQSS and review of available agency documents and scientific sources on water quality criteria. A number of water quality factors were identified which affect the beneficial uses, and a monitoring program was designed to collect data on these factors. The findings with regard to these factors are discussed briefly in subsequent paragraphs of this summary.

STUDY METHODOLOGY AND APPROACH

A comprehensive water quality monitoring program of Lake Mead and Las Vegas Wash was conducted over a 22-month period from April 1979 through January 1981. The program consisted of five major components: limnological monitoring, bioassay studies, wash monitoring, monitoring of the plume discharge to the lake, and various special studies. The limnological monitoring program provided detailed information about water quality conditions in Las Vegas Bay and Boulder Basin. A wide range of physical, chemical, biological, and physiological measurements were made. Sampling was also conducted in an area of the lake unaffected by the wash discharge, Bonelli Bay, to provide an indication of background conditions. Several types of bioassays were conducted to help in assessing the effects of nutrients on algae growth. Five locations were regularly sampled in Las Vegas Wash to determine water quality conditions in the wash from the point of discharge of the wastewater treatment plants to Northshore Road and to estimate pollutant loads discharged to Las Vegas Bay. The discharge from the wash is highly saline so it forms a plume which sinks below the lake water surface. Plume monitoring included measurements of specific conductance and two dye surveys. In addition, several special studies were performed: sediment survey, metalimnetic dissolved oxygen survey, bacteriological sampling, marina sampling, and stormwater runoff sampling.

Over 100,000 water quality measurements were made in the WQSS. Bacause of the large data base, a computerized data management system (STORET) was used. This approach facilitated preparation of tabular and graphical data presentations and performance of the many statistical analyses which were required.

LAS VEGAS WASH

The Las Vegas Wash routine monitoring program consisted of sampling at five stations every two weeks from July 1979 through December 1980. In situ measurements were made for physical parameters, including dissolved oxygen, temperature, conductance, and pH. Samples were analyzed for suspended solids, biochemical oxygen demand, nutrients, and bacteriological quality. Additional sampling was conducted in the last few months of 1980 and early 1981 to more intensively assess water quality conditions. The intensive sampling included a longitudinal survey, 24-hour sampling, a dye survey to determine time of travel, groundwater sampling, and sampling of surface water sources tributary to the wash.

Results indicated seasonal variations in water quality and differences in water quality at the different stations sampled. Temperature, biochemical oxygen demand, total phosphorus, and total nitrogen concentrations generally decreased between the confluence of the treatment plants and Northshore Road. Dissolved oxygen concentrations were lowest in the marsh areas upstream of Pabco Road (generally less than 2 mg/l) and were near saturation at Northshore Road due to reaeration. Suspended solids levels increased substantially downstream of Pabco Road due to the severe erosion occurring. Ammonia concentrations decreased in the lower wash, while nitrate concentrations increased. Coliform concentrations were quite low in the area downstream of the treatment plants but increased dramatically in the ponded area upstream of Pabco Road and remained high at downstream stations.

The Clark County Sanitation District and City of Las Vegas treatment plants are the major source of both phosphorus and nitrogen to the wash. During the WQSS, an average of about

25 percent of both total phosphorus and total nitrogen were removed. Present phosphorus removal is comparable to historic removals, but present nitrogen removals (particularly ammonia) are substantially less than historic removals.

Conclusions resulting from the analysis of the wash data are listed in Table 1-1, along with the conclusions from the other major chapters of the report. Recommendations related to the beneficial uses and necessary water quality criteria for Las Vegas Wash are described in the last section of this summary.

NUTRIENT BUDGET

Water quality conditions in Las Vegas Bay are affected by nutrient loads from Las Vegas Wash and other sources. To identify the various nutrient sources and estimate their relative magnitudes, a nutrient budget task was performed. A preliminary nutrient budget was prepared which relied upon literature and data available at that time. The preliminary nutrient budget indicated potential major sources of nutrients to the bay and identified areas where additional effort was needed. As a result, data collection including a study of sediments was completed. Other sources of data included stormwater analyses performed by the Clark County Department of Comprehensive Planning as part of its 208 work, groundwater analyses performed as part of the WQSS, and information provided by the U.S. Bureau of Reclamation.

Nutrient budgets were prepared for orthophosphorus, total phosphorus, inorganic nitrogen, and total nitrogen for the period of routine lake monitoring, i.e., July 1979 through November 1980. Elements of the nutrient budgets included

Table 1-1. Summary of Water Quality Standards Study Key Conclusions

LAS VEGAS WASH - CHAPTER 9

1. The Clark County Sanitation District and City of Las Vegas treatment plants contribute 96 percent of the total phosphorus load and 94 percent of the total nitrogen load to Las Vegas Wash. The other surface water sources contribute 2 percent of the total phosphorus load and 4 percent of the total nitrogen load. Groundwater contributes the remaining 10 percent of the total nitrogen load.

2. Las Vegas Wash has historically removed 15 to 25 percent of the total phosphorus, 9 to 31 percent of the total nitrogen, and 93 to 96 percent of the ammonia load discharged to the wash from the treatment plants.

3. During the WQSS, approximately 250 kg/day or 30 percent of the total phosphorus was removed in 1979. In 1980, an average of 530 kg/day or 58 percent of the total phosphorus was removed. The decrease in removal occurred after the large storm of February 1980, when the headcut advanced by 8,500 feet and drained a large area of marsh.

4. Most of the total phosphorus removal occurs in the upper wash between Stations 1 and 2. Phosphorus removal in the wash is likely due to absorption to sediments, settling of particulate phosphorus, and biological uptake.

5. During 1979, approximately 1,300 kg/day or 24 percent of the total nitrogen was removed in the wash. In 1980, an average of 630 kg/day or 12 percent of the total nitrogen was removed. The decrease in removal occurred after the large storm of February 1980 which resulted in a decrease in the marsh acreage.

6. Most of the total nitrogen removal occurs in the upper wash between Stations 1 and 2, however, most of the ammonia removal occurs in the lower wash. Nitrogen removal in the wash is likely due to biological nitrification, denitrification, and absorption to sediments.

7. The nutrient removal capacity of the wash is remarkable considering that the travel time is only 28 hours and the flow is channelized throughout most of the wash. If the flow was slowed down by spreading the water throughout the marsh or impounding the water in a series of ponds, greater nutrient removal would be expected to occur. Since the nutrient removal capacity of the wash is decreasing, consideration should be given to mechanisms that will prevent future loss of removal capacity in the wash.

8. Regarding the beneficial uses of Las Vegas Wash, the following is recommended: irrigation, stock watering, and wildlife should be maintained as uses; aesthetics and recreation should be maintained as a use, but it should be qualified to exclude body-contact recreation; and fish should be deleted as a use.

9. The data collected in WQSS provide a basis for comparing existing water quality conditions to water quality criteria. Water quality standards recommendations can be made for most key parameters; the recommendations developed in this chapter are summarized along with the overall WQSS recommendations in Chapter 13.

NUTRIENT BUDGET - CHAPTER 7

1. Las Vegas Wash is the primary source of phosphorus to Las Vegas Bay. On an annual basis (October 1979 to September 1980), the wash contributed 94 percent of the total phosphorus and 89 percent of the orthophosphorus.

2. Las Vegas Wash is the primary source of nitrogen to Las Vegas Bay. On an annual basis (October 1979 to September 1980), the wash contributed 95 percent of the total nitrogen and 96 percent of the inorganic nitrogen.

3. Data to estimate nutrient sinks, particularly Boulder Basin exchange and biological uptake, are inadequate to develop a balance between sources and sinks.

TRANSPARENCY, ALGAE & NUTRIENTS - CHAPTER 8

Transparency Dependence

1. The chlorophyll concentration is the most significant water quality factor affecting transparency in Las Vegas Bay. Other water quality parameters contribute only marginally to controlling transparency.

2. Quantitative relationships between 1/SD and total chlorophyll in Las Vegas Bay vary seasonally and are best described by dividing the WQSS data into two groupings, spring (April to June) and summer (July to September):

   a. April to June, 1/SD = 0.017 + 0.014 TCHl
   b. July to September, 1/SD = 0.178 + 0.013 TCHl

3. Transparency varies significantly depending on location in the bay, decreasing with increasing proximity to the wash. But, the seasonal quantitative relationships describe the relationship between transparency and chlorophyll levels at all locations for that period of the year.

4. Transparency in Las Vegas Bay during the recreation season is controlled by the discharge of nutrients from the wash during that period. Winter discharge of nutrients appears to have little effect on transparency during the recreation season.

Algae Dependence

1. Algal chlorophyll concentrations in Las Vegas Bay are controlled by either nitrogen or phosphorus availability depending on location in the bay and season.

2. Quantitative relationships between total chlorophyll and total nitrogen or total phosphorus in Las Vegas Bay are best described by dividing the WQSS data into two groupings, spring (April to June) and summer (July to September):

   a. April to June, TCHl = -12.6 + 0.042 TN
   b. July to September, TCHl = -10.1 + 0.00 TN
   c. April to June, TCHl = 0.00 + 0.27 TP
   d. July to September, TCHl = 0.000 + 0.71 TP

3. Chlorophyll levels vary significantly depending on location in the bay. But, the seasonal quantitative relationships describe the relationship between chlorophyll and nutrient levels at all locations for that period of the year.

Transparency Control Procedure

1. Transparency of inner Las Vegas Bay is expected to increase in proportion to reduction in nitrogen loading from Las Vegas Wash if the dissolved N/P ratio of the wash entering the bay is less than 10 according to:

   a. The quantitative relationship between Secchi depth and total chlorophyll for the appropriate time of the recreation season.

   b. The quantitative relation between total chlorophyll and total nitrogen for the appropriate time of the recreation season.

   c. The reduction in the total nitrogen level in the epilimnion based on dilution levels between the wash and the bay as limited by background nitrogen levels in the bay.

2. Transparency of inner Las Vegas Bay is expected to increase in proportion to reduction in phosphorus loading from Las Vegas Wash if the dissolved N/P ratio of the wash entering the bay is greater than 10 according to:

   a. The quantitative relationship between transparency and total chlorophyll for the appropriate time of the recreation season.

   b. The amount of phosphorus limitation required to make phosphorus limiting, i.e., N/P = 10.

   c. The quantitative relationship between total chlorophyll and total phosphorus for the appropriate time of the recreation season.

   d. The reduction in the total phosphorus level in the epilimnion based on dilution levels between the wash and the bay.

Beneficial Uses and Water Quality Criteria

1. Secchi depth should be used as the basis for transparency measurement and for water quality criteria in the bay.

2. A minimum Secchi depth of 1.7 meters should be maintained in all areas of Lake Mead designated for swimming. This criteria should be met 90 percent of the time from May 1 through September 30.

3. The issue of whether Secchi depths greater than 1.8 meters should be required in any areas of the lake must be resolved by local decision makers and should include consideration of the likelihood of diving in areas of restricted transparency.

4. A mixing zone, within which the proposed criteria would not apply, should be allowed extending from the mouth of Las Vegas Wash downstream to WQSS Station 2.

5. For nitrogen and phosphorus loading conditions during the 1979 and 1980 recreation seasons, Secchi depths inwards of WQSS Station 2 did not meet the proposed criterion, i.e. Secchi depths were less than 1.2 meters more than 10 percent of the time.

6. Improved transparency would have beneficial effects on swimming, aesthetic, and fishing uses in the inner bay; but nutrient reductions to improve transparency may have some adverse effects on the fishery, particularly downstream of Lake Mead, due to reduced algal productivity.

DISSOLVED OXYGEN - CHAPTER 9

1. The metalimnetic minimum DO occurs throughout Lake Mead during the summer period of thermal stratification. The depletion in Las Vegas Bay is more severe than in Boulder Bay and Virgin Basin. In Las Vegas Bay, DO concentrations drop below the current standard of 5 mg/l between depths of 15 meters and 30 meters throughout most of the summer.

2. The minimum DO concentration in Boulder Bay was generally near 7 to 8 mg/l, whereas the minimum concentration in Las Vegas Bay was less than 1 mg/l. The oxygen-depleted zone occupied a greater volume of water in Las Vegas Bay. For example, 40 to 60 percent of the volume of Las Vegas Bay and 2 to 10 percent of the volume of Boulder Bay had dissolved oxygen concentrations less than 5 mg/l during September.

3. Results of the DO balance for overall Lake Mead indicated that respiration by algae and zooplankton accounted for about 30 percent of the oxygen demand, while nitrogenous and carbonaceous biochemical oxygen demand (BOD) from the wash accounted for most of the remainder. In the inner bay, the BOD from the wash was the major oxygen-demanding factor accounting for about 60 percent of the demand, while respiration accounted for most of the remainder.

4. Based on a review of agency criteria documents and literature sources, the following water quality criterion is recommended to protect the Lake Mead fishery: mean DO over the water column should not be less than 5 mg/l and monthly mean DO at any point in the water column should not be less than 3 mg/l.

AMMONIA - CHAPTER 10

1. Based on a review of the literature on un-ionized ammonia criteria, a criterion of 0.02 mg/l N is recommended for the protection of the Las Vegas Bay fishery.

2. Toxic concentrations of un-ionized ammonia probably had a minor effect on the fishery of Las Vegas Bay during the WQSS. Based on a criterion of 0.02 mg/l N, toxic concentrations were confined to Station 1 and the area near the plume at Stations 2 and 3. Occasionally concentrations exceeded 0.02 mg/l N in the plume at Station 4.

3. Un-ionized ammonia may have a significant impact on the fishery in the future. The load of ammonia from Las Vegas Wash has been increasing since 1977. During the WQSS, the load increased from 1,700 kg/day in 1978 to 2,100 kg/day in 1980. This resulted in higher concentrations of un-ionized ammonia in 1980.

4. Reducing the chlorophyll concentrations in the inner bay will have little effect on the toxicity of un-ionized ammonia in the surface waters or in the plume. Since algae increase the pH of the surface waters through photosynthesis, a relationship was developed between chlorophyll and pH. The relationship showed that the median pH at Station 2 would be reduced by 0.9 pH units if the average chlorophyll concentration was reduced to 20 mg/l. This would have a minor effect on the un-ionized ammonia concentrations. The pH values of the plume waters were typically low, so the high concentrations of un-ionized ammonia were due to high concentrations of total ammonia. Reducing the chlorophyll concentrations of the surface waters would not affect the un-ionized ammonia concentrations in the plume.

PERIPHYTON - CHAPTER 11

1. Laboratory surveys indicate that periphyton growth occurs throughout Boulder Basin and Virgin Basin.

2. Periphyton biomass growth rates on artificial substrates in Las Vegas Bay were three to five times greater than in central Boulder Basin and five to ten times greater than growth rates in Virgin Basin.

3. At all stations, except the one closest to the Las Vegas Wash, growth rates in the nearshore or littoral zone were greater than at the limnetic stations located in the middle of the lake.

4. Periphyton biomass growth rates in Lake Mead were one to two orders of magnitude greater than in Lake Tahoe and comparable to other reference cited.

5. Periphyton growth is affected by a number of factors including temperature, light level, substrate, pH, nutrients, and grazing.

6. Periphyton growth rates can be generally related to inorganic nitrogen or orthophosphorus concentrations using a power function; however, the statistical significance of these relationships is quite low, so the relationships are not suitable for making quantitative predictions of periphyton response to different nutrient levels.

7. Periphyton can impact beneficial uses. Black periphyton growth was noted on boat hulls in Las Vegas Wash during the WQSS. Extensive periphyton growth can reduce aesthetics and interfere with body-contact recreation; however, no surveys were included in WQSS to assess the extent of these impacts in Lake Mead.

8. It is not feasible to establish a quantitative water quality standard for periphyton. Thus, it will be necessary to rely on qualitative estimates of changes in periphyton growth resulting from the nutrient loads associated with the transparency control program.

OTHER ISSUES - CHAPTER 12

Water Supply Issues

1. During most of the WQSS, the plume formed by the Las Vegas Wash was at an elevation higher than the SNWA intake.

2. During the winter, plume depth fluctuated widely. It may have reached the depth of the SNWA intake; however, the plume was not detected in the immediate vicinity of the SNWA during two surveys conducted in late fall and winter.

3. Comparison of nutrient measurements at the depth of the SNWA intake indicate that orthophosphorus, total phosphorus, and ammonia are several times higher in outer Las Vegas Bay than in outer Boulder Bay; however, all measurements are within current recommended criteria.

4. Physical conditions including temperature, pH, dissolved oxygen, and conductivity at the depth of the SNWA intake in outer Las Vegas Bay and outer Boulder Bay are nearly identical.

5. Although odors have been a problem since initial operation of the SNWA, the cause of odors has not been determined.

6. Based on data collected by SNWA, odors have steadily decreased since 1979.

Bacteriological Data

1. With the exception of MPN data for a period extending from August 1976 through June 1977, all fecal coliform measurements taken in the inner Las Vegas Bay comply with body-contact recreation criteria.

2. The cause of high coliform concentrations during 1976 and 1977 has not been determined; however, concentrations in the lake were higher than those measured in the WQSS monitoring, while concentrations in the wash were comparable to the two studies.

Toxics Data

1. Some constituents violate EPA priority pollutant criteria and State recommended criteria.

2. Due to the very limited existing data base on toxics, it is not possible to estimate what the background levels are in Lake Mead or to determine what sources may be contributing toxic pollutants.

3. Additional sampling would be required to determine if existing pollutant levels affect fish and wildlife.

Las Vegas Wash flow, groundwater, runoff, sediment, nitrogen fixation, fallout, biological uptake, and Boulder Basin exchange.

The nutrient budgets indicate that Las Vegas Wash is the principal source of nutrients to Las Vegas Bay. The wash supplied 89 percent of orthophosphorus, 74 percent of total phosphorus, 96 percent of inorganic nitrogen, and 95 percent of total nitrogen to the bay. Surface runoff, not including runoff from the Las Vegas Valley which passes through Las Vegas Wash, amounted to 20 percent of the total phosphorus load. Sampling of surface runoff in Gypsum Wash and at several other locations indicated quite high total phosphorus concentrations. It is probable that most of the total phosphorus settles out of the bay as sediment and is not biologically available; however, surface runoff loads should be carefully evaluated when the load allocation is performed. The sediment study indicated that sediment contributes about ten percent of the orthophosphorus to the bay.

TRANSPARENCY, ALGAE, AND NUTRIENTS

During the initial development of the WQSS work plan, water transparency was identified as one of the key water quality issues to be assessed. Much of the monitoring program design centered around the transparency issue. The transparency of recreational waters is important to aesthetics. Clear waters are more appealing to swimmers, thus enhancing the recreational benefits derived from the water. Transparency is important from the safety standpoint as well. Swimmers and divers should be able to see a certain distance below the surface of the water so they can avoid hazardous submerged objects.

Data collection in the WQSS to define transparency-algae-nutrient relationships can be divided into four major groups:

general water quality, transparency relationships, algal relationships, and nutrient limitation. General water quality data were collected at the 11 lake sampling stations on a weekly basis during the spring and summer months and biweekly or monthly for the remainder of the year. In addition, four intensive or synoptic surveys were conducted to show spatial variations in water quality. Water transparency was determined by measurement of the Secchi disc depth and light transmittance. Algal concentrations were established by measurement of chlorophyll, counting algal numbers, and determining algal cell volumes. Several types of date were taken to identify nutrient-limiting conditions in the algal populations: nitrogen and phosphorus concentration data; physiological measurements, including alkaline phosphatase activity, nitrogen fixation, and dark ammonia uptake; and an extensive program of bioassays.

Secchi depths ranged from a minimum of about 1 meter in the inner bay to a maximum of about 20 meters in Boulder and Virgin Basins. Secchi depths at all stations were lower in 1980 than in 1979. Chlorophyll measurements follow the same general trends as Secchi depth with peaks occurring in the spring, summer, and fall months. Changes in chlorophyll levels from week to week were large, particularly in the inner bay. Dominant algal species early in the year were diatoms and Cryptomonads, while green algae dominated the population later in the season, August through October. Chlorophyll data collected since 1972 were reviewed. The data indicate that both maximum and minimum chlorophyll values in the inner bay gradually decreased from 1972 through 1977 and then increased from 1978 to the present.

At the outset of the WQSS, study participants agreed that data analysis would be restricted to empirical methods and that mathematical modeling would not be used. Thus, statistical

procedures have been used to develop correlations for Las Vegas Bay transparency, algae, and nutrient concentrations and for nutrient concentrations and wash loadings. Different types of correlations were developed for many different groupings of the data in an effort to develop the most reliable relationships. A two-step linear relationship was selected to relate Secchi depth to chlorophyll and chlorophyll to phosphorus/nitrogen. Nutrient concentrations are then related to wash concentrations based on wash dilution relationships. Table 1-1 shows the final relationships. To facilitate calculation of transparency control requirements for different conditions, the control relationships were converted to graphical form.

The literature review conducted by the PMC indicates there are very few transparency-related criteria that have been developed. A minimum Secchi depth of 1.2 meters (4 feet) appears to be the criterion most commonly used and is recommended as the minimum acceptable transparency level for areas of Lake Mead designated for swimming. It is recommended that the 1.2-meter criterion be imposed during the swimming season from May through September and be met 90 percent of the time during that period. It is further recommended that a mixing zone, within which the criterion would not be applied, be allowed extending from the point at which the wash enters the bay downstream to WQSS Station 2. The issue of whether Secchi depths greater than 1.2 meters should be required must be decided by local decision makers and should include consideration of the likelihood of diving in areas of restricted transparency. The work proposed under TFS-II is intended to provide data on costs, energy, and treatment facilities associated with achieving minimum Secchi depths greater than 1.2 meters.

DISSOLVED OXYGEN

Depletion of dissolved oxygen in the metalimnion (middle water layer) in Lake Mead was first reported in 1944 and has probably occurred since Lake Mead was formed in 1935. Oxygen depletion occurs to some degree throughout Lake Mead during the period when the lake is stratified (vertically stabilized), approximately from May through October. During the remainder of the year, oxygen levels are close to saturation throughout the water column. Dissolved oxygen concentrations were routinely measured throughout the water column during the limnological monitoring program. A special dissolved oxygen study was conducted in September 1980 to determine the cause of the oxygen depletion in Las Vegas Bay and to attempt to determine the impact of the Las Vegas Wash load on dissolved oxygen depletion.

During 1980, minimum dissolved oxygen levels occurred in September. Minimum dissolved oxygen concentrations were 1 to 2 mg/l in Las Vegas Bay and 3 to 4 mg/l in Bonelli Bay. The oxygen-depleted zone occupied a greater proportion of the water volume in Las Vegas Bay. For example, 40 to 50 percent of the volume of Las Vegas Bay and 5 to 10 percent of the volume of Bonelli Bay had dissolved oxygen concentrations less than 5 mg/l during September. Dissolved oxygen data from 1968 to the present for a location in the middle bay were compiled, and the progression of the dissolved oxygen depletion in the metalimnion during the summer months of each year was plotted. The same general pattern in oxygen depletion occurred each year and reached a minimum of less than 2 mg/l in the early fall.

There are several potential factors contributing to the depletion of dissolved oxygen in the metalimnion of Las Vegas Bay. To determine the relative impact of the

oxygen-demanding factors on the depletion, mass balances of oxygen were calculated for overall Las Vegas Bay and for the inner bay. Respiration by algae and zooplankton accounted for 90 percent of the demand, while nitrogenous and carbonaceous biochemical oxygen demand (BOD) from the wash accounted for most of the remainder. In the inner bay, the BOD from the wash was the major oxygen-demanding factor accounting for about 80 percent of the demand, while respiration accounted for most of the remainder. The BOD estimates are maximum values, since some portion of the BOD load may not exert an oxygen demand in the zones analyzed. The data were analyzed to attempt to develop relationships between wash nutrient and BOD loads and dissolved oxygen depletion in the bay. Although some general relationships exist, there are insufficient data to develop quantitative relationships upon which allowable loads can be computed.

A review of agency criteria documents and literature sources was performed to provide a basis for a dissolved oxygen criterion for Lake Mead. The sources generally indicate that 5 mg/l dissolved oxygen is desirable to support a diverse fishery and dissolved oxygen levels less than 3 mg/l adversely affect some fish such as striped bass. A dissolved oxygen criterion for Lake Mead needs to take into account the fact that the lake is stratified in the summer months. Portions of the water column have high levels of oxygen, while the metalimnion is significantly depleted. On this basis, it is recommended that the mean dissolved oxygen concentration over the water column should not be less than 5 mg/l and that the monthly mean dissolved oxygen concentration at any point in the water column should not be less than 3 mg/l.

AMMONIA

When ammonia dissolves in water, a chemical equilibrium is established between un-ionized ammonia, ionized ammonia, and hydroxide ions. The un-ionized form of ammonia is considerably more toxic than the ionized form. The concentration of un-ionized ammonia is a function of the concentration of total ammonia, temperature, pH, and the total dissolved solids concentration of the water. The need to analyze the potential for ammonia toxicity was identified during WQSS planning and preliminary data analysis work. Measurements of ammonia and associated water quality parameters were routinely made at all sampling stations, so un-ionized ammonia concentrations could be calculated. The concentrations of un-ionized ammonia were highest during the spring and summer months when temperatures were highest and algal-induced increases in pH were greatest. Un-ionized ammonia concentrations were highest in the inner bay in the vicinity of the plume. For example, at Station 2 at a 10-meter depth, which was generally slightly above the plume, un-ionized ammonia concentrations ranged from 0.003 to 0.22 mg/l (as N) with a median concentration of 0.041 mg/l. Un-ionized ammonia concentrations were generally less than 0.02 mg/l outward of Station 4.

Based on a review of various agency water quality criteria documents and scientific sources, a criterion of 0.02 mg/l of un-ionized ammonia (as N) is recommended for the protection of the Lake Mead fishery. Based on the criterion of 0.02 mg/l of un-ionized ammonia, toxic concentrations were confined to Station 1 and the area near the plume at Stations 2 and 3. Occasionally, concentrations exceeded 0.02 mg/l N in the plume at Station 4. It is proposed that the ammonia criterion be applied as a mean value over the water column.

Relationships between wash ammonia loads at Northshore Road and ammonia concentrations in the bay were assessed. Ammonia concentrations are reduced in the bay by physical dilution of the plume, and they are also reduced by conversion of ammonia to nitrate and algal uptake of ammonia. A method was developed for relating wash total ammonia concentration to un-ionized ammonia concentration in the inner bay. It can be used to determine allowable ammonia loads at Northshore Road to meet an un-ionized ammonia criterion.

PERIPHYTON

Concern over periphyton (attached algae) growth in Las Vegas Bay was first reported in 1967 when floating mats of Cladophora were sighted in Las Vegas Bay. Extensive growths of Cladophora were also observed in the Las Vegas Wash. There are also reports of complaints about algae growth on boat hulls by boat owners at Las Vegas Wash Marina, particularly during the early 1970s. As a result of these concerns, a periphyton study was performed as part of the WQSS. The objectives of the periphyton study were to document periphyton conditions during the WQSS and to identify factors which affect periphyton growth.

Two types of monitoring were conducted as part of the periphyton study: (1) routine sampling to determine periphyton growth rates on artificial substrates along the shoreline and at the lake stations and (2) four quarterly surveys involving rock scraping along the shorelines of Las Vegas and Bonelli Bays. WQSS results demonstrated a consistent trend of decreasing periphyton growth rates with increased distance from the wash.

Literature on periphyton was reviewed to put conditions in the study area in perspective. Much of the literature, however, deals with sampling procedures, and relatively few reported

results utilize comparable sampling techniques. Various factors which affect periphyton growth were reviewed and conditions in Lake Mead were analyzed. The only factor that could be correlated with periphyton growth was nutrient concentration.

Statistical analysis of nutrient/periphyton relationships did not yield a significant numerical function which could be used to make quantitative predictions of the effect of nutrient control strategies. Currently, there are no state or federal standards for periphyton, and surveys to quantify the impact of periphyton on beneficial uses were not authorized. The periphyton study did meet its objectives, however, by documenting periphyton conditions in Lake Mead during the WQSS and investigating factors which affect periphyton growth rates. Results of the study may be used to make qualitative predictions of the effect of alternative control strategies, and may be compared to results of future monitoring.

OTHER ISSUES

In addition to the major issues identified at the outset of WQSS, several secondary issues were raised subsequently: (1) water supply issues, (2) analysis of bacteriological data, and (3) analysis of toxics data. These issues were analyzed in preliminary reports prior to the annual report, and the Program Management Consultant's response to comments on the annual report indicated that additional work would be required to adequately answer many of the comments. Most of the additional work, however, was never approved by the WQSB. Utilizing all available data from the WQSS and other sources including the U.S. Geological Survey (USGS), Southern Nevada Water System (SNWS), and University of Nevada at Las Vegas (UNLV), each secondary issue has been assessed and conclusions have been drawn.

Water supply issues include the relationship of the Las Vegas Wash discharge to water supply intake structures in outer Las Vegas Bay and taste and odor problems in the water supply. Although the primary focus of the Hydraulic Study was circulation in the inner and middle bay, data collected during intensive surveys conducted November 30, 1979, and January 20, 1980, indicate that the plume traveled along the axis of the bay and not in the vicinity of the water supply intakes. In addition, during most of the year, the plume remains in the upper 20 meters of the lake well above the depth of the intakes at current lake levels. During winter and early spring, when the lake is destratified, plume depth fluctuates widely, dispersing the plume over a large vertical extent. Taste and odor problems have occurred in the SNWS since its initial operation, although odors have steadily decreased over the past decade. As part of the WQSS, water quality factors typically associated with odors were analyzed, and the studies performed by SNWS to determine the cause of odors were reviewed. The cause of odors could not be determined.

As a result of excessive fecal coliform bacteria, the inner Las Vegas Bay has been posted as a no swimming area since the mid-1950s. Bacteriological monitoring was conducted as part of the WQSS to document existing bacteriological conditions and to identify sources of bacteria. Results of other monitoring were also reviewed. Results of WQSS monitoring in the inner bay were well within criteria for body-contact recreation as were all other data reviewed with the exception of a period extending from August 1976 through June 1977. The cause of high coliforms during the 1976-1977 period could not be determined.

In November 1980, EPA published water quality criteria for 64 classes of priority pollutants which have toxic effects. Although analysis of lake and wash samples for all of the pollutants was proposed in the WQSS, the work was never authorized. A few of the pollutants were measured periodically during the WQSS, and USGS and SNWS monitoring results were reviewed. Of the 128 pollutants recognized by the state and/or EPA, results for 28 were analyzed. There were violations of human health criteria for 10 pollutants and fish and wildlife criteria for 12 pollutants. However, the existing data base is insufficient to make any firm conclusions. Nor have any site-specific studies been conducted in Lake Mead to indicate whether or not present toxics levels constitute a problem.

CONCLUSIONS AND RECOMMENDATIONS

Key conclusions of the WQSS are contained in Table 1-1. Recommendations related to beneficial uses, water quality criteria and allowable loads are summarized below.

For Las Vegas Wash, it is recommended that the uses of irrigation, stock watering and wildlife be maintained. Aesthetics and recreation should be maintained as a use, but it should be qualified to exclude body-contact recreation. Fish should be deleted as a use, since the wash does not contain an appreciable area with suitable habitat to support a diverse fishery. Despite the current physical and water quality constraints, it is likely that mosquito fish and small numbers of other fish will continue to inhabit the wash in the ponded areas near Pabco Road. For Lake Mead, it is recommended that all current uses be maintained: water supply, recreation, fish and wildlife. The attainability of maintaining adequate transparency for swimming in the inner bay should be assessed in TFS-II.

In the early planning for the WQSS, several approaches were considered for developing appropriate water quality criteria necessary to support the beneficial uses of Las Vegas Wash and Lake Mead. The approach that was adopted by the WQSB consisted of scientific evaluation of data collected in WQSS and review of available agency documents and scientific sources on water quality criteria. Recommendations for water quality criteria for Las Vegas Wash and Lake Mead are contained in Tables 1-2 and 1-3, respectively.

After water quality criteria are identified, allowable loads or total maximum daily loads (TMDLs) may need to be established to assure that water quality criteria will be met. No TMDLs are required for Las Vegas Wash. TMDLs are needed to assure that recommended criteria for transparency, un-ionized ammonia and dissolved oxygen in Lake Mead are met. The transparency criterion can be met with either a TMDL for phosphorus or nitrogen. The un-ionized ammonia criterion requires a TMDL for total ammonia. The dissolved oxygen criterion requires a TMDL for ultimate oxygen demand (nitrogenous BOD and carbonaceous BOD). Procedures have been developed to compute TMDLs for nutrients (phosphorus and nitrogen) and ammonia. However, the data base and associated analysis for BOD/DO relationships are insufficient for computing a TMDL for oxygen-demanding substances, but can be used to approximate the BOD load that would be needed to meet the recommended dissolved oxygen criterion. Recommended TMDLs are presented in Table 1-4.

Treatment plant effluent limitations cannot be precisely defined until TFS-II is completed. Thus, before the Consent

Table 1-2. Water Quality Criteria Recommendations for Las Vegas Wash

Parameter/Current Standard[a]	Recommendation
Temperature June to September: Average—not more than 27°C Maximum[b]—not more than 31°C October to May: Monthly Mean—not more than 23°C Maximum[b]—not more than 27°C	Retain current standard.
pH Monthly Median—within range 6.5 to 8.5 Maximum[b]—within range 6.5 to 8.5	Monthly Median—within range 6.5 to 8.5 Single Value—within range 6.0 to 9.0.
Dissolved Oxygen Monthly Mean—not less than 5 mg/l Minimum[c]—not less than 4 mg/l	Aerobic conditions should be maintained.
Biochemical Oxygen Demand Monthly Mean—not more than 10 mg/l Maximum[b]—not less than 15 mg/l	Delete current standard.
Chemical Oxygen Demand Monthly Mean—not more than 40 mg/l Maximum[b]—not more than 50 mg/l	Delete current standard.
Suspended Solids Monthly Mean—not more than 2 mg/l Maximum[b]—not more than 5 mg/l	Delete current standard.
Surfactants (MBAS) Monthly Mean—not more than 0.8 mg/l Maximum[b]—not more than 1.0 mg/l	Retain current standard.
Phosphorus Monthly Mean—not more than 0.5 mg/l Maximum[b]—not more than 1.0 mg/l	Delete current standard.
Turbidity Monthly Mean—not more than 5 JTU	Delete current standard.
Fecal Coliform Monthly Geometric Mean[d]—not more than 200/100 ml Maximum[e]—not more than 400/100 ml	Delete current standard.
Nitrate No standard	Maximum of 25 mg/l.

[a]Table 47—State of Nevada Water Pollution Control Regulations.
[b]Maximum refers to single value in 90 percent of the samples.
[c]Minimum refers to single value in 90 percent of the samples.
[d]Based on a minimum of five samples during any 30-day period.
[e]Based on a minimum of five samples during any 30-day period; not more than 10% of total samples shall exceed 400/100 ml.

Table 1-3. Water Quality Criteria Recommendations for Lake Mead

Parameter/Current Standard[a]	Recommendation
Temperature June to September: Average--not more than 16°C Single Value--not more than 18°C October to May: Single Value--not more than 14°C No temperature increase above natural levels when water temperature is greater than or equal to 14°C and a maximum temperature increase of 1°C when the water temperature is less than 14°C.	Delete average and single value provisions but retain the provisions regarding temperature increase above natural levels.
pH Annual Median--within range 7.5 to 8.2 Single Value--within range 7.0 to 8.5	Annual Median[b]--within range 7.5 to 8.3. 90% of the Time[b]--within range 6.5 to 9.0.
Dissolved Oxygen (DO) June to September: Average--not less than 6 mg/l All Year: Single Value--not less than 5 mg/l	Mean DO over the water column should not be less than 5 mg/l, and monthly mean DO at any point in the water column should not be less than 3 mg/l.
Biochemical Oxygen Demand Single Value--not more than 2 mg/l	Delete current standard.
Phosphates Annual Average--not more than 0.04 mg/l as PO_4 Maximum Value in 90% of Samples--not more than 0.06 mg/l as PO_4	Delete current standard.
Nitrates Single Value--not more than 7 mg/l as NO_3 Annual Average--not more than 4 mg/l as NO_3	Single Value--not more than 10 mg/l as N.
Fecal Coliform Geometric Mean[c]--200/100 ml Maximum[d]--400/100 ml	Retain current standard.
Color Color shall not exceed that characteristic of natural conditions by more than 10 units Platinum Cobalt Scale.	Delete current standard.
Turbidity Turbidity shall not exceed that characteristic of natural conditions by more than 10 JTU.	Delete current standard
Total Dissolved Solids 723 mg/l at Hoover Dam.	No recommendation.
Secchi Depth No standard.	A criterion of 1.2 meters (4 feet) be adopted as the minimum acceptable transparency level for areas of Lake Mead designated for swimming. The criterion should be imposed from May through September only and should be met 90% of the time during that period.[b]
Un-Ionized Ammonia No standard.	Mean over the water column should not be more than 0.02 mg/l as N.[b]

[a]Table 45--Nevada Water Pollution Control Regulations.
[b]Criterion does not apply to portion of Las Vegas Bay upstream of WQSS Station 2.
[c]Based on a minimum of five samples during any 30-day period.
[d]Based on a minimum of five samples during any 30-day period; not more than 10% of total samples shall exceed 400/100 ml.

Decree objectives can be fulfilled, certain work needs to be conducted under TFS-II, or some comparable study. Specific issues that need to be addressed in that work are identified in Chapter 13. There is a need to continue to monitor water quality conditions in Lake Mead and Las Vegas Wash to obtain a longer term data base collected under a range of future conditions. Future monitoring also needs to provide additional information related to several issues that have been identified through the WQSS analysis. These issues are defined in Chapter 13.

Table 1-4. Recommended Total Maximum Daily Loads (TMDL)

Lake criterion	Substance to control	Mean 1980 load, lbs/day	TMDL, lbs/day
Secchi depth	Phosphorus	860 1,300	May to June: 680 July to Sept: 600 Oct. to April: No TMDL
	or		
	Nitrogen	6,400 6,900	May to June: 4,200 July to Sept: 3,500 Oct. to April: No TMDL
Un-ionized ammonia	Ammonia (as N)	4,600[a]	All year: 6,600
Dissolved oxygen	Ultimate oxygen demand[b]	26,000	Unable to compute a TMDL[c]

[a]Maximum daily load in 1980 was about 8,000 lbs/day.
[b]Includes carbonaceous BOD and nitrogenous BOD.
[c]Preliminary calculations indicate that the ultimate oxygen demand would have to be limited to about 22,000 lbs/day to meet the dissolved oxygen criterion.

CHAPTER 2

INTRODUCTION

The Water Quality Standards Study (WQSS) is one of several studies being conducted as part of the Las Vegas Valley Water Quality Program. This chapter describes the background of the program, WQSS objectives, program organization, and organization of this report.

BACKGROUND

The Las Vegas Valley Water Quality Program is a study of water quality and wastewater treatment facilities in the Las Vegas area. The program is the result of a Consent Decree in a litigation action filed by the Cities of Las Vegas and North Las Vegas in July 1978. The suit was filed against the U.S. Environmental Protection Agency (EPA), the State of Nevada, and Clark County requesting that water quality standards for Las Vegas Wash and Lake Mead be reevaluated. The Consent Decree was negotiated by the parties and issued by the Federal District Court on March 15, 1979.

The Consent Decree identified a series of studies that was to be conducted. The studies can be divided into two parts: (1) those related to water quality and (2) those related to treatment facilities. In the Consent Decree, the Phase II Treatment Study (TFS-II) is referred to as part of the WQSS. At the outset of the program, an overall work plan was developed which included TFS-II as part of the WQSS. However, the facilities-related tasks were removed from that work plan and deferred for conduct at a later date. Due to this separation,

the term "WQSS" has generally been used throughout the program, and will be used in this report, to refer to just the water quality tasks and excludes the tasks which have been proposed to be conducted as part of TFS-II. This distinction between WQSS and TFS-II is important in understanding the scope of WQSS work that has been conducted and is presented in this report. The relationship between WQSS and TFS-II is further discussed in the "Objectives" Section of this chapter and in Chapter 5.

Figure 2-1 indicates the current schedule of the Consent Decree studies. More detailed schedules of the key events in WQSS and the monitoring program are provided in Chapter 5. Work on WQSS can be divided into five parts:

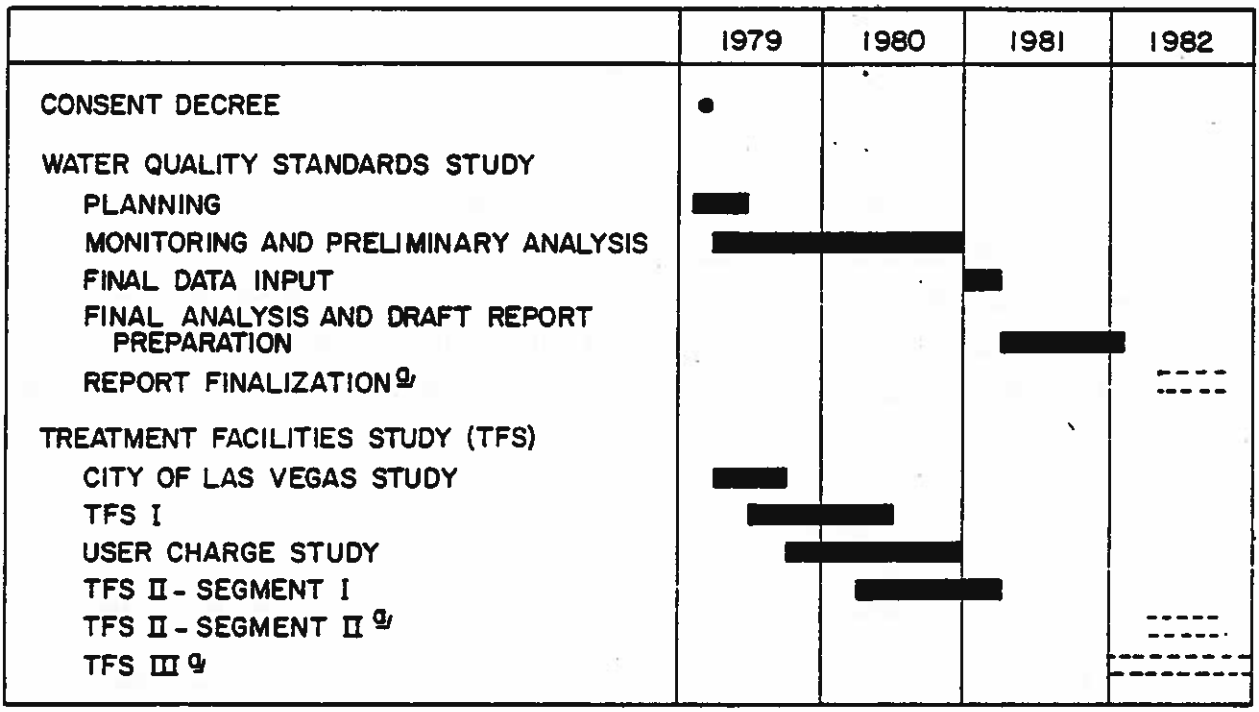
1. Planning--After the Consent Decree was signed, a series of eight technical meetings were held over a 4-month period to develop the WQSS work plan.

2. Monitoring and preliminary analysis--An interim monitoring program was conducted in the spring of 1979, and the comprehensive program was initiated in July 1979 and conducted through December 1980.

3. Final data input--Approximately 4 months were required to input a large backlog of data into STORET and to perform a point-by-point check of the data base.

4. Final analysis and draft report preparation--Following the data base check, the final analysis was initiated in April 1981. The results of the analysis are contained in this draft WQSS report.

5. Report finalization--At the present time, the Water Quality Study Board (WQSB) has not adopted a plan for finalizing the draft WQSS report.



a/ No specific schedule for completing this portion of the work has been adopted by the Water Quality Study Board

Figure 2-1 Schedule of Studies - Las Vegas Valley Water Quality Program

A series of treatment-related studies have also been conducted and their schedules are identified on Figure 2-1. Significant portions of TFS-II have not yet been conducted, and the WQSB has not adopted a plan for completing TFS-II. Also,

the Consent Decree requires that TFS-III be conducted after a specific set of water quality standards are adopted by the Nevada Environmental Commission, if the resulting effluent limitations are more stringent than 30/30/1.

OBJECTIVES

The Consent Decree provides the basic framework for conducting WQSS and TFS-II. The ultimate objective of the combined WQSS/TFS-II process is to provide the basis upon which the Nevada Environmental Commission can make administrative determinations required by Section 303 of the Clean Water Act. These determinations identified in Paragraph 25 of the Consent Decree are as follows:

1. Specify beneficial uses.
2. Investigate the attainability of the beneficial uses.
3. Identify water quality criteria to meet the beneficial uses.
4. Identify the physical, chemical, and biological factors affecting the water quality criteria.
5. Develop allowable waste load limitations necessary to meet the water quality criteria.
6. Allocate the waste load between point and nonpoint sources to determine effluent limitations necessary to meet the water quality criteria.

To provide the information to allow the State of Nevada (State) to make these six administrative determinations, Paragraph 18 of the Consent Decree indicates that the WQSS (and TFS-II) should include items of work in these same six areas. The work required in these six areas was intended to be conducted partly in the WQSS and partly in TFS-II. The WQSS work plan (Contracts 2 and 6) includes work to accomplish most of Items 1, 3, 4, and 5. Items 2 and 6 remain to be completed in proposed work under TFS-II. In essence, WQSS relates receiving water conditions to waste loads at Northshore Road and TFS-II translates Northshore Road loads into effluent limitations at the wastewater treatment plants. The relationship between WQSS and TFS-II is further described in Chapter 5.

The work that has been conducted to date in WQSS provides an adequate basis to develop many recommendations related to beneficial uses and the water quality criteria necessary to support those uses and those recommendations are presented in this report. However, treatment plant effluent limitations cannot be defined until the remainder of TFS-II is completed.

The WQSS work plans identified several key water quality areas that were to be addressed in the study:

1. Transparency, algae, and nutrients.
2. Periphyton.
3. Las Vegas Wash water quality.
4. Las Vegas Wash plume behavior.
5. Nutrient budget.
6. Dissolved oxygen.
7. Un-ionized ammonia.

The first five items were specifically identified in the scope of work introduction in the original WQSS contract (Contract 2). The dissolved oxygen and un-ionized ammonia issues were discussed at the data review meetings and were the subject of subsequent work plan proposals. The water quality analysis and presentation of results in this report have been structured around these key issues. Part way through the WQSS, the plume study work was transferred from WQSS to TFS-II due to funding resources and, thus, is covered in a separate report, which is contained in Appendix F to this report.

PROGRAM ORGANIZATION

The Consent Decree specified a particular organizational structure for the conduct of the water quality and treatment facilities studies. Figure 2-2 shows the structure followed in conducting the WQSS. Management of the studies is provided by an interagency entity called the Water Quality Study Board (WQSB). The WQSB consists of one representative each from Clark County, the Cities of Las Vegas and North Las Vegas, the State of Nevada, and EPA. The WQSB directs the activities of the Program Management Consultant (PMC), whose responsibilities are carried out by the consulting firms of Brown and Caldwell and Culp/Wesner/Culp. The Consent Decree also established a Technical Advisory Board (TAB) consisting of several scientists and engineers, to provide advice during the conduct of the studies and to assist in the formulation of recommendations.

The PMC has utilized two primary subcontractors to perform portions of the technical tasks. The University of Nevada at Las Vegas conducted most of the field sampling in Lake Mead, routine sampling in Las Vegas Wash, and most of the laboratory

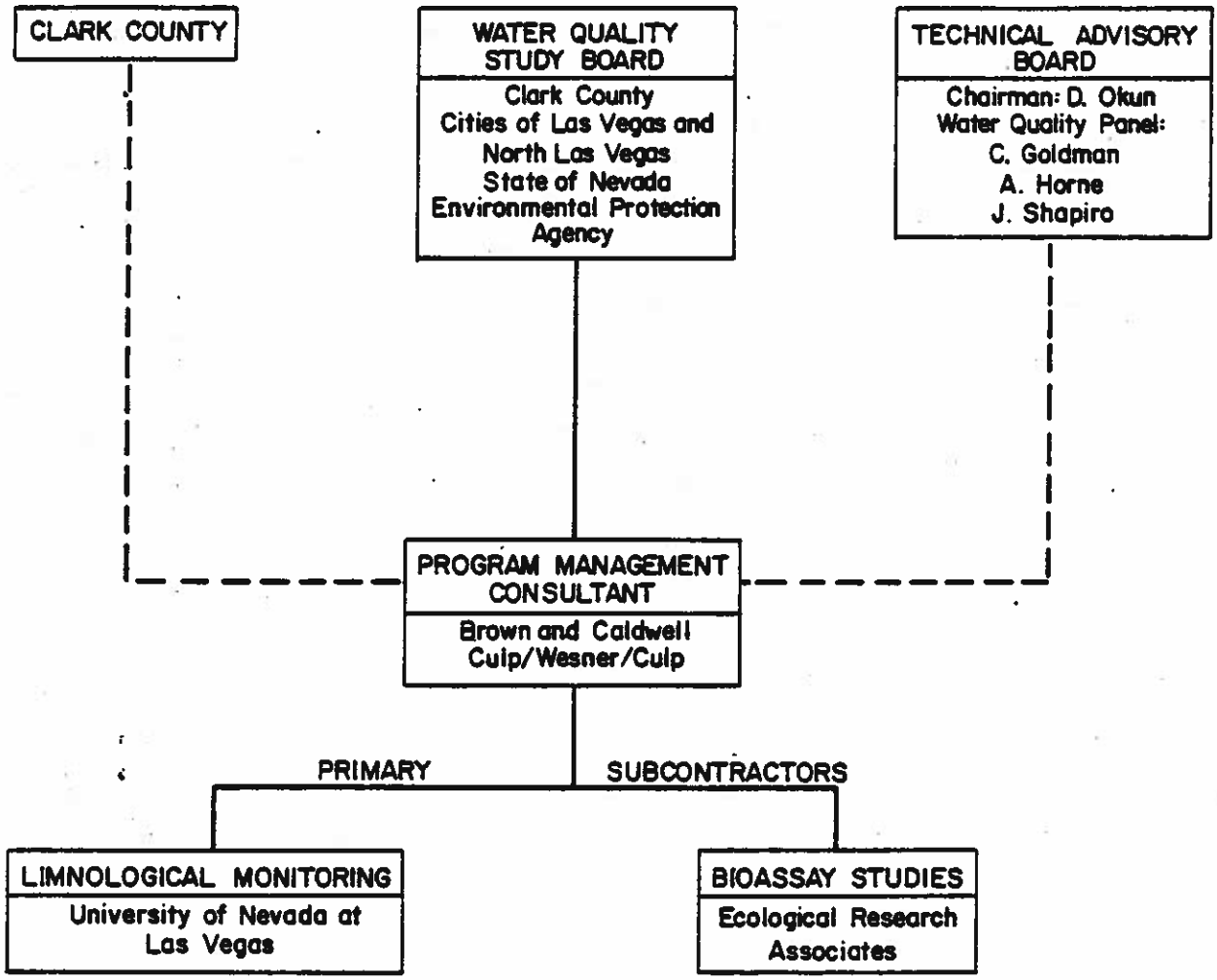


Figure 2-2 Water Quality Standards Study Organization Chart

analyses for the lake samples. Ecological Research Associates (ERA) conducted the bioassay studies. Several other subcontractors and agencies have conducted portions of the work: Dr. James Murray performed a sediment survey; EPA's Environmental Monitoring and Surveillance Laboratory in Las Vegas handled phytoplankton enumeration; EPA's Corvallis, Oregon, laboratory conducted algal assay procedure bioassays; bacteriological sampling in Las Vegas Bay was conducted by ERA and samples were analyzed at the State of Nevada, Bureau of Laboratories and Research Laboratory in Las Vegas; Desert Research Institute collected groundwater samples in the Las Vegas Wash area; keypunching was provided by J&S Keypunch Service; and EPA's Storage and Retrieval System (STORET) was utilized for data management.

REPORT ORGANIZATION

The WQSS report consists of a main report and a series of appendices. The main report is organized into four parts:

1. Summary--Chapter 1 summarizes the key points of each of the 12 chapters and the Conclusions and Recommendations.

2. Background--Chapters 2 through 5 provide background information in four areas to provide better understanding of the water quality results:

   a. Chapter 2. General study background.
   b. Chapter 3. Physical setting.
   c. Chapter 4. Beneficial uses.
   d. Chapter 5. Methodology and approach.

3. Results and Analysis--Chapters 6 through 12 present the water quality results for the key water quality areas identified in the Objectives section of this chapter:

   a. Chapter 6--Las Vegas Wash
   b. Chapter 7--Nutrient budget
   c. Chapter 8--Transparency, chlorophyll, and nutrients
   d. Chapter 9--Dissolved oxygen
   e. Chapter 10--Un-ionized ammonia
   f. Chapter 11--Periphyton
   g. Chapter 12--Other data not specifically covered under one of the preceding six water quality areas

4. Conclusions and Recommendations--Chapter 13 presents WQSS conclusions and water quality standards recommendations.

A very large amount of data was collected in WQSS and is presented in this report. In an effort to simplify the data presentation, we have followed a standardized format to the extent possible. Chapters are generally organized into the following sections:

1. Introduction.
2. Methodology.
3. Results (seasonal, spatial, and frequency distributions; Las Vegas Bay/Bonelli Bay comparison).
4. Data comparisons (historical and other lake data).
5. Analysis and load methodologies.
6. Effect on beneficial uses.
7. Conclusions.

A second method used to simplify the data presentation and to minimize the length of the main report is to put much of the material in appendices. Much of the supporting data is contained in a series of appendices which are listed in the Table of Contents. Most all of the water quality data are available in the permanent STORET data file.

There are also several related reports which have been prepared as part of the Las Vegas Valley Water Quality Program. These reports are listed in Chapter 5.

ACKNOWLEDGMENTS

Numerous individuals have helped to successfully complete this report. The names of most of those individuals are contained in the list of program participants at the beginning of the report. Brown and Caldwell is especially grateful to three groups who made major technical and scientific contributions to the study. Professors Joseph Shapiro, Alex Horne, and Charles Goldman of the Water Quality Panel of the Technical Advisory Board provided invaluable assistance in designing the monitoring program, analyzing the water quality results and reviewing individual draft chapters of this report, although the need to expedite completion of this report limited the depth of their review of the complete document. Dr. Larry Paulson and Mr. John Baker of the University of Nevada at Las Vegas and their staff were responsible for conduct of a landmark limnological monitoring program which has served to establish a thorough characterization of water quality conditions in Lake Mead. Dr. Richard Gersberg of Ecological Research Associates was project manager for the comprehensive bioassay program which added significantly to the depth of the analysis of algal limiting nutrient conditions.

CHAPTER 3

PHYSICAL SETTING

The Water Quality Standards Study (WQSS) addresses water quality conditions in Las Vegas Wash and Lake Mead. The physical setting of the study area is important to understanding water quality considerations and provides information used in many of the analyses which follow. The description of the study area is presented in three parts: (1) study area characteristics, (2) Las Vegas Wash description, and (3) Lake Mead description.

STUDY AREA CHARACTERISTICS

As shown on Figure 3-1, the study area is located at the junction of the states of Nevada, Arizona, and California. Areas of principal interest in the study include Las Vegas Wash, Las Vegas Bay, Boulder Basin, and Virgin Basin. Most residents in the region live in the Las Vegas Valley which has a population of about 500,000. Las Vegas Wash is the chief drainage channel of the valley. The local economy is highly dependent upon tourism and the recreational aspects of the area. Lake Mead is a major tourist attraction, attracting more than four million visitors each year for swimming, boating, water skiing, fishing, and camping.

History

The first modern settlement in the Las Vegas Valley was established in 1855. Farming and mining formed the original economy of the region. In 1905, when designated as a major

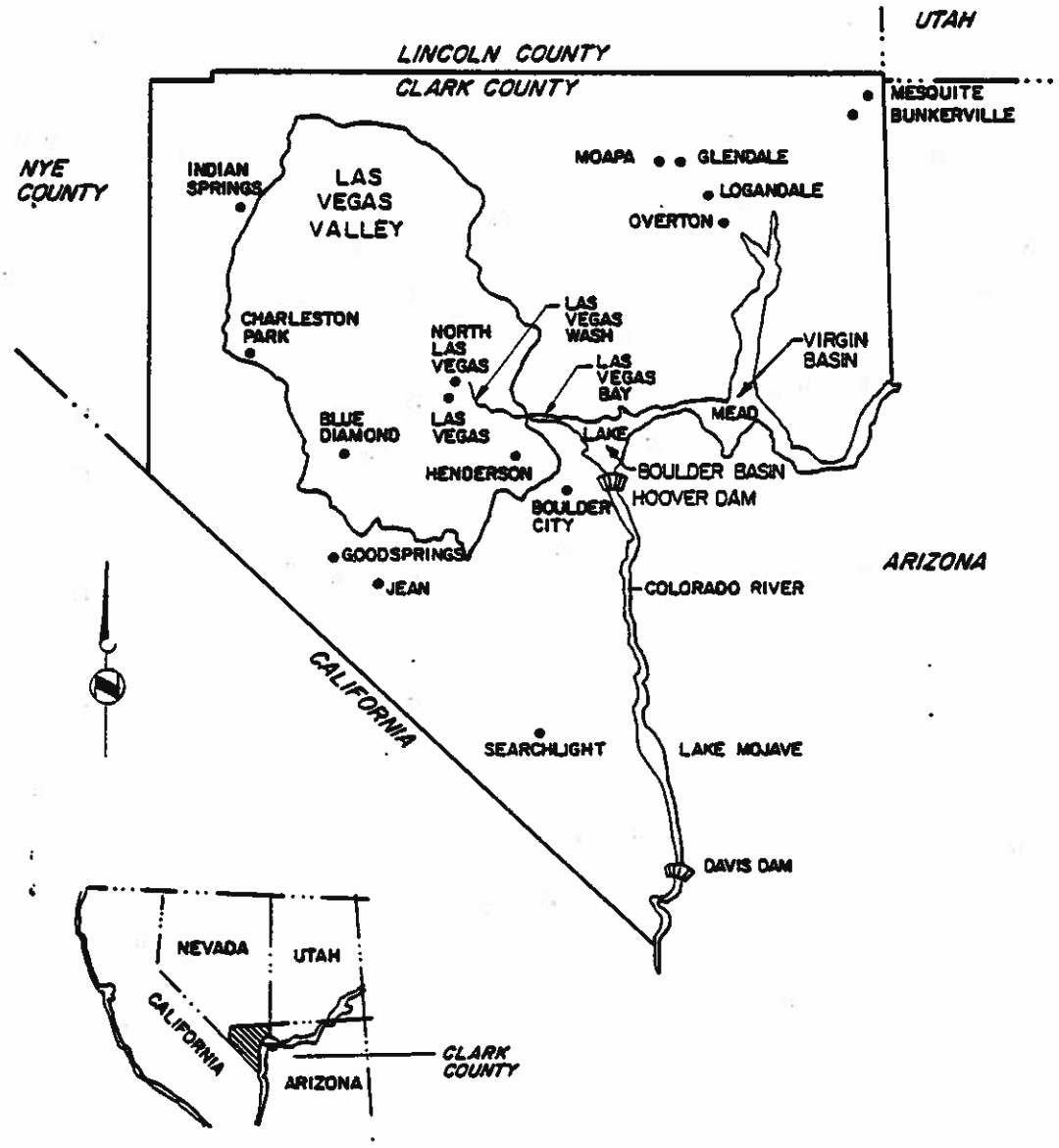


Figure 3-1 General Vicinity Map

point of the Union Pacific Railroad, the city of Las Vegas was established. Las Vegas reached a population of 800 by 1910.

Prior to construction of Hoover Dam, the lower Colorado River usually ran high in the late spring and early summer, occasionally attaining flows in excess of 100,000 cubic feet per second (cfs). During high flow periods, the river frequently inundated floodplain areas for miles around. Construction of Hoover Dam was begun in April 1931, and the dam began impounding water in February 1935. Storage of water behind the dam approached current levels in 1939.

Boulder City was developed to house laborers engaged in the construction of Hoover Dam. Las Vegas remained a railroad and agricultural service center until 1931 when gambling was legalized. Ten years later, military and defense facilities were established. After World War II, casinos and hotels flourished.

Existing Beneficial Uses

Beneficial uses of Lake Mead and Las Vegas Wash are detailed in Chapter 4. Beneficial uses of Lake Mead include recreation and aesthetics, water supply, fish and wildlife, and hydropower. All forms of water-oriented recreation are enjoyed in Lake Mead, including swimming, sunbathing, water-contact sports, boating, fishing, and aesthetic enjoyment. Lake Mead supplies the majority of water used for public supply in the Las Vegas Valley. The lake supports a substantial fishery consisting of striped and largemouth bass, threadfin shad, catfish, and carp. Three species of amphibians, 2 species of mammals, and 44 species of birds inhabit the lake environment.

The riparian and marsh communities of Las Vegas Wash are unique in the desert environment. Current aesthetic and recreational uses include birdwatching, hiking, and hunting. Plans to develop the wash into a wetlands park are currently under consideration. The Las Vegas Wash provides a diverse terrestrial habitat for a wide range of mammals, reptiles, and birds.

Climate

The Las Vegas Valley is subject to four well-defined seasons. Summers provide typical desert weather of hot, dry days with maximum temperatures normally above 100°F. Winters are relatively mild with average maximum temperatures of 55° to 65°F and average minimum temperatures of about 35°F. During the fall and spring, maximum temperatures of 70° to 90°F and minimum temperatures of 45° to 65°F normally occur.

Precipitation averages about 4 inches per year. About half of the precipitation occurs in the summer during periods when warm, moist tropical air predominates weather conditions. During these periods, localized thunderstorms develop which, at times, result in flash flooding. Low humidity and abundant sunshine produce rapid evaporation which averages over 100 inches per year.

Winds in the Las Vegas Valley average about 9 miles per hour from the southwest. Occasionally, strong winds of over 50 miles per hour occur. However, the area is essentially surrounded on all sides by mountain ranges and, during much of the year, circulation is thermally induced rather than the result of large-scale cyclonic activity. Temperature inversions

prevail about 45 percent of the year, and acute periods of stagnation can last for several days, particularly during November, December, and January. Temperature, wind speed, cloud cover, and precipitation data for the period of the WQSS are summarized on Figure 3-2.

Geology and Hydrology

The Las Vegas Valley is composed of three distinct physiographic units, including the mountains, alluvial aprons, and basin lowlands. The basin lowlands are composed of silts, sands, and gravels, with shallow caliche deposits.

Four principal aquifers have been identified in the Las Vegas Valley. The "near surface" aquifer extends to depths of 61 meters (200 feet) with present depths to water ranging from ground surface to about 61 meters (200 feet) near the base of the zone. The near-surface aquifer contains water of generally poor quality, due to natural salt buildup as well as man-made causes such as landscape irrigation, septic tanks, sewage effluent disposal, and irrigation with sewage effluent.

Beneath the near surface aquifer lie three additional aquifers, including the shallow-zone aquifer from approximately 61 to 152 meters (200 to 500 feet), the middle-zone aquifer from approximately 152 to 213 meters (500 to 700 feet), and the deep-zone aquifer below 213 meters (700 feet). The near surface aquifer is unconfined, but the lower three zones are confined. Some vertical exchange between aquifers occurs because of irregular deposition and erosion of sediments, faulting in the valley fill, and leakage resulting from improper well

construction. Groundwater moves downslope and laterally in the direction of the hydraulic gradient from the large alluvial fans at the base of the Spring Mountains to the southwest portions of the valley.

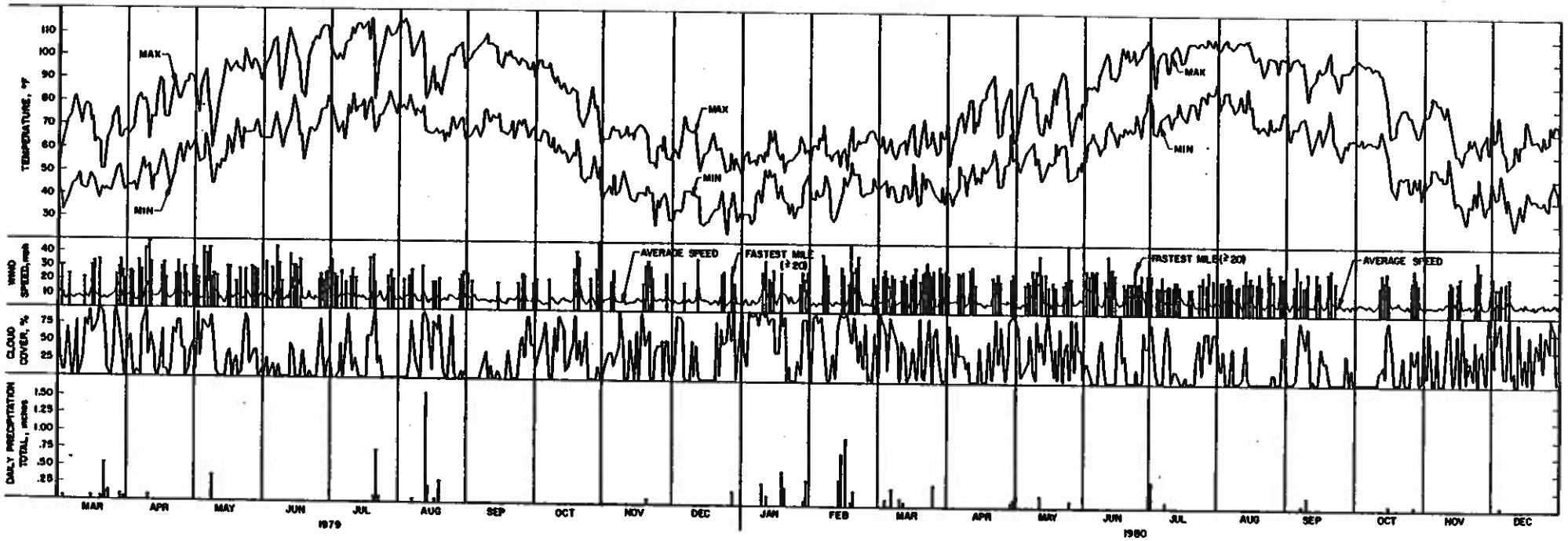
LAS VEGAS WASH DESCRIPTION

Las Vegas Wash is a wetlands ecosystem at the terminus of the Las Vegas Valley drainage basin, discharging into Las Vegas Bay of Lake Mead. The physical and biological characteristics of the wash are described in this section.

Physical Characteristics

Las Vegas Wash originates in the Spring Mountains approximately 45 kilometers (km) north of Las Vegas. The wash has been altered drastically in the last 100 years due to changes in the water resources induced by occupation of the valley. Early historic accounts of the wash indicate that the stream was quite small and may have been seasonally intermittent. It was fed only by springs, and flow may have been subsurface during part of the year. Early historic pictures of the wash show a sparsity of vegetation and general lack of water.

The wash is currently an intermittent stream from its origin to the vicinity of the City of Las Vegas wastewater treatment plant. A perennial stream fed by treated wastewater effluent, surfacing groundwater, and surface water runoff, flows in the 18-km stretch between the city treatment plant and Las Vegas Bay. During the WQSS, the wash discharged an average of 100 cfs to Las Vegas Bay. Figure 3-3 shows the location and



Note: Measurements taken at Mc Carran Airport.

Figure 3-2 Meteorologic Data for Las Vegas, Nevada, During WQSS

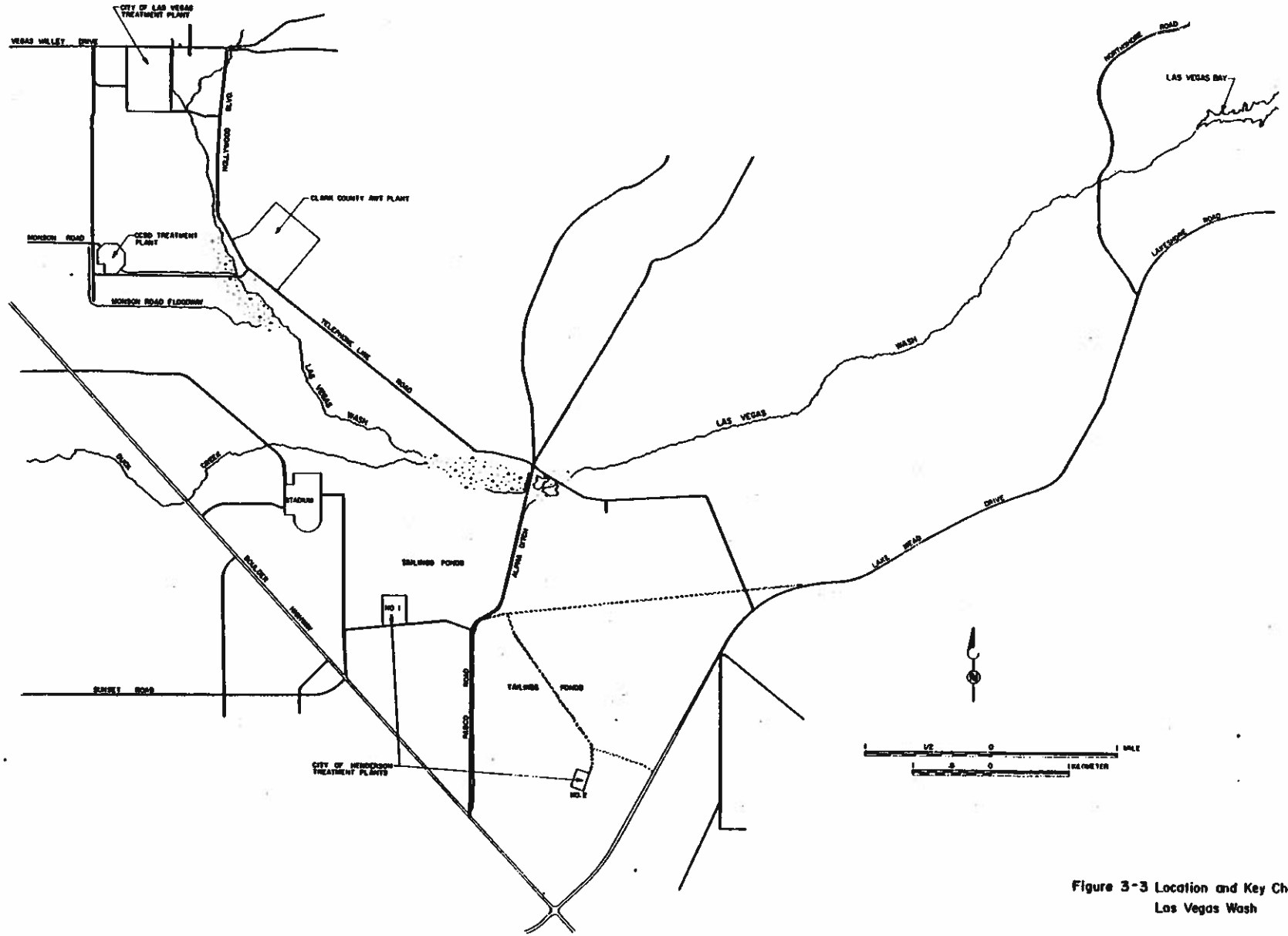


Figure 3-3 Location and Key Characteristics of Las Vegas Wash

key characteristics of Las Vegas Wash. The wash currently receives secondary treated wastewaters from the City of Las Vegas and Clark County Sanitation District treatment plants. The two secondary treatment plants currently discharge about 85 cfs of treated wastewaters to the wash. The treated wastewater flows through a 15-km reach of Las Vegas Wash and is then discharged to Las Vegas Bay. During the WQSS, surfacing groundwater contributed 23 cfs and surface water runoff contributed 18 cfs to the wash flow.

The area between the city treatment plant and Las Vegas Bay is characterized by four distinct regions; an extensive tule and cattail marsh with a swift-moving channel flowing through the northern portion upstream of Pabco Road; a series of ponds downstream of Pabco Road (Pabco Ponds); a tule and cattail marsh immediately downstream of the Pabco Ponds; and a channelized, fast-flowing stream bordered by steep canyons from the end of the marsh to Las Vegas Bay. Erosion in both the upper wash (upstream of Pabco Road) and lower wash (downstream of Pabco Road) has resulted in the drainage of large areas of marsh land and the creation of channels. The erosion in the upper wash is due to the excavation of a channel by Clark County from the confluence of the discharges from the two treatment plants to 1.6 km downstream. This channelization resulted in the drainage of much of the marsh upstream of Pabco Road. The erosion in the lower wash has been occurring for about five years. During the WQSS, the headcut advanced by 1.4 kilometers during one storm in February 1980.

Biological Characteristics

Las Vegas Wash provides a diverse terrestrial animal and bird habitat. According to URS Company, 48 species of

mammals, 29 species of reptiles, 252 species of birds, 6 species of amphibians, and 4 species of fish inhabit Las Vegas Wash.[1] The Las Vegas Wash Environmental Assessment lists 276 species of birds.[2] Wildlife species inhabiting the wash are closely associated with the vegetative communities of the wash.

Marsh, desert riparian, saltbush, and desert are the vegetative communities occurring in the wash. The marsh community, located immediately upstream and downstream of Pabco Road, is dominated by cattails, bullrushes, sedges, and reeds. These plants grow in saturated soils and areas of standing water. The highest bird density in the wash occurs in the marsh community. Waterfowl and shorebirds inhabit the marsh and open water areas of Las Vegas Wash. Many of these species are migratory so the heaviest use of the wash occurs during the spring and fall migrating seasons. A few species of amphibians and mammals inhabit the marsh community.

The desert riparian community occurs adjacent to watercourses in the wash. Salt cedar and mesquite are the dominant plant species. Dense stands of salt cedar occur near the treatment plants and in the area of the headcut. Many of the permanent winter resident bird species inhabit the desert riparian community. Snakes, toads, and mice are also found in the riparian community.

The saltbush community occurs on saline soils at the confluence of Duck Creek and Las Vegas Wash. This community is composed of species of Atriplex with an understory of saltgrass. A number of seed-eating mammals and seed and insect-eating birds inhabit this community.

The desert area surrounding Las Vegas Wash is dominated by the creosote bush community. A few species of seed and insect-eating birds, a few mammals, and a wide variety of reptiles inhabit this community.

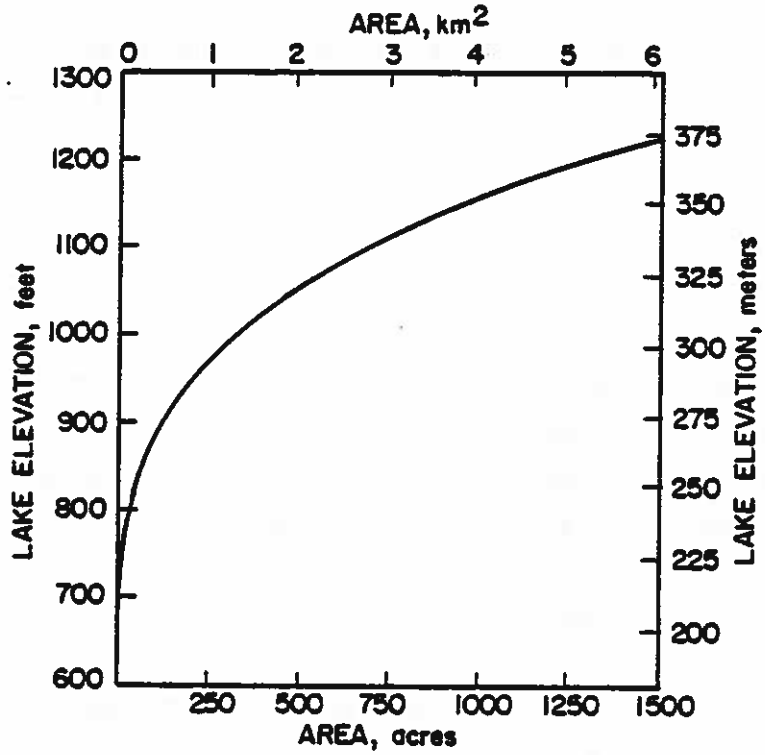
LAKE MEAD DESCRIPTION

The following paragraphs describe Lake Mead in terms of its surface area and volume, sources and losses of water, and past and projected lake level. This information provides the bases for many of the analyses which follow.

Surface Area and Volume

The high water line of Lake Mead is 375 meters (1,229 feet) above sea level. At this water surface elevation, water is flowing over the top of the spillway. With water surface elevation at 372 meters (1,221.4 feet), the water surface is at the top of the spillway gates. During the WQSS, water surface elevation ranged from about 364 meters (1,195 feet) to 367 meters (1,205 feet) and averaged about 366 meters (1,200 feet). At a water surface elevation of 366 meters (1,200 feet), Lake Mead has a maximum depth of about 170 meters (560 feet), contains about 31 km^3 (25,000,000 acre-feet) of water, extends about 161 km (100 miles) upstream, and has a surface area of about 600 km^2 (230 square miles). Area and capacity curves for Lake Mead are presented on Figure 3-4.

For purposes of the WQSS, the Las Vegas Bay has been defined as that portion of Boulder Basin west of Saddle Island. The bay is a wedge-shaped, flooded canyon embayment. At its widest point, the bay is about 5.6 km (3.5 miles) across. The bay has



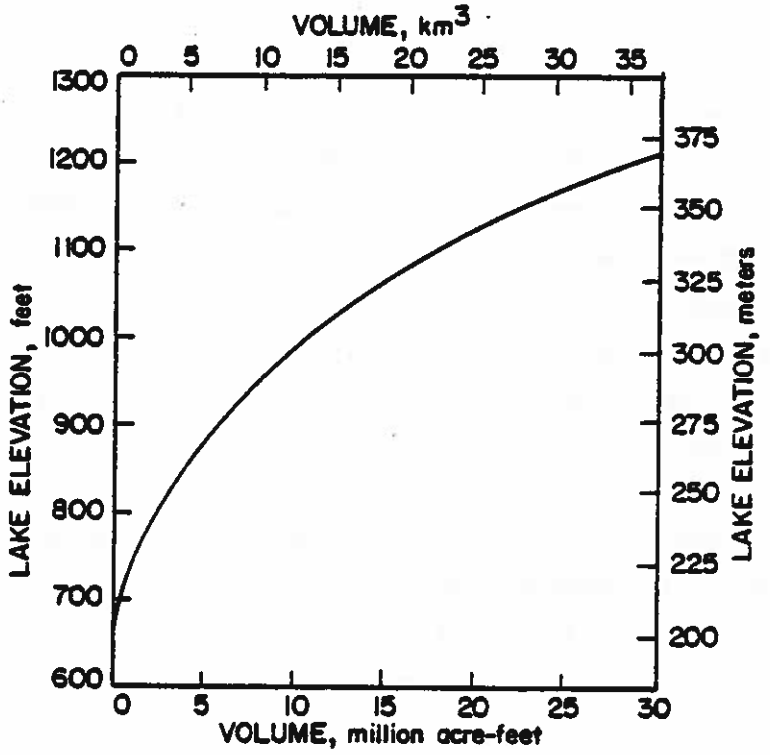


Figure 3-4 Lake Mead Area and Volume Versus Elevation Curves

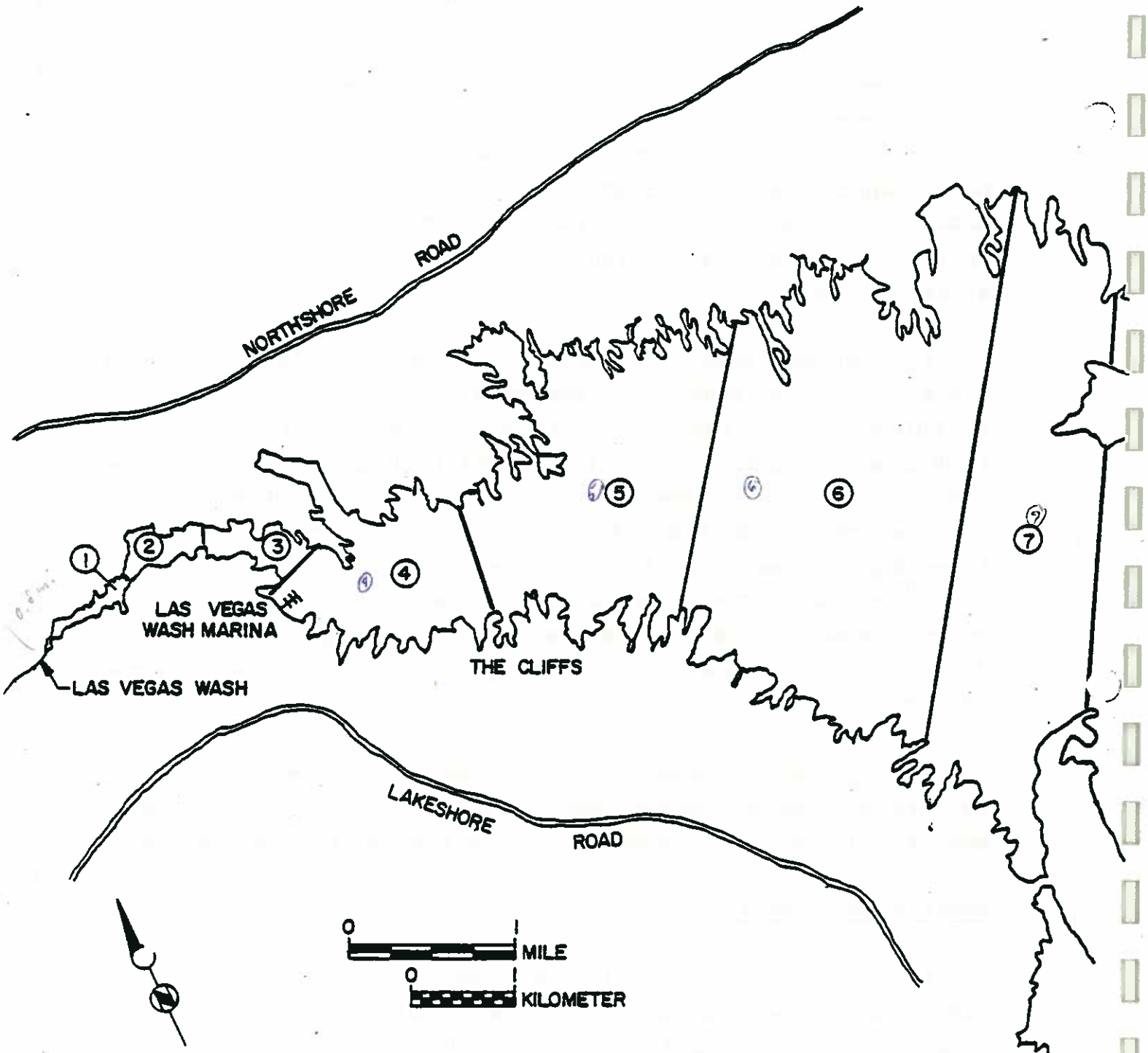
a maximum depth of about 116 meters (380 feet). Overall, the rate of change of depth is relatively uniform along the axis of the bay from the confluence of the wash and bay to the deepest point, approximately 10.5 km (6.5 miles) out along the bay axis. Sediment carried out in the wash has formed a delta. The bay bottom is generally flat with a notch at the location of the old stream channel.

In previous studies, the bay has been divided into three areas called the inner bay, the middle bay, and the outer bay. In the WQSS, the bay has been further segmented into zones. Each zone is associated with a WQSS limnological monitoring station. Borders between zones were drawn to be normal to the original channel bottom. Zones 1, 2, 3, and 4 characterize the inner bay. Zones 5 and 6 lie in the middle bay. Zone 7 defines the outer bay. The zones are shown on Figure 3-5. Area and volume curves for the bay and each zone are presented on Figures 3-6 and 3-7, respectively, and are utilized later in the analysis.

Bonelli Bay, adjacent to Virgin Basin, was selected as the background area for comparison of water quality data. Although smaller in size, its configuration is similar to Las Vegas Bay.

Sources and Losses of Water

The Colorado River is the main source of surface inflow to Lake Mead. The nearest stream gaging station, which is near Grand Canyon, Arizona, is about 306 km (190 river miles) upstream from the lake. Other sources of surface water are the Virgin River, the Muddy River, and Las Vegas Wash. A total of nearly 435,000 km^2 (168,000 square miles) drain to Lake Mead.



NOTE: Lake Mead surface elevation 1200 feet (366 meters)

(1) Zone designation for use in computing areas and volumes

ALSO SHOWN LOCATIONS.

Figure 3-5 Las Vegas Bay Zones

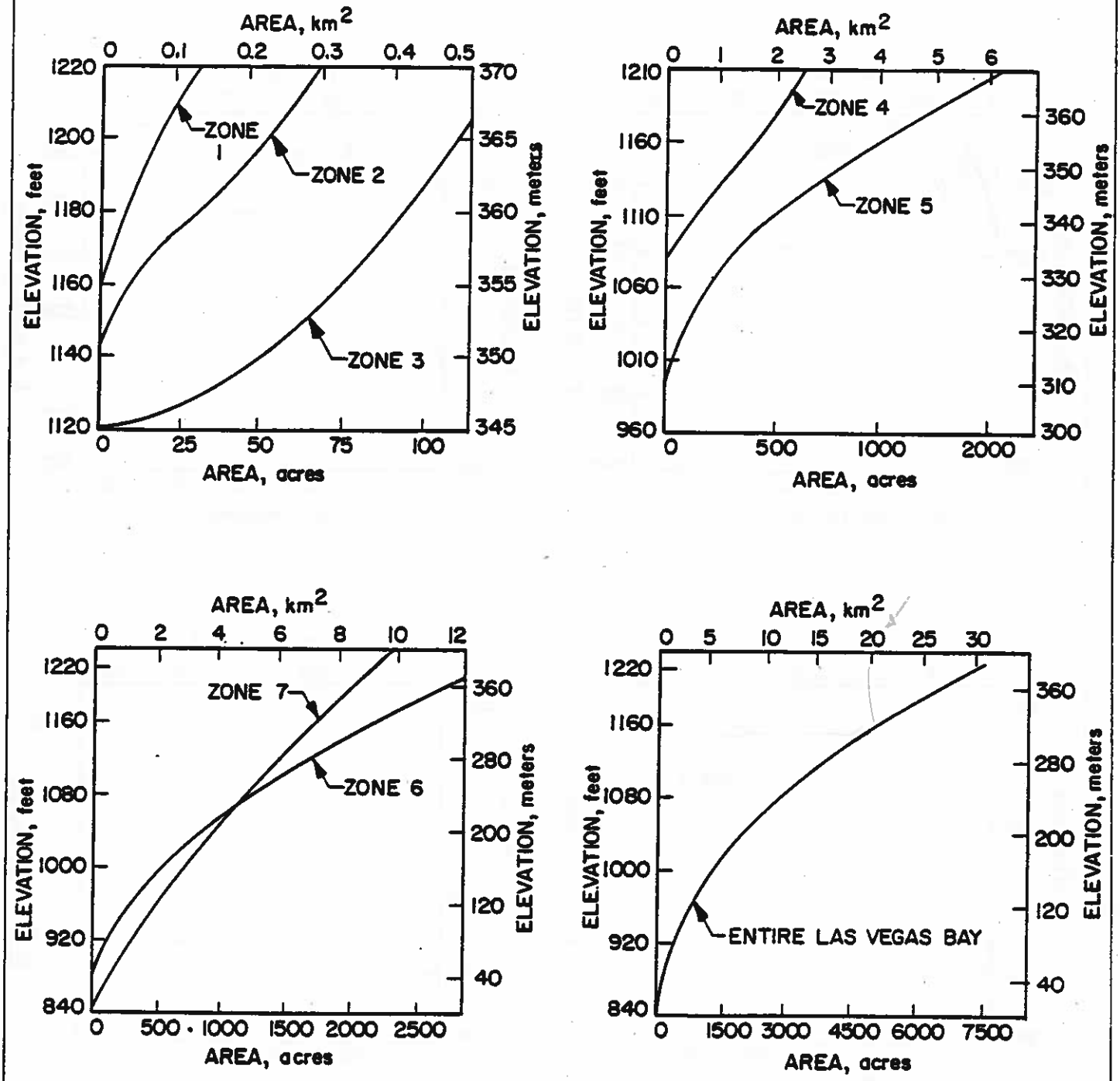


Figure 3-6 Area Versus Elevation for Las Vegas Bay, Zones 1-7

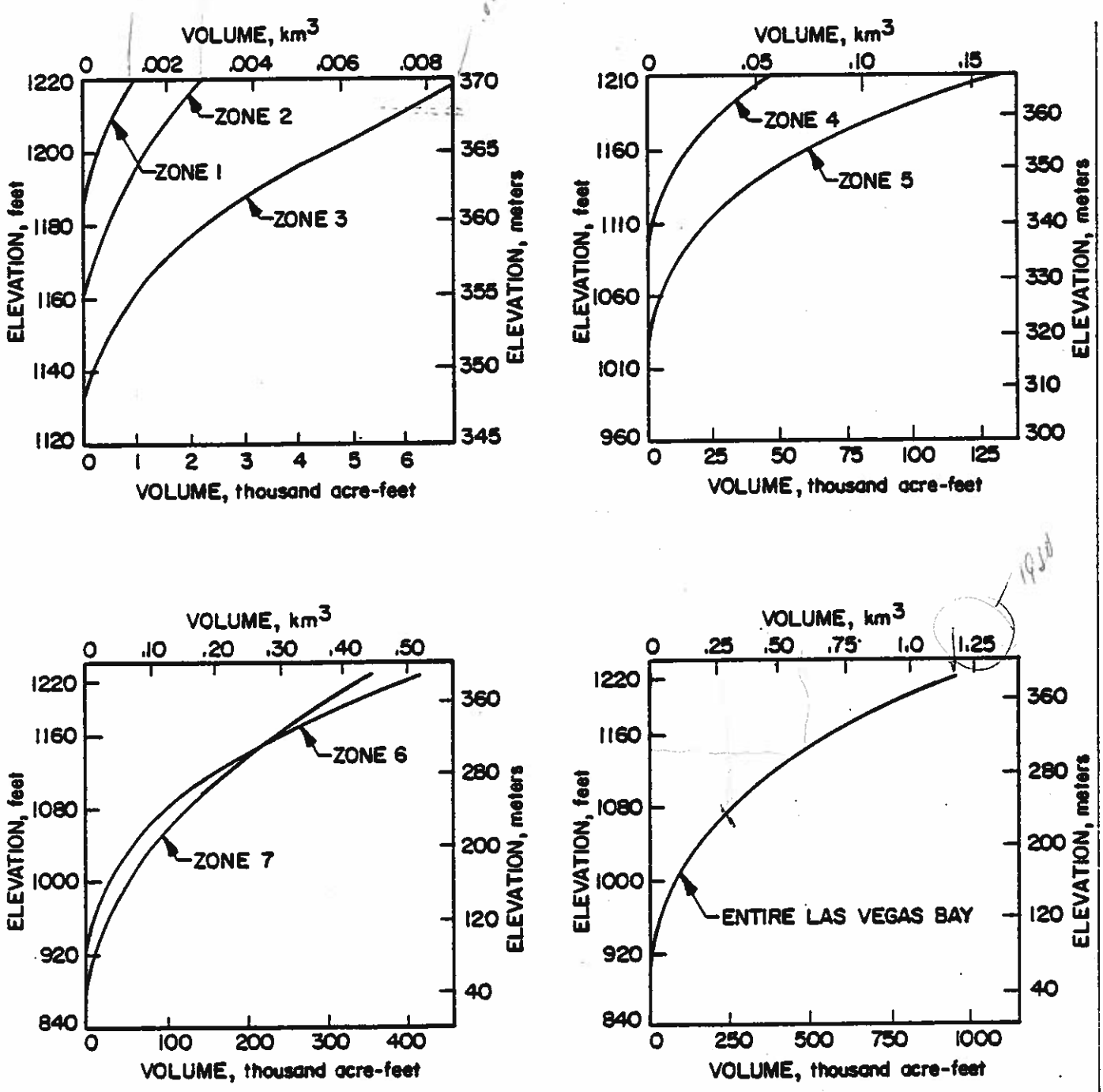


Figure 3-7 Volume Versus Elevation for Las Vegas Bay, Zones 1-7

Hoover Dam discharge is the primary means by which water is removed from Lake Mead. Withdrawals for water supply are made through the Southern Nevada Water System and the Basic Management Incorporated intake structures. Significant losses from Lake Mead result from evaporation. The sources and sinks of water for Lake Mead are summarized in Table 3-1. Because of differences in the period of record used to obtain average annual flows and the recent filling of Lake Powell, the sources and sinks tabulated in Table 3-1 do not balance.

Table 3-1. Sources and Losses of Water for Lake Mead

Component	Flow, acre-feet/year
Sources	
Colorado River near Grand Canyon	9,200,000[a]
Virgin River	160,000[b]
Muddy River	7,600[c]
Las Vegas Wash	68,000[d]
Losses	
Hoover discharge	9,500,000[e]
Municipal and industrial withdrawls	11,000[f]
Evaporation	875,000[g]

[a]1965 to 1978, unadjusted for storage in Lake Powell.
[b]1929 to 1979.
[c]October 1978 to September 1979.
[d]October 1979 to September 1980.
[e]1935 to 1979.
[f]1980.
[g]Reference 3.

Historic and Projected Lake Level

Because hydroelectric power generation at Hoover Dam is varied to meet peak electric power demands, flow through the dam varies significantly over the year. As a result, lake level varies. Average monthly lake level and the range of elevations over the course of the monitoring program are plotted on Figure 3-8. The U.S. Bureau of Reclamation has projected future lake levels through the year 2040 for alternative hydrologic projections of river flow. Historic lake levels at the end of water years 1960 through 1980, and the average and range of projected future lake levels, are plotted on Figure 3-9. Between 1960 and 1980, lake level fell and then rose by over 30 meters (100 feet). From 1964 to the present, lake level has risen nearly every year. In 1980, lake level reached its highest level since 1962.

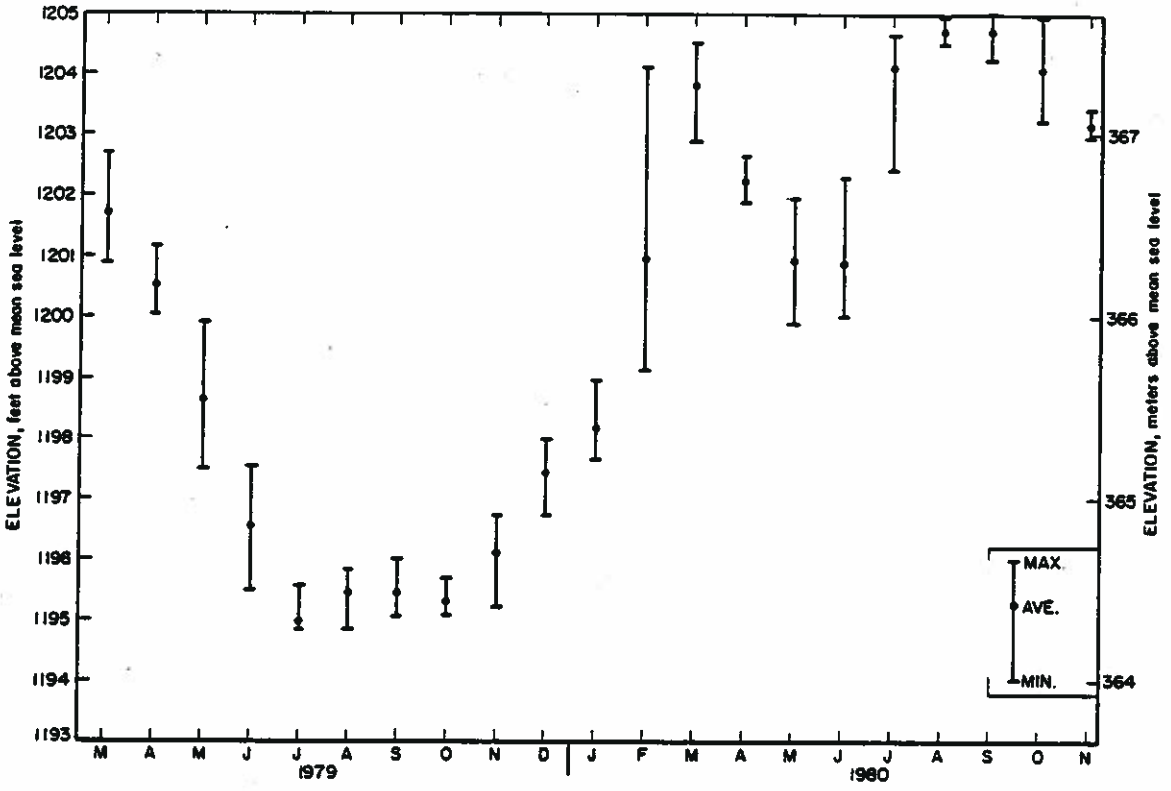


Figure 3-8 Lake Mead Surface Elevation

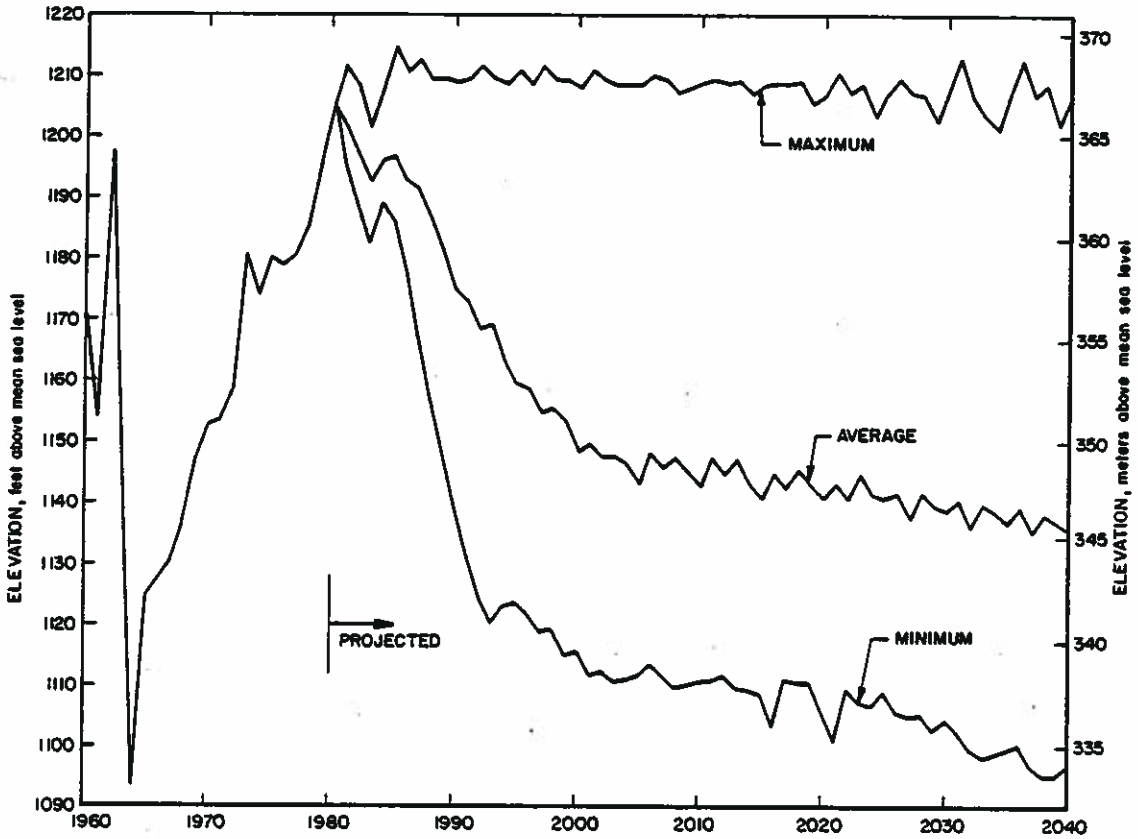


Figure 3-9 Historic and Projected Surface Elevation of Lake Mead

CHAPTER 4

BENEFICIAL USES

As described in Chapter 2, two of the key objectives of the combined effort of the Water Quality Standards Study (WQSS) and Phase II Treatment Facilities Study (TFS-II) are to specify beneficial uses for Las Vegas Wash and Lake Mead and to identify appropriate water quality criteria necessary to support those uses. The process of developing recommendations related to beneficial uses and water quality criteria involves a series of interrelated steps. Some of the steps are covered in this chapter and the remaining steps are covered in subsequent chapters.

INTRODUCTION

This section presents the background of the beneficial use work. The specific objectives of this chapter are identified, along with related work on beneficial uses and water quality criteria provided in subsequent chapters. The organization of this chapter is also described.

Background

In the initial WQSS contract (Contract 2), the scope of work for Task 6, Beneficial Uses and Water Quality Criteria, identified four possible methods for determining appropriate water quality criteria:

uses and water quality criteria; however, the proposed work was not approved. During July 1981, the PMC developed alternative approaches for continuing work on beneficial uses and criteria. On July 28, 1981, the WQSB adopted a different approach for continuing WQSS, but a contract was never approved by the WQSB. Thus, the work on beneficial uses and water quality criteria is based on the two existing WQSS contracts, Contracts 2 and 6.

Objectives

This chapter has two specific objectives which represent the initial steps in the beneficial use and water quality criteria process:

1. Describe existing and potential beneficial uses of Las Vegas Wash and Lake Mead.

2. Identify the water quality parameters or factors that affect each use.

Chapters 6 through 12 present data for the key water quality areas addressed in WQSS. In those chapters, the remaining steps in the beneficial use and water quality criteria process are performed:

1. The numerical water quality criteria, or range of criteria necessary to support the uses, are identified based on available agency criteria documents and scientific sources.

Aesthetics and Recreation

The riparian and marsh communities of Las Vegas Wash provide a unique educational and recreational opportunity in the desert environment of Las Vegas.

Historic and Projected Use. Current aesthetic and recreational uses of Las Vegas Wash are birdwatching, hiking, and hunting. Body contact recreation (swimming) and boating are not current uses of the wash. The potential use of the wash as a nature park for recreation and educational purposes was evaluated in the Las Vegas Wash Environmental Assessment for Clark County Wetlands Park.[1] A number of nonbody contact recreational and educational activities were identified. Body contact recreation was not considered in the Environmental Assessment due to the discharge of treated wastewaters to Las Vegas Wash.

Alternative 2 for both the upper and lower wash identified in the Environmental Assessment has been adopted by the Clark County Board of Commissioners as the recommended plan. According to the Clark County Department of Comprehensive Planning, the master plan for the park is scheduled for approval by the Clark County Board of Commissioners in March 1982.[2] If the Wetlands Park is developed, the recreational opportunities of the wash will be greatly increased. Alternative 2 provides for development of a wetlands interpretive center; increased marsh acreage; construction of ponds for waterfowl use; and construction of observation blinds, boardwalks, and trails in the upper wash. In the lower wash, the erosion or headcut would be controlled by construction of a dam across the wash. An interpretive center, desert museum, trails,

Table 4-1. Recreation Use Compatibility for Las Vegas Wash.

Use	Area		Qualifications
	Upper wash	Lower wash	
Wildlife observation	C	C	
Environmental interpretation	C	C	
Nature study	C	C	
Equestrian trails	C	C	
Hiking trails	C	C	
Bicycle trails	M	I	
Hunting	M	M	Requires intensive management
Equestrian gymkhana	C*	I	*At Horseman's Park
Picnicking	M	C	Requires cover and utilities
Camping	I	M*	*Heat and insects limit use
Desert museum	C	C	
Off-road vehicle trails	I	I	
Rock climbing	I	I	
Rock hunting	I	I	
Touring	I	M*	*Requires careful routing
Boardwalks/blinds	C	M*	*Depends on wetland rehabilitation

Note: C = Environmentally compatible
M = Compatible only with close management
I = Environmentally incompatible

Source: Las Vegas Wash Environmental Assessment for Clark County Wetlands Park.

inhabited the wash in the past may be related to the fact that the term "Las Vegas Wash" may have included part of inner Las Vegas Bay. Dr. Larry Paulson[5] of the University of Nevada at Las Vegas (UNLV) was not aware of any species of fish in Las Vegas Wash other than mosquito fish either at present or in the past. Mr. Robert Allen[6] of the Nevada Department of Wildlife (NDW) said green sunfish carcasses were found when a section of marsh had dried out due to headcutting. He said there had been goldfish in the wash; however, the goldfish had died off three years ago due to toxic discharges. He also mentioned the presence of mosquito fish. One goldfish was observed near Pabco Road by Brown and Caldwell (BC) and UNLV staff during the intensive survey in November 1980.

At present, mosquito fish (Gambusia affinis) appear to be the only fish populating Las Vegas Wash to a significant degree. They are able to survive in water containing low dissolved oxygen concentrations because they gulp oxygen from the air at the air-water interface. Mosquito fish were also observed in extremely high conductivity (>10,000 umhos/cm) water. They appear to be well adapted to the conditions found in Las Vegas Wash.

Future use of the wash as a fishery is uncertain. There are several alternative wash management plans being considered that will directly impact fish in Las Vegas Wash. If the headcut is not controlled, it may destroy ponded areas near Pabco Road that support the existing mosquito fish population. If the headcut is controlled by a dam across the wash, additional fish habitat would be provided in the pond that would form behind the dam. An evaluation of potential physical changes to Las Vegas Wash is included in the proposed scope of remaining work on TFS-II.

Las Vegas Wash. Many of these species are migratory so the heaviest use of the wash occurs during the spring and fall migrating seasons. A few species of amphibians and mammals inhabit the marsh community.

The desert riparian community occurs adjacent to watercourses in the wash. Salt cedar and mesquite are the dominant plant species. Dense stands of salt cedar occur near the treatment plants and in the area of the headcut. Many of the permanent winter resident bird species inhabit the desert riparian community. Snakes, toads, and mice are also found in the riparian community.

The saltbush community occurs on saline soils at the confluence of Duck Creek and Las Vegas Wash. This community is composed of species of Atriplex with an understory of salt grass. A number of seed-eating mammals and seed and insect-eating birds inhabit this community.

The desert area surrounding Las Vegas Wash is dominated by the creosote bush community. A few species of seed and insect-eating birds, a few mammals, and a wide variety of reptiles inhabit this community.

BENEFICIAL USES OF LAKE MEAD

Current beneficial uses of Lake Mead are recreation, boating, water supply, fish, wildlife, and irrigation. Another current use is hydropower, but it is not discussed since it does not closely relate to the water quality issues assessed in WQSS. Major facilities in the study area are shown on Figure 4-1.

Recreation

Recreational use consists of body-contact recreation which includes swimming, bathing, and water contact sports; and noncontact recreation including boating, fishing, and aesthetic enjoyment. All forms of water-oriented recreation are enjoyed in Lake Mead. All of these uses are discussed in this section. The fishery is presented separately in a following section.

Lake Mead is part of the Lake Mead Recreation Area which includes both Lake Mead and Lake Mohave. The Lake Mead Recreation Area was established in 1964. The National Park Service (NPS) has jurisdiction over recreational uses of the area.

Historic and Projected Use. NPS collects use data for the recreational area through a system of vehicle counters located on various access roads. Total numbers of visitors to Lake Mead for the period 1973 through 1980 are presented on Figure 4-2. During that period, total visitors ranged from 3 to 4.6 million. No clear trend can be discerned from the historic data, although the area has not reached its maximum carrying capacity.[8]

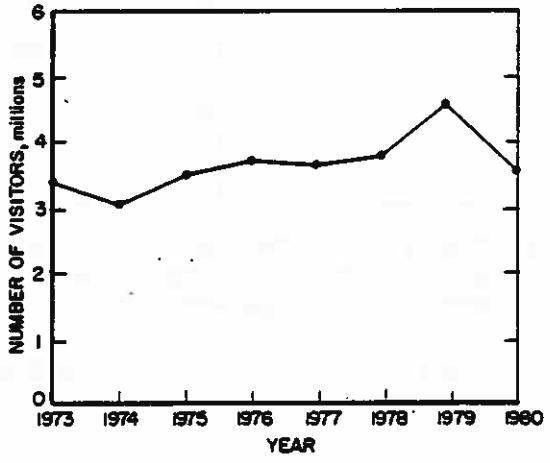


Figure 4-2 Total Visitors to Lake Mead

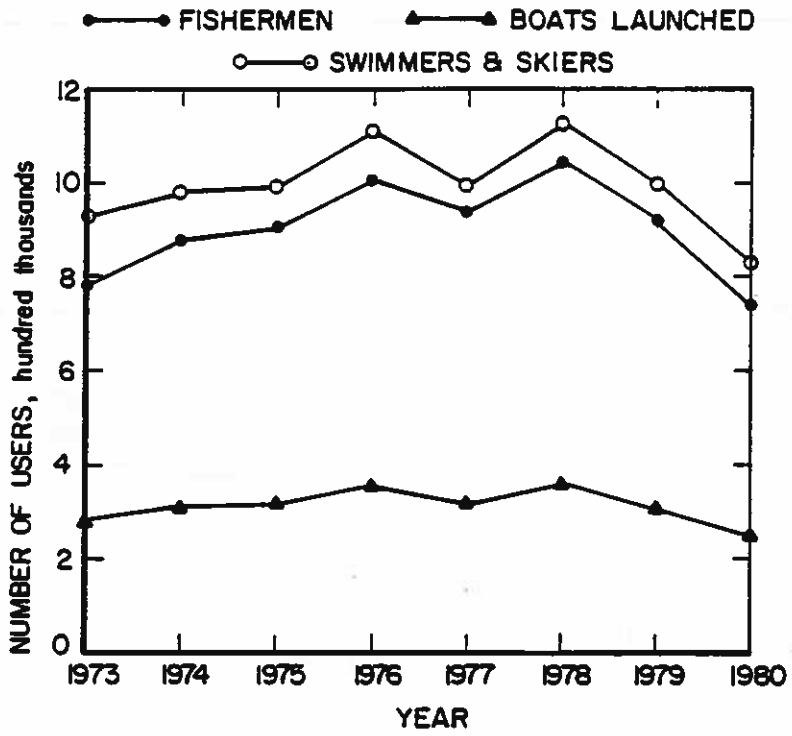


Figure 4-3 Historic Use Estimates for the Lake Mead Recreational Area

Seasonal and Spatial Use. Estimated monthly use for 1978 through 1980 is shown on Figure 4-4. Minimum use typically occurs in December and January. Maximum use occurs in June and July. Determination of the percentage of use occurring during various seasons emphasizes the importance of the summer recreational season (May through September) during which time approximately 93 percent of all swimming and water skiing, 65 percent of all boat launching, and 53 percent of all fishing occurs.

NPS data for the Las Vegas Wash Marina access road, which provides access to the marina and campground, and for the Boulder Beach access road are shown on Figure 4-5. As seen on

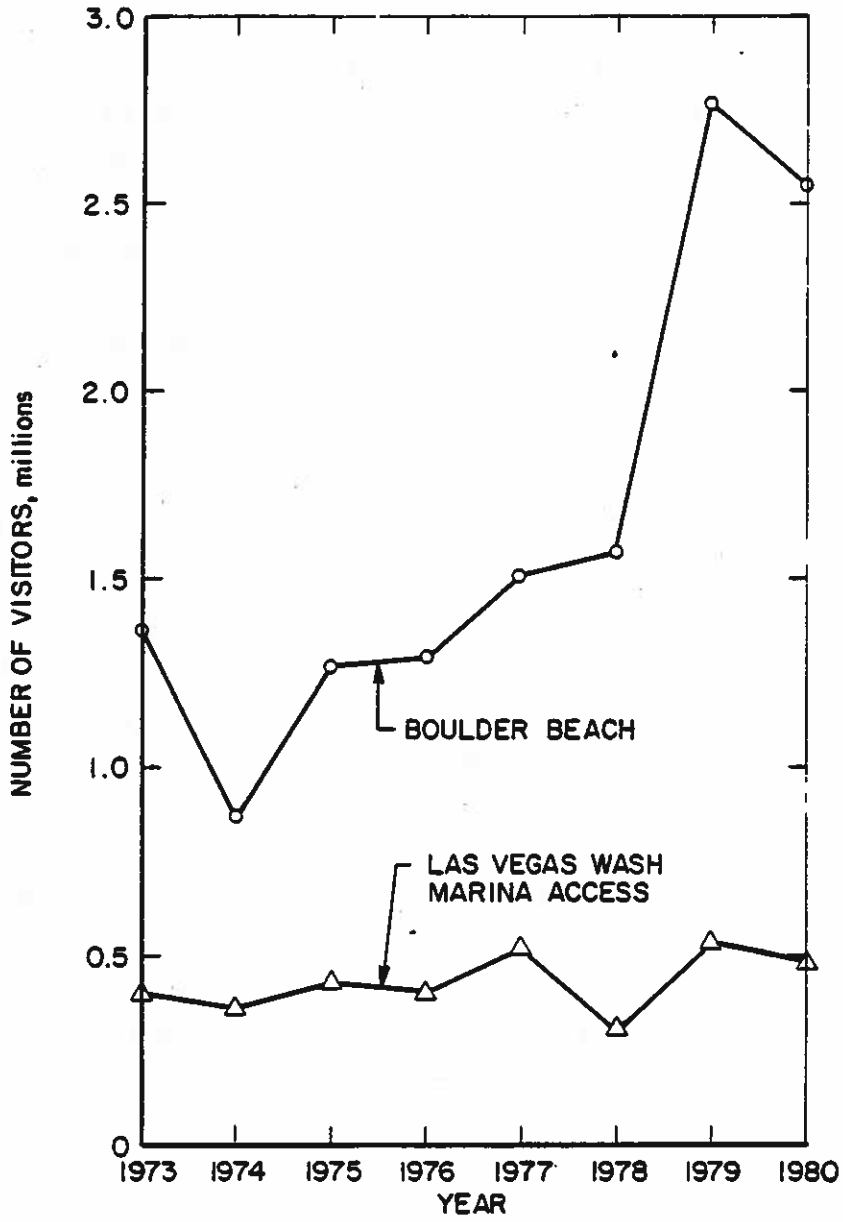


Figure 4-5 Historic Visitor Data for Boulder Beach and Las Vegas Wash Marina Access

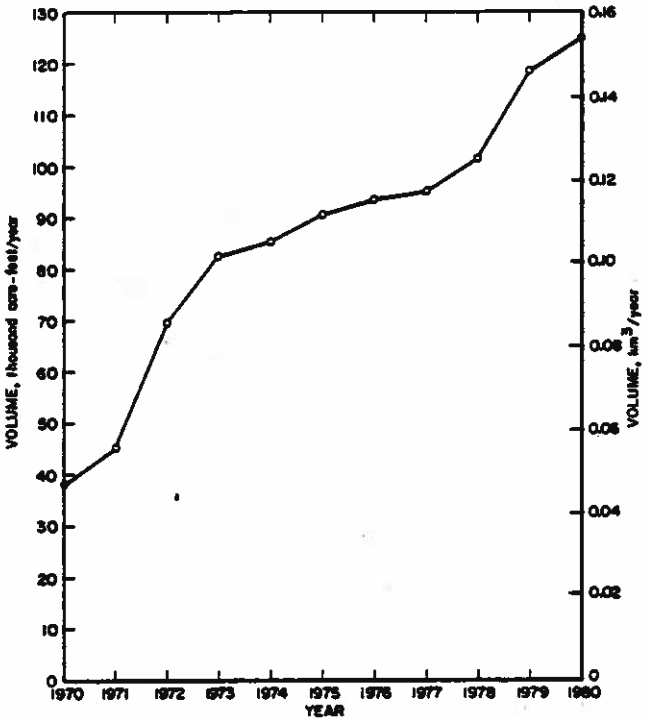


Figure 4-6 Water Supply Diversions From Lake Mead, 1970 Through 1980

Current Use Characteristics. About 0.15 km^3 (125,000 acre-feet) of water was withdrawn from Lake Mead in 1980. Figure 4-7 depicts the seasonal variation of withdrawals. Peak diversions usually occur in June or August, and in recent years have been about 140 percent of the average monthly rate. Minimum diversions occur in January, February, or March and are about 40 percent of the average monthly rate.

About 82 percent of the water supply withdrawals from Lake Mead are made through the Southern Nevada Water System (SNWS), which serves the Las Vegas Valley Water District, the City of North Las Vegas, Boulder City, Henderson, and Nellis Air Force Base. About 16 percent of the water

supply withdrawals are made through facilities belonging to Basic Management Incorporated (BMI), and are used by the City of Henderson, the State Fish and Game and Park Services, and the BMI Complex. Thus, the SNWS and BMI facilities together withdraw about 98 percent of the total water supply diversions from Lake Mead. The location of these facilities is indicated on Figure 4-1.

Fish

Fish habitat is a designated beneficial use of Lake Mead. The lake supports a substantial fishery consisting of striped and largemouth bass, threadfin shad, catfish, and carp.

Historic and Projected Use. There was a limited amount of fishing for channel catfish and Colorado squawfish in the area now occupied by Lake Mead before construction of Hoover Dam and subsequent filling of the lake. Two native species, the bonytail chub and the humpback sucker were also present in the system before construction of Hoover Dam.

Filling of Lake Mead began in 1935 when construction of Hoover Dam was nearly complete. The lake was full by 1941. Largemouth bass, black crappie, bluegill, and green sunfish were stocked by the U.S. Fish and Wildlife Service. Shortly after filling and stocking of Lake Mead, the system became nationally famous as a warmwater fishery.[9]

The increasing surface area of Lake Mead and inundation of trees and shrubbery along the expanding banks during filling stimulated production of game fish. However, in 1941, largemouth bass were in poor condition due to an insufficient

stocking continued yearly until it was discontinued in 1981.[13] Angler returns of the stocked trout were high from 1970 to 1975, but the quality of the trout fishery began to decline in 1976. Some possible reasons for the decline of the trout fishery are reduced stocking into Lake Mead, heavy removal by anglers, predation by striped bass and other fish, and upstream migrations into the Colorado River.

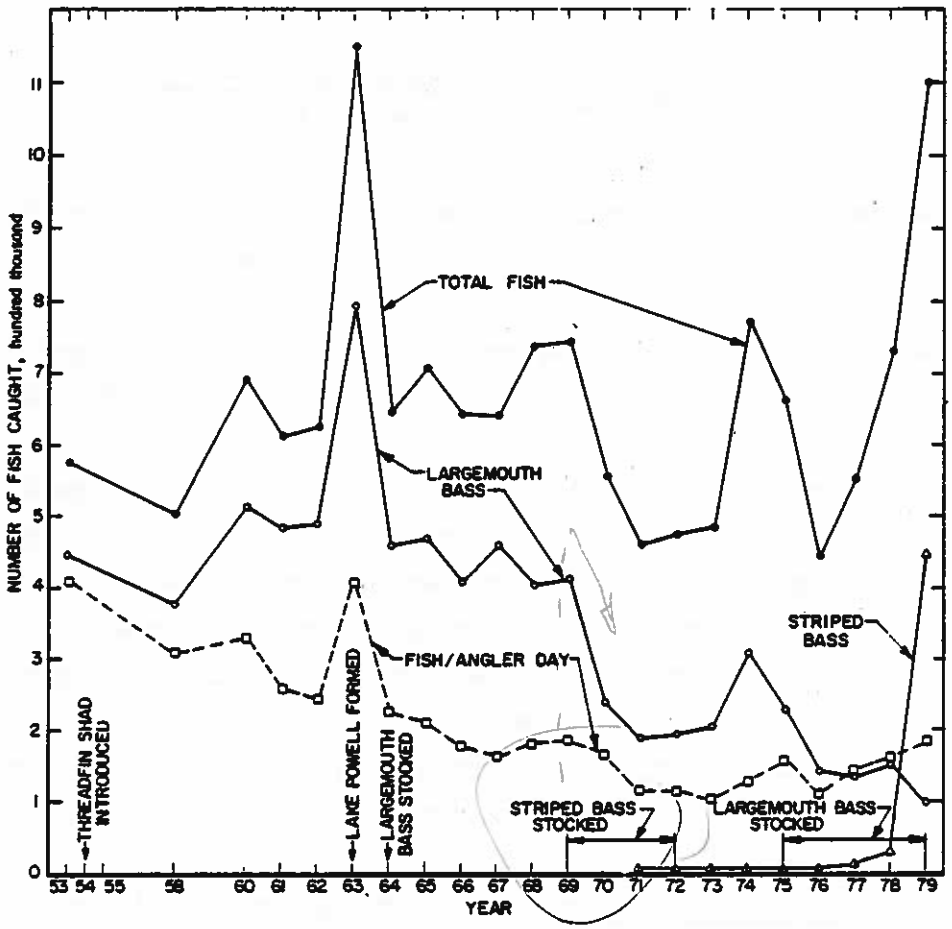


Figure 4-8 Historic Catch Record for Lake Mead Fishery

Stocking of striped bass took place from 1969 to 1972. Natural reproduction of the planted striped bass was documented

that time at $68 million. The fishermen were asked questions about their normal fishing location and their usual launch areas. The Callville Bay Marina was the most popular launch area (25 percent of boat fishermen) and the Las Vegas Wash Marina was the second most popular launch area (18 percent of boat fishermen). As shown in Table 4-3, Las Vegas Bay was the most popular specific fishing location. Over 14 percent of the fishermen sampled named Las Vegas Bay as their usual fishing location. Boulder Basin was named by five percent of the fishermen sampled.

Wildlife

Wildlife is a designated beneficial use of Lake Mead. The lake community is described in detail by Bradley and Deacon.[3]

Table 4-3. Usual Location of Fishing at Lake Mead

Location	Percent of Sample[a]
All over lake	30.0
Lower Basin (Las Vegas Bay)	14.1
Virgin Basin/Canyon	11.7
Iceburg Canyon	11.3
Haystack	8.2
Hualapai	7.7
Monkey Cove	6.4
Gypsum Beds	6.0
Boulder Basin	5.1
Grand Wash	5.0
South Cove	2.9
Muddy River	2.9
Strawberry	2.4
Stewart's Point	2.2
Jackass Cove	1.8
Other places[b]	36.0

[a]Based on response of 548 individuals. Multiple answers were possible.
[b]Other places were mentioned less than 1 percent of the time.

Source: Jones and Stokes.[17]

Table 4-4. Key Factors Affecting Beneficial Uses in Las Vegas Wash and Lake Mead

Beneficial use	Key factors affecting the use	
	Water quality	Other
Las Vegas Wash		
Aesthetics and recreation	Bacteriological quality, dissolved oxygen, MBAS	Access, area of wetlands, erosion, flooding, odors
Irrigation	Suspended solids, TDS	Water rights
Stock watering	Alkalinity, bacteriological quality, pH, TDS, toxics	Access
Fish	Alkalinity, dissolved oxygen, nitrate, nitrite, pH, temperature, toxics, un-ionized ammonia	Amount of fish habitat, erosion
Wildlife	Bacteriological quality, MBAS, Nitrate, nitrite, pH, temperature, toxics	Erosion, human encroachment, water flow
Lake Mead		
Recreation	Bacteriological quality, periphyton, pH, temperature, transparency	Access, availability of facilities, lake level
Water supply	Bacteriological quality, color/turbidity, dissolved oxygen, nitrate, nitrite, taste and odor, TDS, toxics	Lake level
Fish	Algal productivity, dissolved oxygen, nitrate, nitrite, pH, temperature, toxics, un-ionized ammonia	Fish habitat, lake level
Wildlife	Algal productivity, nitrate, nitrite, pH, temperature, toxics	Lake level

In these individual chapters, the numerical water quality criteria or range of criteria necessary to support the beneficial uses are identified, based on a review of available agency criteria documents and scientific sources.

Table 4-5. Water Quality Parameters Which Affect Lake Beneficial Uses

Parameter	Chapter in which data are presented
Physical	
Temperature	8
Dissolved oxygen	9
Specific conductance[a]	8
pH	10
Transparency (including color and suspended solids)	8
Taste and odor	12
Chemical	
Ammonia	10
Nitrate	8
Nitrite	8
Alkalinity	10
Toxics	12[b]
Biological	
Algal productivity (phytoplankton and chlorophyll *a*)	8
Periphyton	11
Bacteriological quality (total and fecal coliform)	12

[a]Specific conductance can be related to total dissolved solids.
[b]Only heavy metals data were collected in WQSS; toxics data from other monitoring programs are also reviewed in Chapter 12.

CHAPTER 5

STUDY METHODOLOGY AND APPROACH

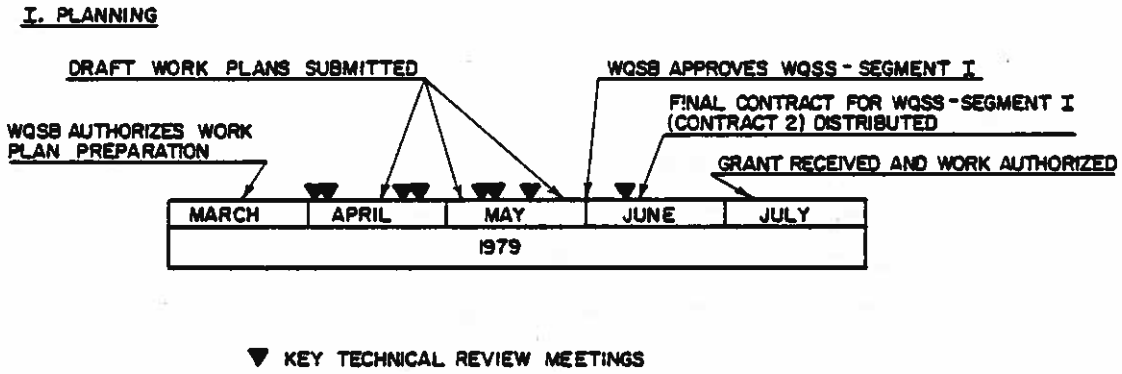
Before presenting the Water Quality Standards Study (WQSS) results, it is important to describe the methodology and approach used in the study. This chapter describes the background and planning behind the study, the monitoring program design, the data management approach, and the methodology for the data analysis.

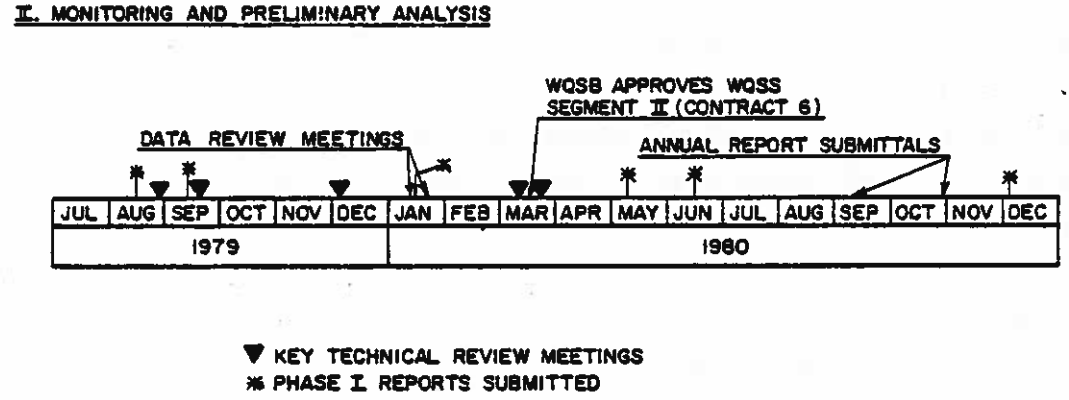
BACKGROUND

Planning for the WQSS was conducted in a very thorough manner with active participation of all Water Quality Study Board (WQSB) members and their representatives, technical advisors and primary subcontractors. Every effort was made to solicit and consider suggestions of all participants. Key program participants were involved in each step including workplan preparation, negotiation of contracts, review of technical reports, and periodic data review meetings. Many check points were designed into the study to provide all parties with the opportunity to monitor work progress and to suggest modifications to the scope of work. Key events during WQSS are identified on Figure 5-1.

Initial Planning

The initial planning for WQSS was conducted over a four-month period from mid-March 1979 to mid-July 1979. Key events during this phase included the following:





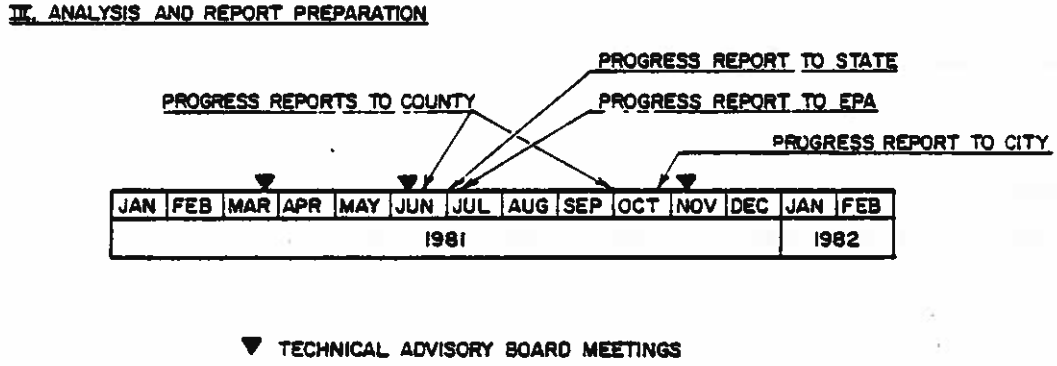


Figure 5-1 Key Events in the Water Quality Standards Study

1. At its first meeting on March 16, 1979, the WQSB authorized the Program Management Consultant (PMC) to prepare a work plan for WQSS. Since it was anticipated that it would take a few months to plan and implement the comprehensive monitoring program, the WQSB also authorized conduct of an interim monitoring program so some basic data could be collected during the Spring of 1979.

2. A series of about eight key technical meetings were held with the Technical Advisory Board (TAB) and other program participants to formulate the WQSS work plan.

3. A draft of the work plan was presented to the WQSB and discussed in detail at the May 17, 1979, meeting. Because of the number of unresolved technical issues at that time, it was agreed that a segmented approach should be followed and those tasks which could be agreed to should be separated and put into a single document for the WQSB's consideration.

4. A final draft of the WQSS work plan was presented to the WQSB and approved on May 31,1979. In order to be sure that adequate check points were provided during the course of the study, certain tasks were segmented so further authorization would be required by the WQSB before proceeding with Segment II of those tasks. All tasks except the Limnological Monitoring Program were segmented. Interim task reports were required on the segmented tasks: Bioassay Studies, Hydraulic Study, Other Lake Studies, Data Management, Beneficial Use Assessment, and Data Analysis.

5. A final contract and plan of study for Segment I of WQSS (Contract 2), incorporating certain changes made at the May 31 WQSB meeting, was prepared and submitted to the WQSB on June 12, 1979.

6. Following Environmental Protection Agency (EPA) grant processing, the PMC received authorization from Clark County, fiscal and contractual agent for the WQSB, to proceed with the WQSS on July 6, 1979.

Segment II Planning

Between August 1979 and March 1980, technical meetings were held on all segmented tasks to further define the scope of work of Segment II. These included technical meetings to finalize the bioassay program and the data analysis procedures. Two additional technical meetings were held in March 1980 to finalize the overall remaining work plan for WQSS. Contract 6, which covered the work to complete the WQSS and the Hydraulic Study, was conditionally approved by the WQSB on March 21, 1980.

Data Review Meetings

Two comprehensive data review meetings were held during the WQSS. The objective of these meetings was to review the data collected to date, so that any necessary modifications to the scope of the monitoring program could be made. The first data review meeting was held January 10 though 12, 1980, and the second meeting was held June 26 through 27, 1980. Both meetings were attended by the TAB members; PMC staff; the two

primary WQSS subcontractors: the University of Nevada at Las Vegas (UNLV) and Ecological Research Associates (ERA); and representatives of all four WQSB members. As a result of these two meetings, both additions and deletions were made to the scope of the monitoring program and suggestions were made to the PMC regarding data analysis methods.

Interim Reports

Table 5-1 lists the interim technical reports that have been prepared during the WQSS. In addition, general progress reports on the status of all program studies including WQSS have been prepared by the PMC and submitted to the WQSB on eight occasions.

Table 5-1. Interim Reports

Title	Date
Water Quality Standards Study	
Data Management Segment I Report	08/15/79
Bioassay Studies Segment I Report	09/13/79
Data Analysis Segment I Report (Logic Diagrams)	12/03/79
First Comprehensive Data Summary	01/10/80
Other Lake Studies Segment I Report	02/80
Preliminary Report on Metalimnetic Dissolved Oxygen	05/08/80
Second Comprehensive Data Summary	06/08/80
Draft Beneficial Use and Criteria Review	06/20/80
Final Annual Progress Report	10/28/80
Phase II Treatment Facilities Study	
Hydraulic Study Segment I Report	08/15/79
Hydraulic Study Segment II Report	03/26/80
Waste Treatment Potential of Las Vegas Wash	04/80
Hydraulic Study Draft Interim Report, Intensive and Dye Studies	06/18/80
Preliminary Study of Interim Headcut Control in Las Vegas Wash	08/22/80
Draft Reuse Report	03/25/81
Draft Final Report, Hydraulic Study	10/08/81

There have been three types of interim technical reports prepared:

1. For several of the WQSS tasks, reports were prepared to document the results of Segment I work and to present work plans for the remaining work needed to complete that particular task during Segment II. Segment I task reports were prepared for the following tasks: bioassay studies, other lake studies, data management, beneficial uses, and data analysis.

2. Data summaries were prepared for both the comprehensive data review meetings. In the summaries, all data collected to that date in the study was presented in graphical and tabular form.

3. Although not specifically included in the approved WQSS work plan, an Annual Progress Report was requested by the City of Las Vegas at the May 1980 WQSB meeting. Numerous technical meetings were held and a series of draft reports were prepared. The final draft report was submitted on October 28, 1980. At the November 3, 1980, WQSB meeting, it was agreed that written comments on the report should be submitted by WQSB members. The PMC submitted responses to these comments on December 23, 1980, and January 2, 1981. The report, the comments themselves, and the response provided further guidance and direction in completing WQSS.

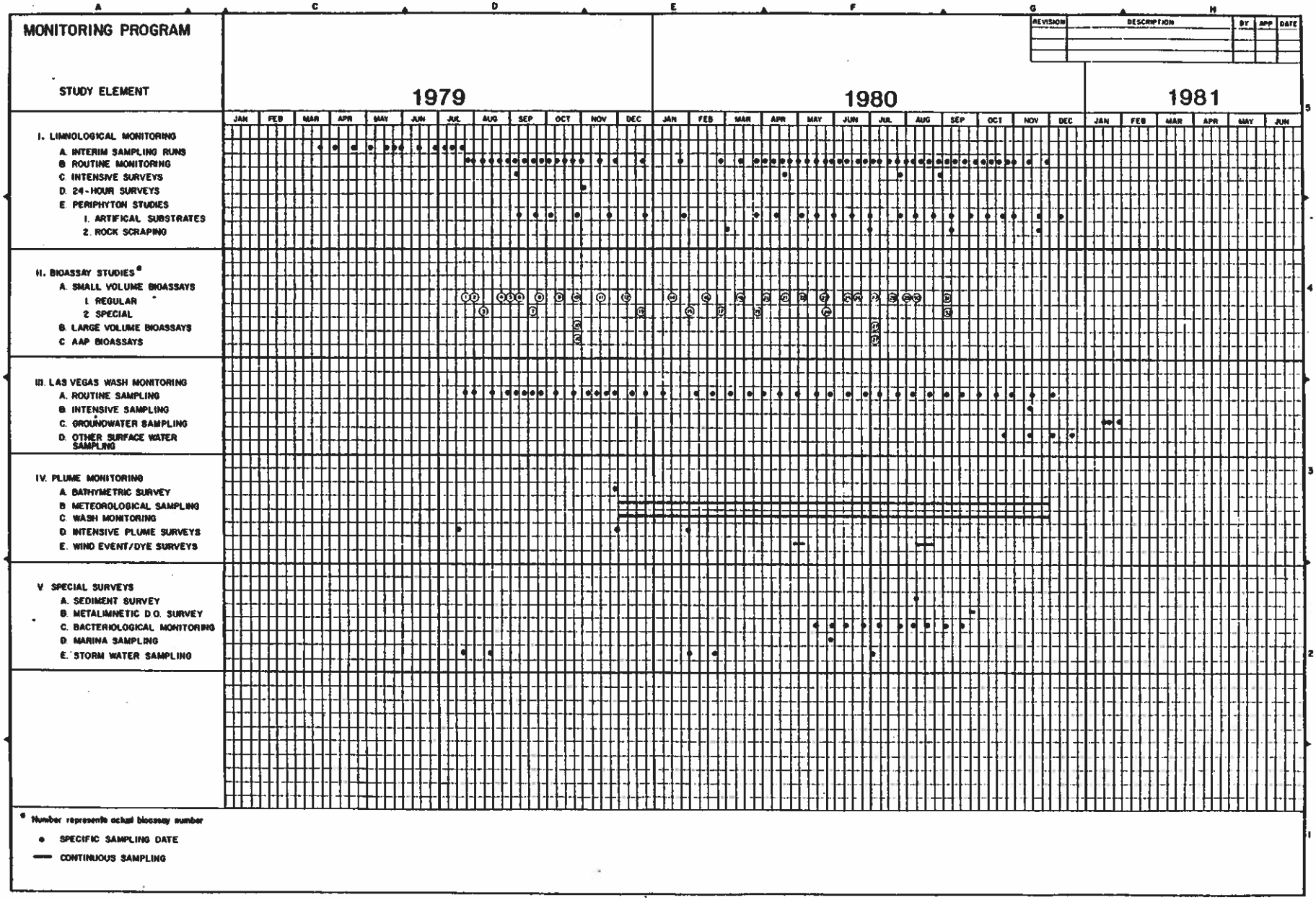


Figure 5-2 Monitoring Program Schedule

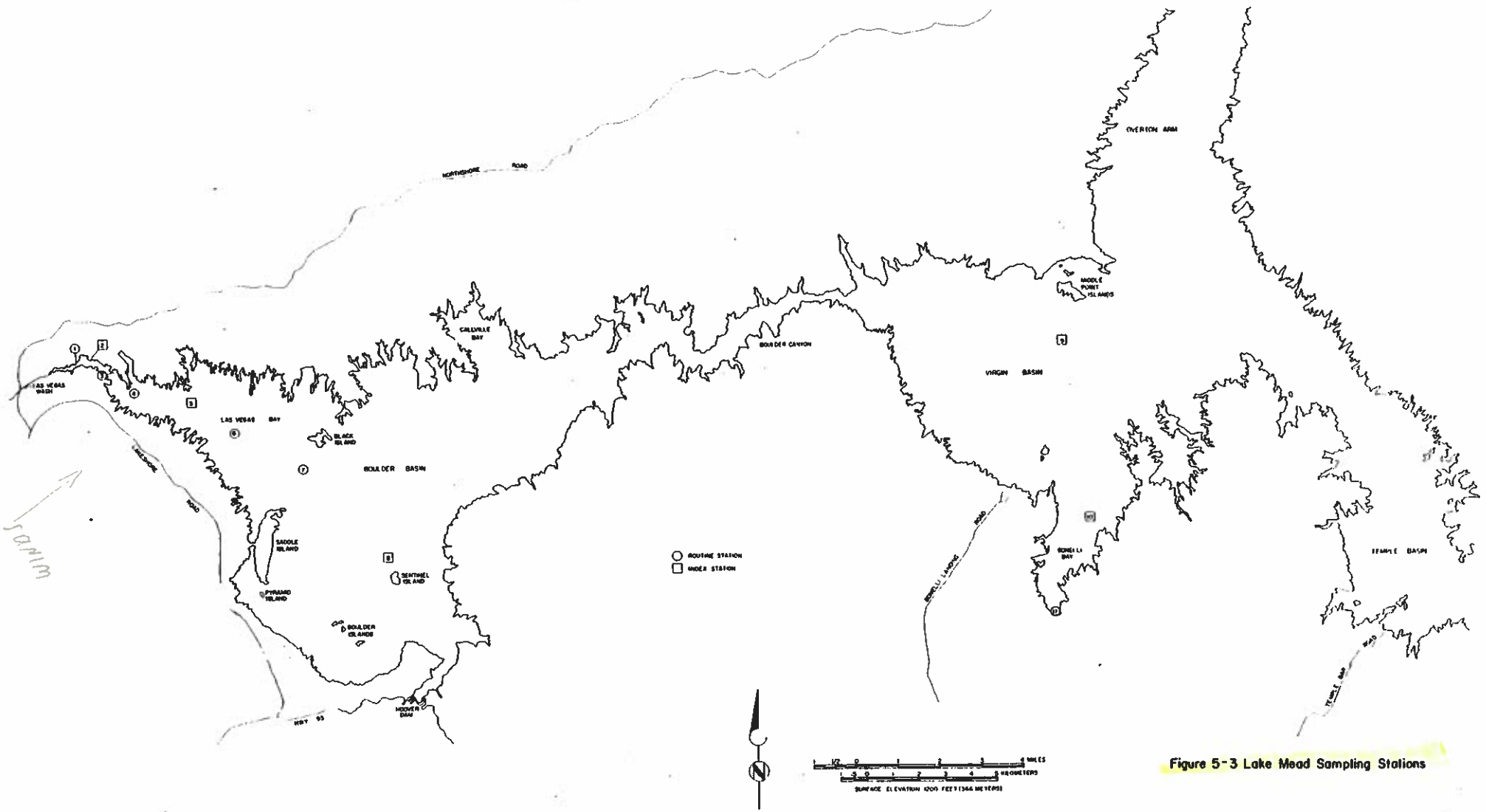


Figure 5-3 Lake Mead Sampling Stations

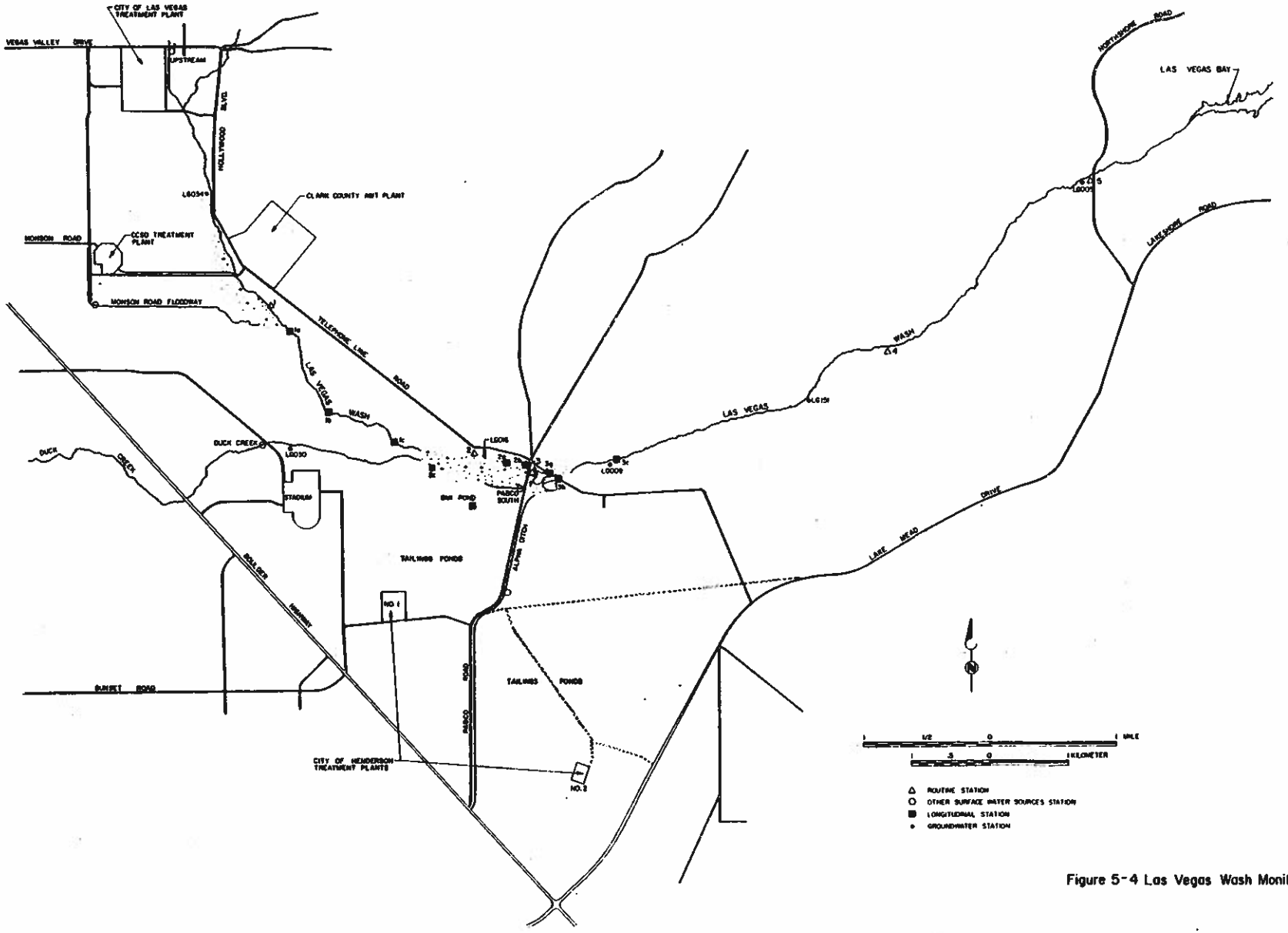


Figure 5-4 Las Vegas Wash Monitoring Stations

MONITORING PROGRAM

A comprehensive water quality monitoring program of Lake Mead and Las Vegas Wash was conducted over a 22-month period from April 1979 through January 1981. The program consisted of five major components:

1. Limnological monitoring
2. Bioassay studies
3. Las Vegas Wash monitoring
4. Plume monitoring
5. Special studies

In this section, sampling stations are initially described. This is followed by a discussion of the scope of each of the five monitoring program components. A detailed monitoring program schedule is shown on Figure 5-2.

Sampling Stations

A limnological monitoring program was conducted to determine current water quality conditions in Las Vegas Bay and Boulder Basin. In planning WQSS, it was agreed to also study a portion of Lake Mead unaffected by the wash discharge to provide an indication of background conditions. Thus, sampling was included in Bonelli Bay and Virgin Basin. Bonelli Bay is similar in shape and size to Las Vegas Bay, but does not receive any wastewater discharges.

Figure 5-3 shows the location of the 11 sampling stations in Lake Mead. Stations 1, 2, 3, and 4 were chosen to characterize inner Las Vegas Bay. Previous investigators had

found that there are considerable changes in physical, chemical, and biological parameters over short distances in the inner bay. Since these changes cannot be adequately defined by a single sampling station, four stations were sampled in the inner bay. Stations 5 and 6 were located in the middle Las Vegas Bay and Station 7 was located in outer Las Vegas Bay. Data collected at these stations were intended to be used to assess the changes in water quality from the inner to the outer bay. According to UNLV researchers, during the fall months, the effects of the Las Vegas Wash plume have been detected in Boulder Basin. Thus, Station 8 was included to characterize the water quality of Boulder Basin. Stations 9, 10, and 11 were included to provide information on background conditions in Virgin Basin and Bonelli Bay. Stations 2, 5, 8, 9, and 10 were designated as index stations. These stations were sampled for many parameters which were not measured at the other stations. This allowed a comprehensive data base to be collected in each area of the lake being studied without producing an inordinate number of samples. An extensive historical data base exists for each of the index stations.

Figure 5-4 shows the location of the five routine sampling stations in Las Vegas Wash. The station locations were selected in a way that changes in Wash water quality could be monitored from the point of discharge of the wastewater treatment plants to the point of input to Las Vegas Bay. Station locations were as follows: downstream of the confluence of the two municipal treatment plant discharges, the marsh upstream of Pabco Road, Pabco Road, the area near the headcut, and Northshore Road.

Limnological Monitoring Program

The limnological monitoring program is described in this section and is subdivided into four elements:

1. Routine sampling
2. Intensive surveys
3. 24-hour surveys
4. Periphyton studies

At the outset of WQSS, detailed discussions were held among the TAB, the PMC, and other program participants regarding the field and laboratory procedures to be utilized in the study. A description of the procedures which were adopted for use in WQSS is contained in Appendix A. A quality assurance program was conducted to ensure reliable results and is also described in Appendix A.

Routine Monitoring. The routine monitoring program was initiated in July 1979 and conducted through November 1980. Samples were generally collected weekly from April through October (recreation season), once every two weeks during November and March, and monthly from December through February. The specific schedule for the sampling runs is identified on Figure 5-2.

Samples were analyzed for a wide range of water quality parameters. As discussed in Chapter 4, many of these parameters are directly associated with the beneficial uses in Lake Mead. The other parameters (such as the physiological tests) are included to help understand the water quality mechanisms occurring in the lake. The significance of each parameter is described in the chapter in which the data for that parameter are presented. Table 5-2 summarizes the routine monitoring program parameters, which fall into four major categories: physical, chemical, biological and physiological. For each parameter, the following are indicated: frequency of measurement, sampling depths, stations at which the parameter

Table 5-2. Limnological Monitoring Program Parameters

Parameter	Frequency of measurement[a]	Sampling depths[b,c]	Sampling stations	Reference[d]
Physical				
Secchi depth	Routine	Surface	All	8
Light-submarine photometer	Routine	1m intervals	All	*
Light-transmissometer	Routine	1m intervals	All	*
Temperature	Routine	2m/5m intervals	All	8
Dissolved oxygen	Routine	2m/5m intervals	All	9
Specific conductance	Routine	2m/5m intervals	All	8
pH	Routine	2m/5m intervals	All	10
Color	Routine	Integrated	1,2,3, & 4	8
Total suspended solids	Routine	Integrated	Index, 1&3	8
Volatile suspended solids	Routine	Integrated	Index, 1&3	8
Chemical				
Total phosphorus	Routine	Routine	All	8
Dissolved phosphorus	Routine	Routine	All	8
Soluble orthophosphorus	Routine	Routine	All	8
Ammonia	Routine	Routine	All	8/10
Nitrate + Nitrite	Routine	Routine	All	8
Nitrite	Routine	Routine	Index, 1&3	8
Total nitrogen	Routine	Routine	Index, 1&3	8
Alkalinity	Biweekly/monthly	0 to 25m	Index	10
Soluble iron	Routine	Routine	Index	8
Silica	Biweekly-March to September	Routine	Index	8
Total dissolved solids	Quarterly	Integrated	2&5	*
Cations, anions, and heavy metals	Quarterly	Integrated	2&8	12
Biological				
Chlorophyll a	Routine	Integrated	All	8
Pheophytin a	Routine	Integrated	All	8
Phytoplankton	Routine	Integrated	All	8
Zooplankton	Routine	Vertical Tow	Index	8
Fish distribution	Routine	Horizontal Transect	Index	9
Physiological				
Nitrogen fixation	Biweekly/monthly	Integrated	Index	*
Alkaline phosphatase	Biweekly/monthly	Integrated	Index	8
Extractable phosphorus	Biweekly/monthly	Integrated	1	*
Primary productivity	Biweekly/monthly	0 to 25m	Index	8

[a]Routine sampling = weekly April to October, biweekly November and March, monthly December to February. Biweekly/monthly indicates biweekly sampling March to November, monthly December to February.
[b]2m/5m = measurements made at 2m intervals from surface to bottom of thermocline and 5m intervals through the hypolimnion.
[c]Routine depths = integrated epilimnetic sample, one metalimnetic sample and one or two hypolimnetic samples depending on the depth of the station. At Stations 3, 4, and 5, a sample is collected at the depth of the highest conductivity on a monthly basis.
[d]Chapter in this report where data are presented.
*Data are included in the STORET data compilation.

was sampled and the chapter or appendix in this report where the data for that parameter are reported.

Intensive Surveys. Short-term intensive, or synoptic, surveys were conducted to determine spatial variability of water quality in Las Vegas Bay. Surveys were conducted during four different seasonal periods: September 1979, April 1980, July 1980 and August 1980. Samples for several parameters were collected at over 35 locations scattered throughout the open water and nearshore areas. With the intensive survey data it was possible to confirm whether or not the regular sampling stations were representative of water quality conducted in that general vicinity.

Twenty-Four Hour Surveys. Sampling over a 24-hour period was conducted to monitor changes in water quality over the day. Measurements were made at Stations 2 and 5 in Las Vegas Bay, for temperature, dissolved oxygen, specific conductance, pH, Secchi depth, chlorophyll a, primary productivity and zooplankton. The original workplan called for four surveys. Based on a review of the results of the first survey in November 1979, it was concluded that daily variations were minor and it was not necessary to conduct the other three surveys.

Periphyton Studies. Because of the potential significance of periphyton to beneficial uses and because of the limited periphyton data base, a periphyton sampling program was conducted in WQSS. The study consisted of an artificial substrate study and a lake-wide rock scraping survey.

1. Artificial Substrates--Fiberglass substrates were set at each of the index stations and at several locations in

the nearshore area of Las Vegas Bay. At approximately two-week intervals, substrates were retrieved from each station and new ones were set. This work was conducted continuously during the recreational season and once per month the remainder of the year. Sampling dates are indicated on Figure 5-2. The substrate was scraped and periphyton biomass, chlorophyll a, and alkaline phosphatase were determined and the dominant periphyton species were identified.

2. Rock Scraping--At twelve locations along the shorelines of Lake Mead, periphyton was scraped from a standard surface area on shoreline rocks on a quarterly basis. Sampling dates are indicated on Figure 5-2. The scrapings were collected in shallow water at a depth of one to two meters out of the area of wave action. The relative amount of biomass was estimated and the dominant periphyton species were identified.

Bioassay Studies

Much of the effort in WQSS was focused on assessing nutrient limitation on phytoplankton growth. The bioassay studies represented one of several approaches utilized to assess this issue. The use of the bioassay studies in the analysis is summarized in Chapter 8 and a detailed report by the bioassay subcontractor is contained in Appendix C. The bioassays were conducted to test the response of algae sampled from Lake Mead to enrichment with various combinations of nutrients. Three different types of bioassays were conducted:

1. Small volume bioassays utilizing indigenous algae species.

2. Large volume in situ bioassays.

3. Standard algal assay procedure bioassays.

The schedule for the bioassay studies is indicated on Figure 5-2 and the types of bioassays are briefly described below.

Small Volume Bioassays. Procedures used in the small volume bioassays were initially developed by Dr. Larry Paulson in earlier work at the UNLV. Detailed procedures for this study were developed jointly by the PMC and the subcontractor, ERA, and were reviewed in detail and approved early in the study by representatives of the TAB and major study participants.

Samples were collected at Stations 2, 4, 5 and 8. Various enrichments were made at the laboratory and samples were incubated in one-liter containers in outdoor pools. A total of 31 small volume bioassays was conducted: 21 regular bioassays and 10 special bioassays. The regular bioassays consisted of separate nitrogen and phosphorus additions, additions of various combinations of nitrogen and phosphorus, and additions of water from Las Vegas Wash. The special bioassays utilized the same sampling and incubation procedure as the regular bioassays, but the enrichments were made to evaluate specific issues such as the effect of addition of treatment plant effluent or trace elements.

Large Volume Bioassays. Large volume in situ bioassays were conducted to confirm the general validity of the small volume bioassays. These bioassays were conducted in October 1979 and July 1980. The containers were fabricated from polyethylene

tubing about 1 meter in diameter with a volume of about 2 cubic meters. The containers were filled at Station 4 and then towed to the breakwater adjacent to the Las Vegas Wash Marina where they were moored on the leeward side. Nutrient additions of phosphorus, nitrogen and combinations of nitrogen and phosphorus were made and the in situ bioassays were conducted for one week.

Algal Assay Procedure Bioassays. Two standard algal assay procedure (AAP) bioassays were conducted by the EPA Corvallis Oregon laboratory in parallel with the two in situ bioassays. The AAP bioassay utilizes the standard Selenastrum capricornutum assay species and follows standard procedures developed by EPA. The AAP bioassay provides a check on the small and large volume bioassays which used indigenous species of algae. They also provided a basis for comparing Lake Mead results with results from other studies.

Las Vegas Wash Monitoring

A monitoring program of Las Vegas Wash was conducted to determine water quality conditions in Las Vegas Wash from the point of discharge of the wastewater treatment plants to Northshore Road and to estimate pollutant loads discharged to Las Vegas Bay. Five stations in Las Vegas Wash were sampled approximately every two weeks from July 1979 through December 1980. Samples were analyzed for physical parameters, nutrients, BOD, solids and bacteria.

In addition to the routine monitoring program an intensive survey was conducted over a one-week period in November 1980 to provide a more complete characterization of water quality conditions in the wash. The survey consisted of the following

elements: a longitudinal survey of 20 points along the wash, a 24-hour survey, and a time of travel study. Samples of several surface water sources tributary to Las Vegas Wash were collected between October and December 1980 and several wells were sampled during January 1981 to determine groundwater quality.

The wash monitoring program is described in detail in Chapter 6.

Plume Monitoring

Monitoring of the Las Vegas Wash plume was conducted as part of TFS-II and is described in detail in a separate report which is included in Appendix F. The monitoring program consisted of several elements:

1. A bathymetry survey to define channel geometry in inner Las Vegas Bay.

2. Continuous monitoring of meterological conditions at Las Vegas Wash Marina from November 1979 through November 1980.

3. Continuous monitoring of wash temperature and specific conductance at Northshore Road.

4. Three intensive plume monitoring surveys consisting of vertical profiles of temperature, specific conductance, salinity, dissolved oxygen, pH, and light transmittance obtained at several locations.

5. Two wind event/dye surveys in which dye tracer was continuously injected into Las Vegas Wash at Northshore Road and monitored throughout Las Vegas Bay over a two-week period.

Special Surveys

Over the course of WQSS, certain additional data needs were identified which were not covered by the scope of the initial monitoring program. These needs were met by conducting several special surveys. These surveys and the location in this report where they are discussed include the following:

1. Sediment survey to estimate the potential for nutrient release from the sediments in Las Vegas Bay (Chapter 7).

2. Dissolved oxygen survey to investigate the factors affecting dissolved oxygen depletion in the metalimnion of Las Vegas Bay (Chapter 9).

3. Bacteriological sampling of inner Las Vegas Bay (Chapter 12).

4. Marina sampling to assess nutrient conditions in the area of the marina on a high-use day (Chapter 11).

5. Stormwater sampling of runoff to Las Vegas Bay from sources other than Las Vegas Wash (Chapter 7).

DATA MANAGEMENT

A computerized data management system was utilized in WQSS for several reasons: the large amount of data (over 100,000 items), the need to provide program participants with periodic tabular and graphical data presentations and the need to perform many statistical analyses of the data. These needs were

recognized in the initial WQSS planning and a task was included in Segment I of WQSS to analyze alternative data management systems and to recommend one for use in WQSS. A report was submitted to the WQSB on August 15, 1979, recommending the use of the EPA Storage and Retrieval System (STORET). On August 20, 1979, the WQSB approved the use of STORET as the data management system for WQSS.

As much of the regular monitoring data as possible was entered into STORET. Only a relatively small amount of the regular limnological and wash data has not been entered due to limitations of STORET parameter codes. All regular limnological monitoring data have been entered with the exception of phytoplankton species counts, zooplankton, fish distribution data and a few parameters which were not routinely sampled. All routine water quality data for Las Vegas Wash have been entered. Bioassay data, plume monitoring data and data from special surveys have not been entered into STORET.

The data management process included the following key steps:

1. Laboratory data sheets were checked for data accuracy and consistency by a designated individual at each laboratory and sent to the Brown and Caldwell (BC) Office in Sacramento.

2. In Sacramento, laboratory data sheets were checked and most data were transferred to BC summary sheets. The data were encoded for keypunching on 80-column keypunch forms. Physical data were encoded from the field data

sheets and other data were encoded from summary forms. Specific procedures for handling rerun samples, quality assurance data and rounding are described in Appendix E. Keypunching was performed by J&S Keypunch Service which also verified the coded data.

3. Approximately twice per month, all new data cards were transferred to a computerized data set. The data set passed through an editing step in which extreme values, invalid parameter codes, and other potential errors were flagged. After this checking step, data were input to the STORET data management system.

4. On six occasions during WQSS, graphical and tabular data output were obtained for distribution to key program participants.

5. Errors detected by program participants during their review of data packages and brought to the attention of the PMC have been corrected.

6. Following completion of data collection, two internal point-by-point checks of the computer output against the laboratory data sheets were made for all routine parameters. Corrected data tabulations were then distributed to the TAB and other program participants.

7. Final data tabulations have been prepared. Appendix E contains instructions for assessing the final data set in STORET.

Much of the statistical analysis of data in STORET has been performed using supporting computer programs. The primary

computer package used was Statistical Analysis System (SAS). This program is widely used and accepted by the scientific community. Computer analyses that have been performed and presented in subsequent chapters in this report include single and multiple parameter correlations, analysis of variance, frequency distributions and various plotting routines.

DATA ANALYSIS METHODOLOGY

The Consent Decree provides the basic framework upon which WQSS and TFS-II are to be performed. As discussed in Chapter 2, paragraph 18 identifies the six key steps to be performed. Paragraph 20 describes the procedures for determining effluent limits related to algae. A summary of these two paragraphs is provided in Table 5-3. The WQSS scope of work contained in Contract 2 and Contract 6 presented the specific work tasks needed to meet the Consent Decree provisions. As described in the background section of this chapter, a significant number of technical progress meetings were held which further shaped the analysis approach.

Analysis Steps

As a result of the Segment I work on data analysis, the PMC prepared two logic diagrams to help guide the analysis. The diagrams were presented to the WQSB on December 7, 1979. Figure 5-5 is a decision diagram which shows the application of the data analysis to legal-regulatory requirements of the water quality standards--effluent limitation process. Figure 5-6 is a workflow diagram which indicates task interactions. Both diagrams cover the complete standards-setting process and, thus, depict work to be performed under TFS-II as well as WQSS work. Since much of TFS-II has not been completed, TFS-II work tasks which have not been conducted are shaded in the two diagrams.

Table 5-3. Summary of Key Consent Decree Provisions

Paragraph 18 (paraphrased)

The Water Quality Standards Study shall include the following:

a. Specify beneficial uses.

b. Investigate the attainability of the beneficial uses.

c. Identify water quality criteria to meet the beneficial uses.

d. Identify the physical, chemical, and biological factors affecting the water quality criteria.

e. Develop maximum pound loads necessary to meet the water quality criteria.

f. Allocate the maximum pound loads among point and nonpoint sources to determine if effluent limits different than 30/30/1 are needed.

Paragraph 20 (paraphrased)

To the extent that load limits are related to algae, the Water Quality Standards Study shall develop an empirical data base and a statement of reasons which establish:

a. A demonstrated relationship between the chemical elements and physical conditions selected for control and the necessary quantity or type of algae;

b. A demonstrated relationship between the concentration of the chemical element selected and the necessary limit on algae and a demonstrated relationship between the numerical value of the physical condition selected and the necessary limit on algae;

c. A demonstrated relationship between the concentration of the chemical element selected as an ambient concentration (i.e., in the receiving water) and the maximum daily load; and a demonstrated relationship between the ambient numerical value for the physical condition and the numerical physical condition effluent limitation selected;

d. An analysis of the "most cost-effective" waste load allocation available for each service area which contributes to maximum daily load, as well as for the entire service area.

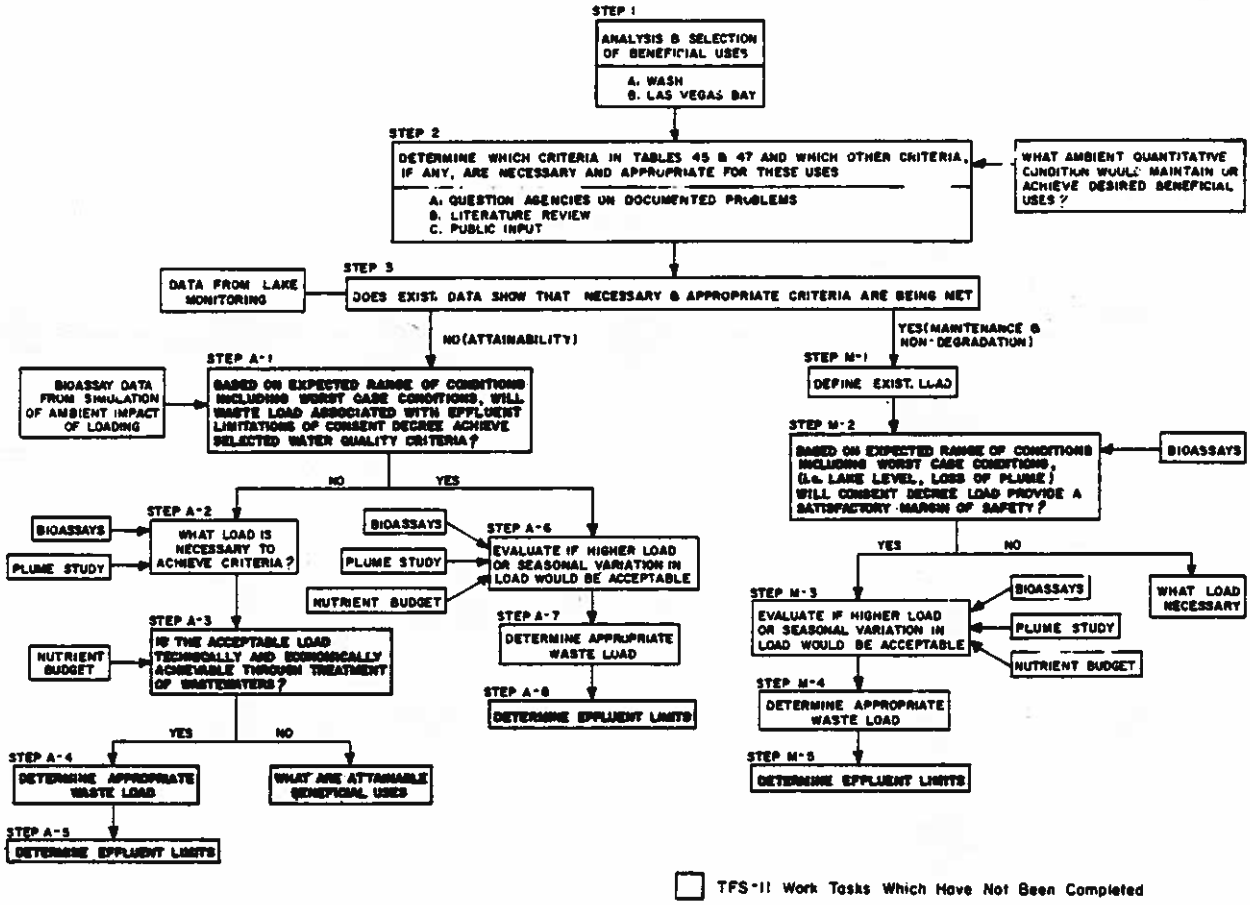


Figure 5-5 Decision Diagram for Las Vegas Valley Water Quality Program

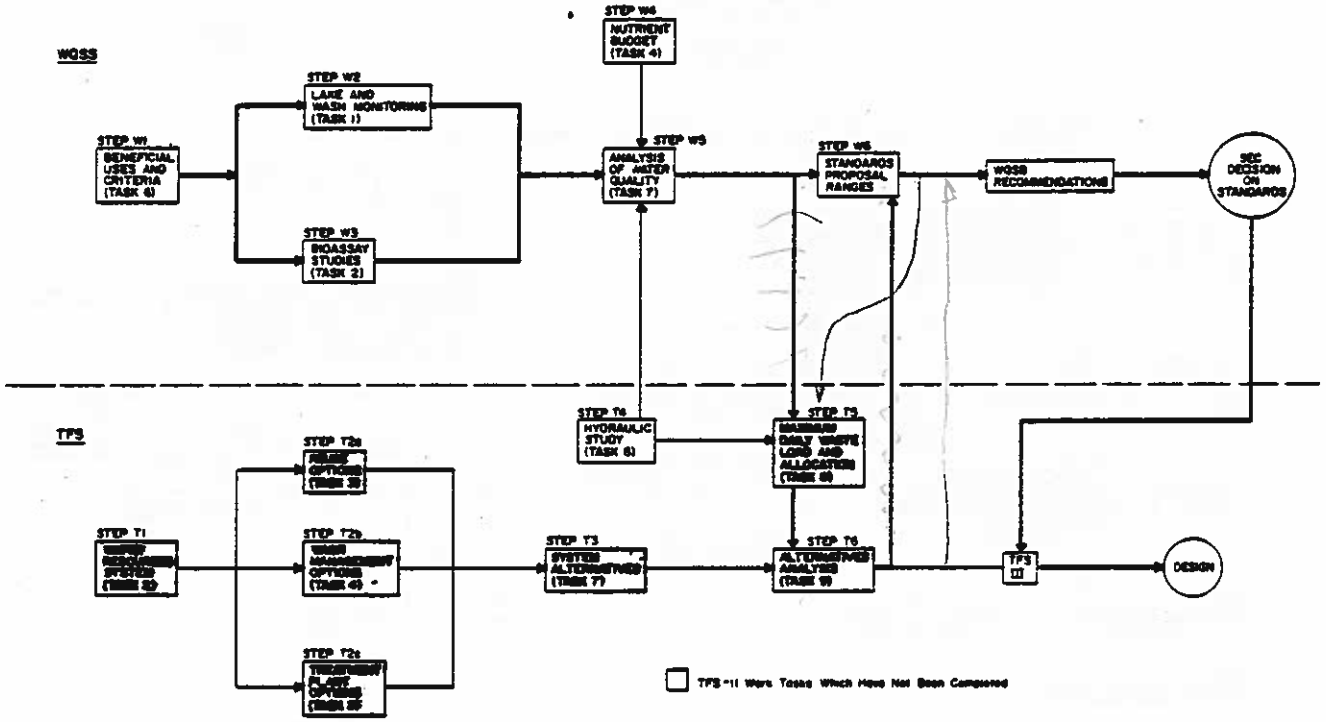


Figure 5-6 Work Flow Diagram for Las Vegas Valley Water Quality Program

Analysis Principles

As a result of workplan provisions and technical guidance of the TAB and other program participants, there are several key analysis principles that have been followed:

1. The development of ambient water quality and load relationships has been based on simple empirical methods and has specifically excluded rational mathematical modeling. Thus, the focus has been on correlations and simple statistics.

2. The bioassay program has been used to provide qualitative information on nutrient limitations. Proposed approaches to the conduct of quantitative bioassays were not approved by the WQSB.

3. Work on determining water quality criteria has been based on a review of scientific and regulatory criteria documents, input from water quality experts and a review of WQSS data. Proposed approaches to obtain public input through user surveys were not approved by the WQSB.

CHAPTER 6

LAS VEGAS WASH

An 18-month monitoring program was conducted to determine water quality characteristics of Las Vegas Wash. Physical characteristics of the wash are described in Chapter 3. This chapter contains a discussion of the monitoring program, loads to Las Vegas Wash, water quality transformations in the wash, and pollutant loads discharged to Las Vegas Bay from Las Vegas Wash at Northshore Road. The beneficial uses of the wash are discussed and criteria necessary to support the uses are compared to existing conditions in the wash.

INTRODUCTION

The background, objectives of the wash analysis, and chapter organization are presented in this section.

Background

Las Vegas Wash is a wetlands ecosystem that currently receives secondary treated wastewaters from the City of Las Vegas and Clark County Sanitation District treatment plants. The two secondary treatment plants currently discharge about 60 mgd of treated wastewaters to the wash. The treated wastewater flows through a 15-kilometer (9-mile) reach of Las Vegas Wash and is then discharged to Las Vegas Bay of Lake Mead. The wash has historically provided additional treatment by removing nutrients (nitrogen and phosphorus) and organic oxygen demanding materials from the wastewaters.

This study was designed to determine water quality characteristics at several key locations in the wash, including Northshore Road. A more intensive monitoring program designed to determine pollutant removal mechanisms in the wash was proposed to be conducted as part of the Phase II Treatment Facilities Study (TFS-II). The more detailed study was not conducted; however, one intensive study of the wash, including a dye study, was approved and conducted in November 1980.

A number of interim reports prepared during the Water Quality Standards Study (WQSS) have presented information related to Las Vegas Wash and have been utilized in preparing this chapter:

1. Two comprehensive data review summaries (January and June 1980).
2. The report on waste treatment potential (April 1980).
3. The preliminary study of interim headcut control (August 1980).
4. Annual Progress Report (October 1980).

Objectives

The Las Vegas Wash analysis has four major objectives:

1. Describe water quality conditions in Las Vegas Wash and compare these conditions to water quality criteria.
2. Determine the loads of pollutants entering Las Vegas Bay at Northshore Road.

3. Determine the loads of pollutants entering the wash from wastewater treatment plants, surface runoff, and groundwater.

4. Gain some understanding of the pollutant removal mechanisms that are active in the wash to provide a basis for more detailed evaluations in TFS-II.

Chapter Organization

This chapter has been divided into six sections:

1. Introduction.

2. Methodology--The field program and analytical procedures are discussed.

3. Results--The data collected during the routine wash monitoring program, the intensive survey, the other surface water sources monitoring program, and the groundwater sampling program are presented in this section.

4. Analysis--The pollutant loads to Las Vegas Wash from the wastewater treatment plants, other surface water sources, and groundwater; water quality transformations in the wash; and the pollutant loads at Northshore Road are presented in this section.

5. Effect on Beneficial Uses--The effects of pollutants on the beneficial uses of the wash and criteria necessary to protect the uses are discussed.

6. Conclusions.

METHODOLOGY

The Las Vegas Wash monitoring program consisted of a routine sampling program that was conducted from July 1979 through December 1980 and special intensive studies conducted during the last few months of 1980. A groundwater sampling program was conducted in January 1981.

Routine Sampling Program

Five stations in Las Vegas Wash were sampled every two weeks from July 1979 through December 1980. Figure 6-1 shows the location of the sampling stations. Station 1 was located about 100 meters downstream from the confluence of the effluent discharges from the Clark County Sanitation District and the City of Las Vegas treatment plants. At this point, the stream is channelized and fast-flowing. Station 2 was located about 3.2 kilometers downstream in the middle of a cattail marsh. The water is slow-moving and shallow. Station 3 was initially located at the U.S. Geological Survey (USGS) gaging station on the upstream side of Pabco Road. In January 1980, the station was moved to the downstream side of the road. Flow from Duck Creek mixes with flow from Las Vegas Wash in the vicinity of Pabco Road. A better mixed sample was collected from the downstream station. The water is deep and fast-flowing at this point and has been filtered by the marsh. Station 4 was located about 4.8 kilometers downstream of Pabco Road. This station was located near the headcut when the study was initiated. The headcut had advanced about 1.6 kilometers upstream by the end of the study. The wash is a deep, fast-flowing channel at Station 4. Station 5 was located at the Northshore Road bridge. Northshore Road has historically been the regulatory control point for water quality standards. Station 5 is about 0.8 kilometers upstream from Las Vegas Bay. The wash is a deep, fast-flowing channel at this point.

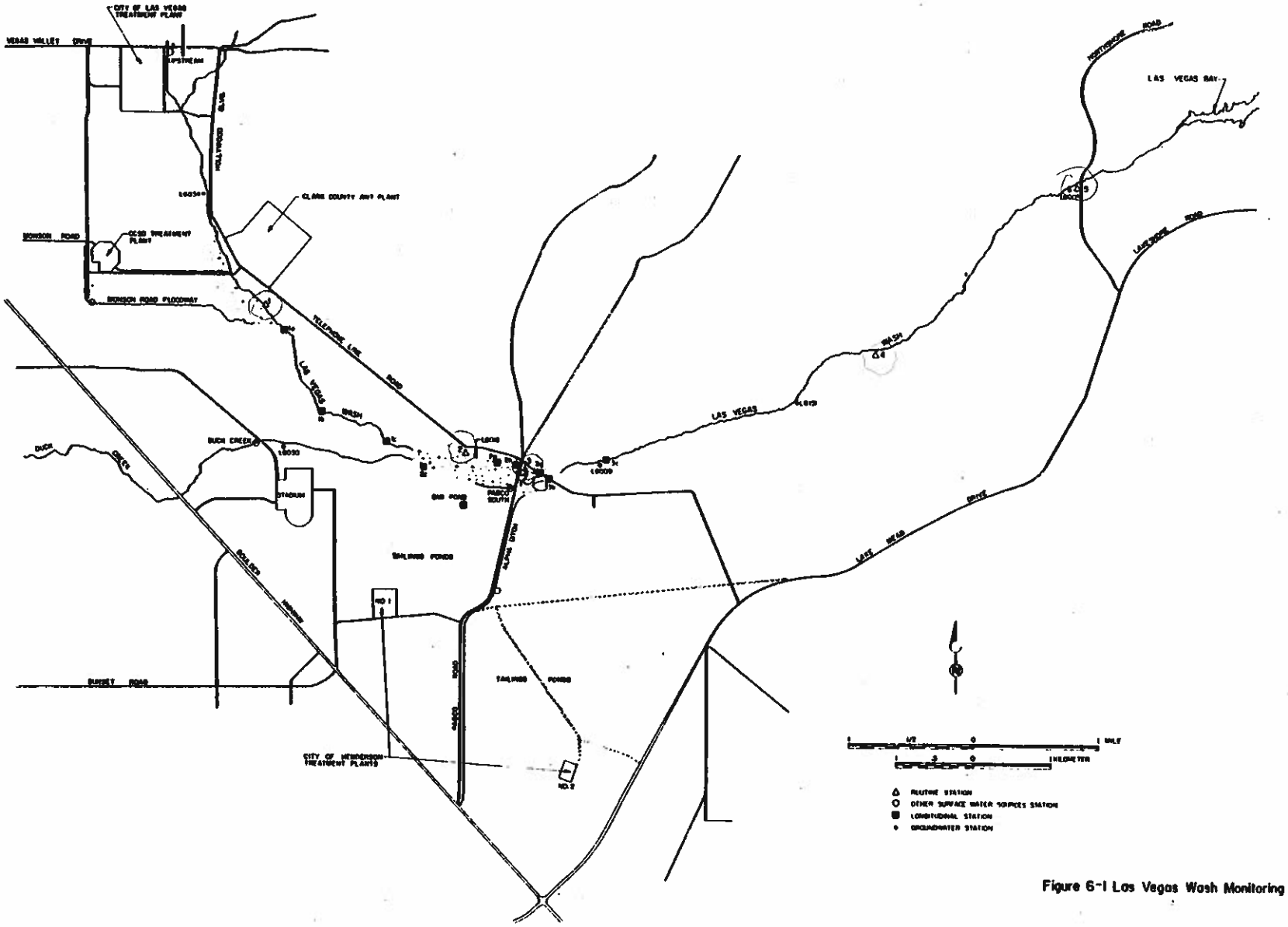


Figure 6-1 Las Vegas Wash Monitoring Stations

Samples were collected from each station every two weeks and analyzed for physical parameters, nutrients, biochemical oxygen demand (BOD), solids, and bacteria. A complete list of the parameters analyzed and the purpose of each analysis are presented in Table 6-1. The physical parameters were measured in situ with a Hydrolab. Grab samples were collected at Stations 1 through 4 and a 24-hour composite sample was collected at Station 5 for the other analyses. Details on the sampling and analysis procedures are presented in Appendix E.

In addition to the routine sampling program, a longitudinal study, diurnal study, and dye study were conducted on Las Vegas Wash. Samples were also collected from five other surface water sources draining into the wash for a two-month period. A groundwater sampling program was conducted in January 1981 and a laboratory experiment to determine if the wash soils would adsorb ammonia was conducted in November 1980.

Other Surface Water Sources Sampling Program

Samples were collected from five surface water sources tributary to the portion of Las Vegas Wash studied in this program: Las Vegas Wash, upstream of the treatment plants; Duck Creek; Monson Road Floodway; Alpha Ditch; and a small creek flowing into the wash from the southern portion of the marsh at Pabco Road (Pabco South). Samples were collected during the last four sampling trips of the the wash monitoring program and were analyzed for all of the routine parameters.

The locations of the sampling stations are shown on Figure 6-1. Las Vegas Wash, upstream of the treatment plants, is a slow-moving, shallow stream. The water in the stream is

Table 6-1. Parameters Measured in Las Vegas Wash Intensive Survey and Routine Sampling Program

Analysis	Purpose of analysis
Dissolved oxygen	Indicates oxygen concentration.
Temperature	Indicates temperature of water.
Conductance	Indirect measure of salinity.
pH	Indicates relative acidity and alkalinity of water.
Total biochemical oxygen demand (BOD_5)	Indicates oxygen demand.
Carbonaceous BOD	Indicates oxygen demand due to organic decomposition.
Nitrogenous BOD	Indicates oxygen demand due to nitrification.
Alkalinity	Indicates buffering capacity of water.
Total dissolved solids	Indicates salinity of water.
Total suspended solids	Measures amount of suspended material in water column.
Volatile suspended solids	Indicates proportion of solids that is organic.
Total phosphorus Dissolved phosphorus Soluble orthophosphorus	Phosphorus stimulates algal growth in Lake Mead. The different forms of phosphorus indicate the relative amounts of algal available P and non-available P.
Total Kjeldahl nitrogen Nitrate Nitrite Ammonia Total nitrogen	Nitrogen stimulates algal growth in Lake Mead. The different forms of nitrogen indicate the relative amounts of algal available N and non-available N. The various forms provide information on transformation processes.
Dissolved iron	Iron may stimulate algal growth in Lake Mead.
Total coliforms Fecal coliforms	Coliforms are indicative of the general bacteriological quality of the water. If coliforms are present, other pathogenic bacteria may be present.
Fecal streptococci	The ratio of fecal coliform to fecal streptococci indicates whether the source of coliforms is human or non-human.

mainly runoff from the Winterwood Golf Course. The Monson Road Floodway station was located in the dirt channel near the Clark County Sanitation District treatment plant. The water in the channel is mainly surface water runoff. Duck Creek flows from the East Las Vegas area, past the Silver Bowl Stadium, into Las Vegas Wash. Samples were collected from the dirt channel just upstream of Stadium Drive. The flow is due to surface water runoff and cooling water from the Clark Station power plant. Alpha Ditch contains cooling water from Basic Management Incorporated (BMI) industries. Samples were collected from a dirt channel near Pabco Road just north of the BMI tailings ponds. Pabco South is a stream that drains the area near the Henderson treatment plant and the BMI tailings ponds. This stream may contain a significant amount of surfacing groundwater. The channel is narrow with a gravel and silt bottom. The sampling site was on the western side of Pabco Road.

Physical measurements were determined in situ with a Hydrolab. Grab samples were collected and analyzed for all of the remaining parameters listed in Table 6-1. Flow measurements were taken so that nutrient loads to the wash could be calculated.

Dye Study

To determine the major flow paths and travel times in Las Vegas Wash, three separate dye releases were made in the wash on November 11 and 12, 1980. One release was made just below the confluence of the effluent discharges from the Clark County Sanitation District and the City of Las Vegas treatment plants (Station 1); another was at Pabco Road

(Station 3); and the final release was below the marsh, downstream of Pabco Road (Station 3c). In each release, 1.5 to 2 gallons of Rhodamine WT dye was dumped into the wash. Samples were collected manually or by Isco automatic samplers every few minutes at downstream stations. The dye concentrations of the samples were measured with a Turner Designs Model 10 fluorometer. Travel times between various stations in the wash were determined by the amount of time it took for the peak dye concentration to reach each station.

Longitudinal Study

The longitudinal study was conducted on November 13, 1980. Figure 6-1 shows the location of the sampling sites. Samples were collected from the five routine stations and ten additional stations in the wash. The five other surface water sources stations were also sampled on the same day. The type of sample collected (grab or composite) and the parameters that were measured are described in Table 6-2. Table 6-3 summarizes the major characteristics of each longitudinal sampling site.

Table 6-2. Longitudinal Study Samples

Station	Type of sample	Parameters
1,2,3,4,	Grab	Routine
5	4-hour composites collected over a 24-hour period	Routine except bacteria (coliforms and fecal streptococci)
Upstream, Monson Road Floodway, Pabco South	Grab	Routine
Duck Creek	14-hour composite Grab	Routine except bacteria Bacteria
Alpha Ditch	15-hour composite Grab	Routine except bacteria Bacteria
1a,1b,1c,2a, 2b,2c,3a,3b, 3c, BMI Pond	Grab	Routine except bacteria

Table 6-3. Longitudinal Sampling Station Descriptions

Station number	Station type	Description
1	Channel	Confluence of treatment plant effluents. Dirt channel, about 8 feet wide, 3 feet deep, fast-flowing. Lined with salt cedars.
1a	Channel	Just downstream of USGS gaging station. Dirt channel, about 8 feet wide, 3 feet deep, fast-flowing, mostly salt cedars, some cattails.
1b	Channel	About 0.6 mile below Station 1. Dirt channel about 10 feet wide, 2 feet deep, fast-flowing. Lined with salt cedars, no cattails.
1c	Channel	About 1.2 miles below Station 1. Just above the marsh.
2	Marsh	At north edge of marsh, about halfway to Pabco Road from the beginning of the marsh. Water about 0.5 foot deep, slow-flowing. All cattails about 15 feet tall. Grayish fungi attached to cattails and salt cedars.
2a	Marsh	At north edge of marsh, about 0.1 mile above Pabco Road. Water about 0.2 foot deep. Dense cattails.
2b	Channel	At north end of Pabco Road about 8 feet wide, 3 feet deep, fast-flowing. Many cattails on banks. Drains the marsh.
2c	Marsh	At south edge of marsh, near BMI tailings ponds.
3	Channel	Pabco Road station. Dirt channel about 20 feet wide, 1 to 3 feet deep. Cattails and salt cedars on banks.
3a	Pond	Upper Pabco pond. Sampling site at Telephone Line Road culvert. Water about 2 feet deep. Cattails and salt cedars.
3b	Pond	Lower Pabco pond. Sampling site at Telephone Line Road culvert. Water about 2 feet deep. Salt cedars on banks. Cattails in marshy area. Lots of floating algal debris probably Oscillatoria.
3c	Channel	New headcut just downstream from Southern Nevada Water System (SNWS) pipeline crossing. Dirt channel about 15 feet wide, 1 foot deep, fast-flowing. Cattails in channel, dead cattails on bank above water level. Stream bed sandy near shore, cobbles mid-stream. Long strands of Cladophora (6 feet) attached to salt cedars, water clear.
4	Channel	Old headcut. Dirt channel about 15 feet wide, 1 to 2 feet deep, fast-flowing turbid water. Mostly salt cedars, some cattails.
5	Channel	Northshore Road. Dirt channel about 15 feet wide, 1 to 2 feet deep, fast-flowing, cascading over small waterfalls. Very turbid water. Little vegetation.
BMI pond	Pond	Small pond near BMI tailings ponds. High conductivity. Many mosquito fish. Cattails and salt cedars around pond.

Diurnal Study

The diurnal, or 24-hour, study conducted November 12 through November 13, 1980, consisted of setting an automatic sampler at Northshore Road to collect samples every hour. Samples collected every four hours were composited to produce six samples for analysis. The samples were analyzed for all of the routine parameters except bacteria. The complete set of physical parameters was measured once during the 24-hour period at Station 5. Dissolved oxygen (DO) concentrations and temperature were monitored throughout the wash from November 11 through November 13, 1980. Approximately 90 measurements were taken at 21 locations throughout the wash from 6 a.m. to 6 p.m. during the three-day period.

Groundwater Sampling Program

Samples were collected by Desert Research Institute (DRI) from the six wells shown on Figure 6-1 three times during January 1981. Conductivity, temperature, and pH were measured in the field by DRI. Samples were analyzed for dissolved phosphorus, soluble orthophosphorus, nitrate, and nitrite. The same analytical methods that were used on the wash samples were used on the groundwater samples.

Ammonia Adsorption/Nitrification Study

The ammonia adsorption/nitrification study was designed to determine if the Las Vegas Wash stream bed sediments at Station 4 would adsorb or release ammonia. Sediments from the cliff above the water level were also exposed to the wash water to determine if these unexposed sediments would adsorb or release ammonia.

Goldman and Deacon describe an experiment in which 5 mg/l of ammonia was stripped from wash water when mixed with 2,000 mg/l of dried clay.[1] Brown and Caldwell (BC) conducted a similar experiment in November 1980. Sediment samples were collected from the Las Vegas Wash stream bed and from the cliff above the wash at Station 4 on November 10, 1980. A grab sample of water was also collected from the stream on this date. The sediment was mixed with the wash water sample in polyethylene bottles. Two experiments were conducted using varying sediment concentrations. The bottles were shaken on a mechanical shaker for two minutes each day for several days. The ammonia concentration was measured initially and periodically thereafter.

RESULTS

The results of the routine wash monitoring program and the special studies conducted from October 1980 through January 1981 are presented in this section. As the treatment plant effluent flows along the wash to Las Vegas Bay, it is filtered by the marsh and mixed with other surface waters and groundwater. A number of changes occur in the quality of the water between the treatment plants and Las Vegas Bay. The five routine wash stations were chosen to monitor the changes in quality as the water flows along the wash. Similarities and differences between the five stations and seasonal changes in the data are discussed.

The longitudinal study, conducted in November 1980, was designed to provide a more detailed picture of changes in water quality as the water flows through the wash. The five routine stations, five other surface water sources stations,

and ten additional stations in the wash were sampled during the longitudinal study. The locations of the sampling stations are shown on Figure 6-1. The data for key parameters are presented in this section. All data collected during the longitudinal study are presented in Appendix E.

The data collected during the routine monitoring program and the longitudinal study have been divided into the following major groups of parameters:

1. Physical parameters
2. Biochemical oxygen demand (BOD)
3. Nutrients
4. Bacteria

In addition to the longitudinal study, a dye study, diurnal study, groundwater sampling program, other surface water sources monitoring program, and an ammonia adsorption/ nitrification study were conducted from November 1980 through January 1981. The results of each of these studies are presented in this section.

Pollutant concentrations in Las Vegas Wash and changes in concentrations as the water travels through the wash are discussed in this section of the chapter. Pollutant loads to Las Vegas Wash and Las Vegas Bay and interpretation of the water quality transformations in the wash are presented in the Analysis section.

Physical Parameters

Temperature, dissolved oxygen, conductivity, dissolved solids, pH, alkalinity and suspended solids were measured at

each of the five wash stations during the routine monitoring program. These parameters were also measured at the five routine stations, five other surface water sources stations, and ten additional stations in the wash during the longitudinal study.

Seasonal Distribution. Data for temperature, dissolved oxygen, conductivity, dissolved solids, pH, and alkalinity at each of the five wash stations are presented on Figure 6-2.

Temperature--There is a large change in the temperature of the wash water over the annual cycle. Maximum temperatures during the summer months ranged from 25°C at Station 5 to 28°C at Stations 1 and 2. Minimum temperatures ranged from 11°C at Station 5 to 16°C at Station 1.

Dissolved Oxygen--The dissolved oxygen (DO) concentrations fluctuated from one sampling trip to the next at the five wash stations with no seasonal trends in the data. The DO concentrations were highest at Station 5, ranging from 4.7 to 10 mg/l. The lowest DO concentrations were found in the marsh at Stations 2 and 3. The DO concentrations at these two stations were generally less than 2 mg/l and often less than 1 mg/l.

Conductivity and Total Dissolved Solids--Conductivity is a measure of the water's ability to conduct an electric current, which is dependent on the dissolved solids concentration of the water. As shown on Figure 6-2, the conductivity and dissolved solids concentration profiles were similar. The conductivity was lowest at Station 2, ranging from 860 to 2,710 umhos/cm and highest at Station 5,

ranging from 2,850 to 4,300 umhos/cm. There were no seasonal trends in the data.

pH--The pH fluctuated from one sampling trip to the next at each station, but there were no seasonal trends in the data. The pH was generally lowest at Station 1, ranging from 6.6 to 7.8 and highest at Station 5, ranging from 6.2 to 8.7.

Alkalinity--In general, the alkalinity was greatest at Station 3 and lowest at Station 1. There were large fluctuations from one sampling trip to the next at each station, but there were no seasonal trends in the data. The alkalinity ranged from 134 to 240 mg/l as $CaCO_3$ at Station 1 and from 172 to 282 mg/l as $CaCO_3$ at Station 3.

Suspended Solids--The total suspended solids concentrations at Stations 1 through 5 in the wash are presented on Figure 6-3. The concentrations were generally low at Stations 1, 2, and 3 and much higher at Stations 4 and 5. The total suspended solids concentrations ranged from 20 to 400 mg/l and the volatile solids concentration ranged from 4 to 56 mg/l at Station 1. The total solids concentrations were generally less than 100 mg/l. Approximately 30 percent of the total solids was volatile. The total suspended solids concentrations were lower at Station 2, ranging from 3 to 58 mg/l. The volatile solids concentrations ranged from 3 to 36 mg/l. The volatile portion of the total solids was near 70 percent. The total solids concentrations at Station 3 were extremely low, ranging from 1 to 23 mg/l. The volatile solids concentrations were relatively constant (less than 1 to 7 mg/l). Approximately 55 percent of the

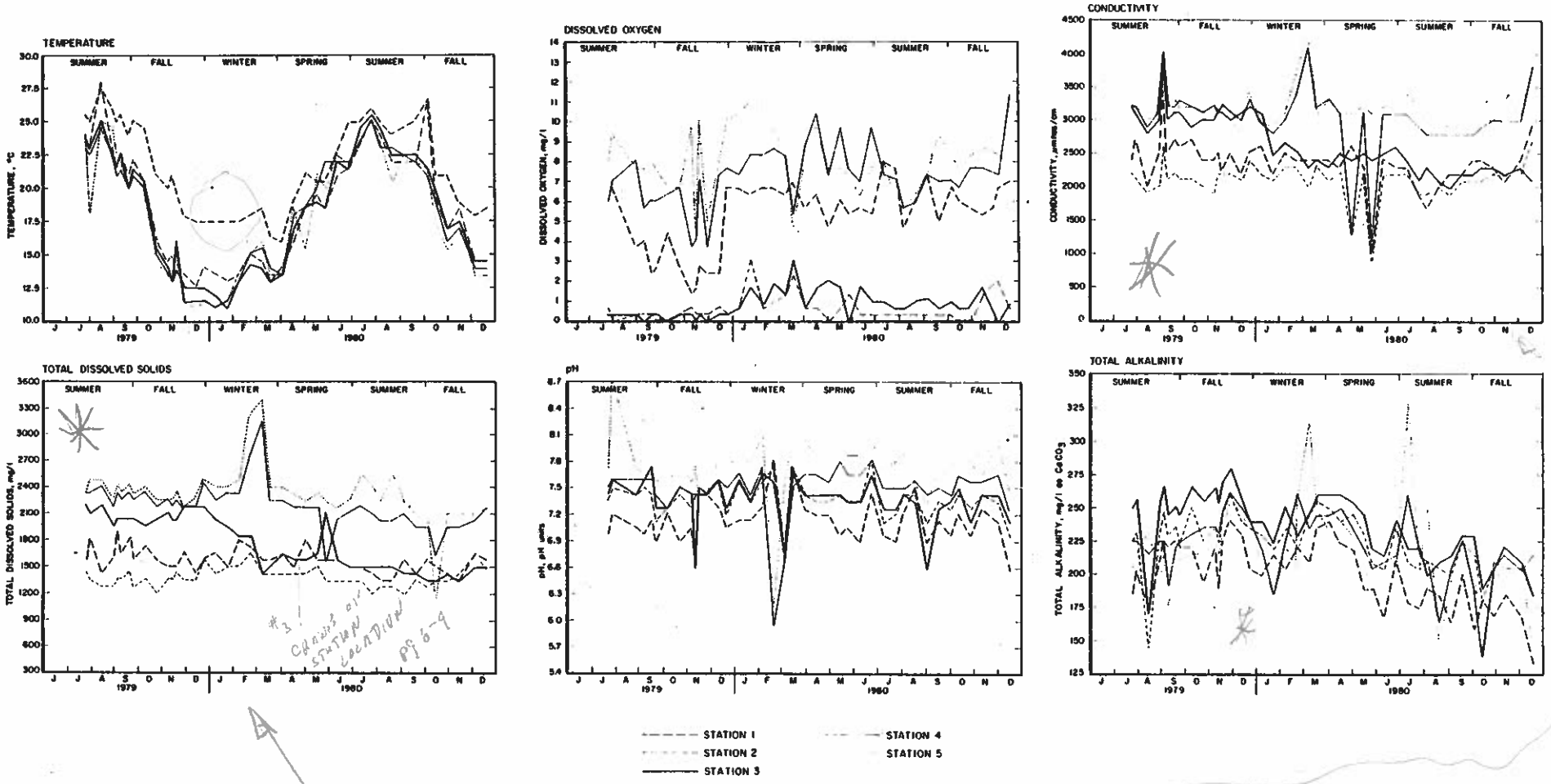


Figure 6-2 Physical Parameters at Routine Wash Stations

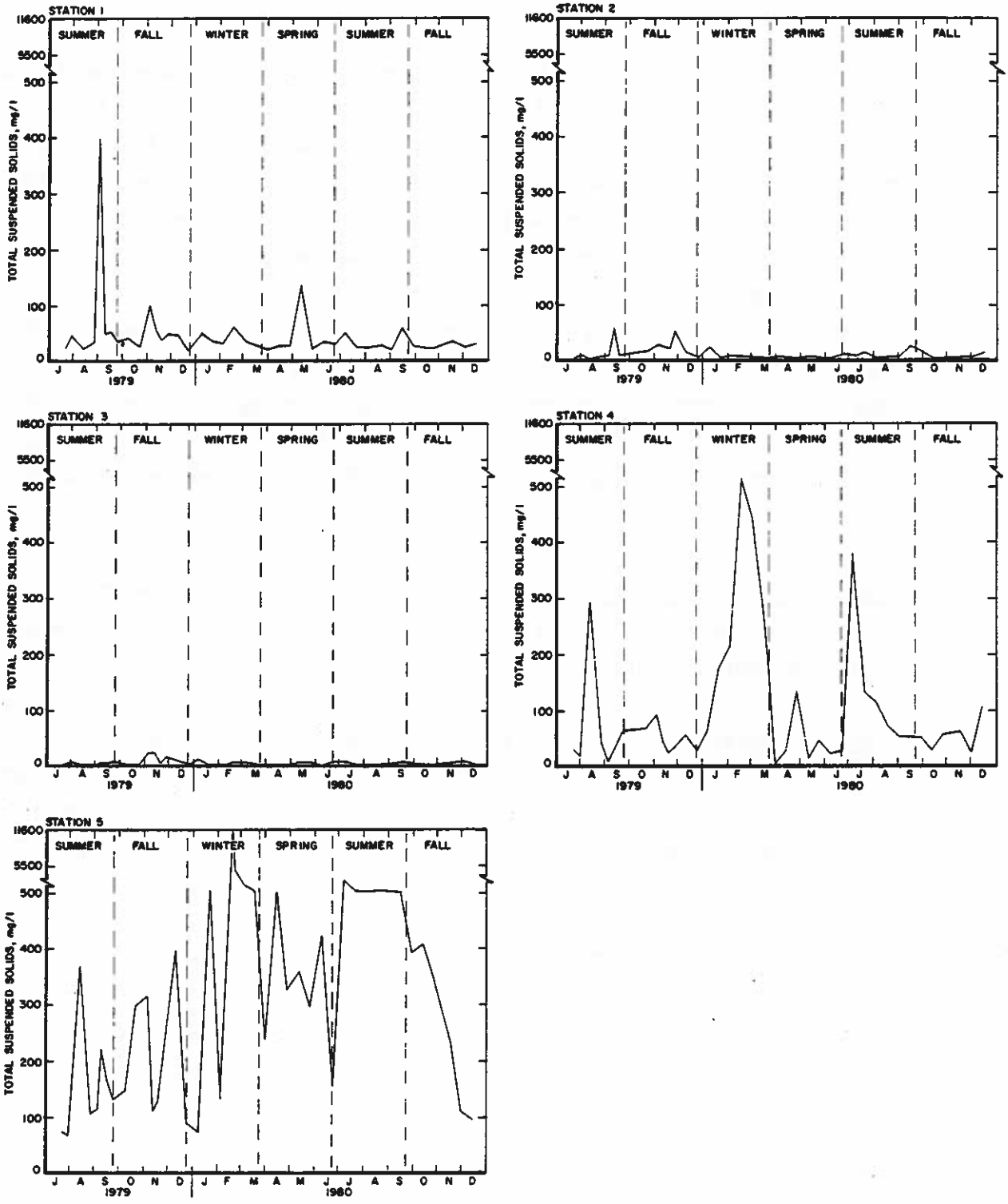


Figure 6-3 Total Suspended Solids Concentrations in Las Vegas Wash

total solids was volatile. The total suspended solids concentrations were much higher in the lower wash, ranging from 4 to 2,037 mg/l at Station 4, and 68 to 11,600 mg/l at Station 5. Less than 10 percent of the total solids concentration was volatile at both of these stations. The volatile solids concentrations ranged from 2 to 119 mg/l at Station 4, and from 5 to 590 mg/l at Station 5. The high solids concentrations at these two stations were due to the severe erosion that occurred in the wash during this study. The solids concentrations were high throughout the study. The concentrations were extremely high during the February 1980 storm and for about one month after the storm, as shown on Figure 6-3.

Spatial Distribution. The average concentrations of each physical parameter at each station during the 18-month wash study are presented on Figure 6-4.

Temperature--The secondary effluent discharged to the wash was relatively warm compared to the ambient water temperature. This resulted in a rapid drop in average temperature from 21.5°C at Station 1 to 18.6°C at Station 2, and then down to 17.9°C at Station 5.

Dissolved Oxygen--The DO concentrations dropped rapidly between Stations 1 and 2 and remained low between Stations 2 and 3. The average concentration at Station 1 was 4.7 mg/l during the study. The average concentrations were only 0.6 mg/l at Station 2 and 0.9 mg/l at Station 3. Bacterial decomposition of oxygen demanding substances in the wash and sediment uptake reduce the oxygen concentrations in the marsh. Minimal reaeration occurs in the marsh because the flow spreads

out and velocities are low. Downstream of Pabco Road, the water flows through two ponds and a marsh and then becomes channelized and fast flowing. Reaeration of the water occurs and the average DO concentration increased to 7.2 mg/l at Station 4. Further reaeration occurs between Stations 4 and 5, increasing the average DO concentration at Station 5 to 8.1 mg/l.

The DO concentrations at each of the longitudinal stations on November 13, 1980, are presented on Figure 6-5. The DO concentrations were quite high upstream of the treatment plants and in the other surface water sources. Some amount of reaeration occurred between Station 1 and Station 1b which was near the end of the channelized portion of the upper wash. Between these two stations, the DO increased from 5.4 to 7.1 mg/l. The DO then decreased by about 6 mg/l in the 3 km reach between Station 1b and Pabco Road. The DO ranged from 0.9 mg/l at Station 2a to 2.2 mg/l at Station 2b. Station 2c was located across from Station 2 on the southern side of the marsh. The DO concentration at Station 2c was 3.3 mg/l, about 2 mg/l higher than the marsh Station 5. Most of the increase in the concentration occurred downstream of Station 3c, which was located at the crossing of the Southern Nevada Water System pipeline.

Conductivity and Total Dissolved Solids--The conductivity and total dissolved solids concentrations decreased slightly between Stations 1 and 2 and then increased from 2,100 umhos/cm at Station 2 to 3,200 umhos/cm at Station 5. High conductivity surface waters and groundwater enter the wash between Stations 2 and 5. The total dissolved solids profile followed the conductivity profile very closely. The

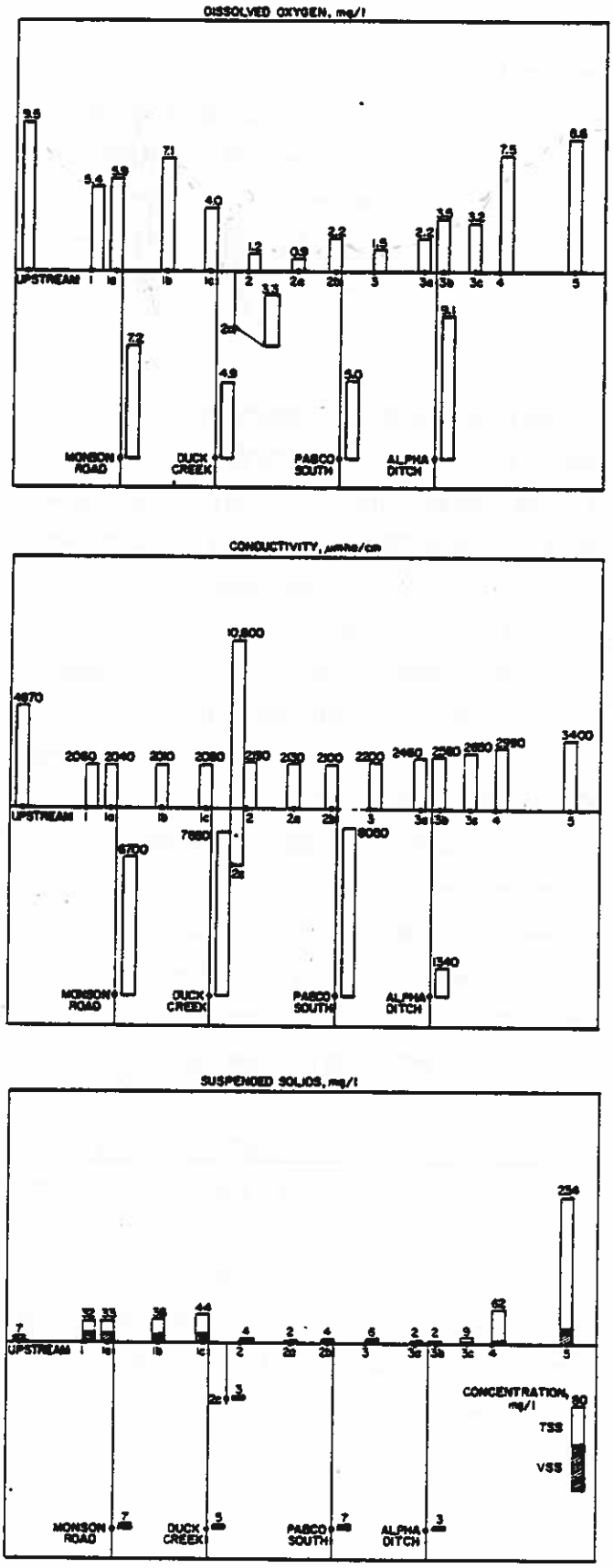


Figure 6-5 Key Physical Parameters Measured During the Longitudinal Study

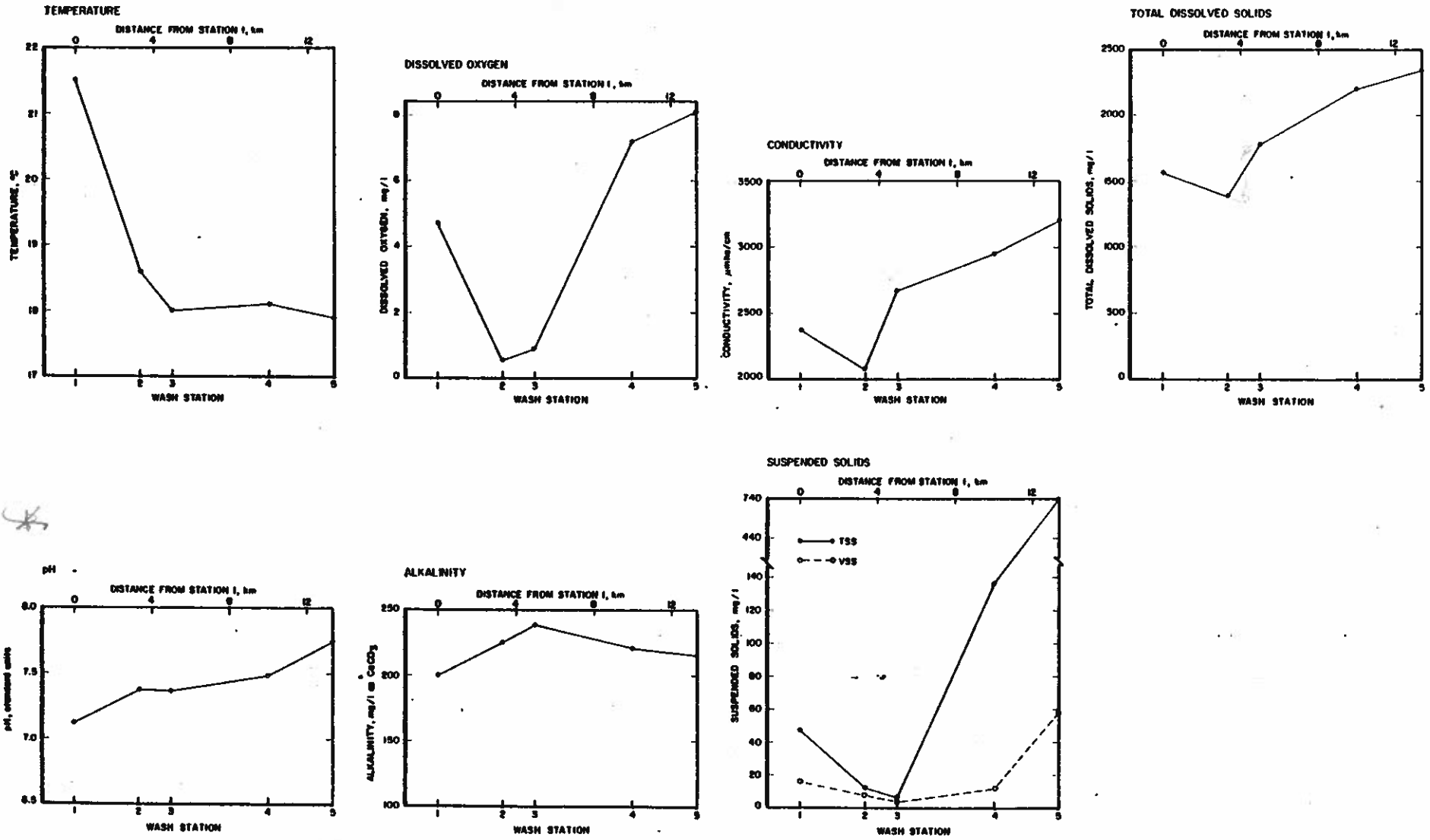


Figure 6-4 Average Physical Parameter Concentrations in Las Vegas Wash

total dissolved solids concentration decreased between Stations 1 and 2 and then increased from 1,400 mg/l at Station 2 to 2,350 mg/l at Station 5.

The conductivity at each of the longitudinal stations on November 13, 1980, is presented on Figure 6-5. The conductivity upstream of the treatment plants and in all of the other surface water sources except Alpha Ditch was much higher than in the main stream of the wash. The conductivity of the other sources ranged from 1,340 umhos/cm at Alpha Ditch to 7,880 umhos/cm at Duck Creek. The conductivity of the wash water increased throughout the wash from 2,060 umhos/cm at Station 1 to 3,400 umhos/cm at Station 5. The greatest increase in conductivity occurred below Pabco Road and is likely due to the inflow of highly saline groundwater.

pH--The average pH in Las Vegas Wash increased from 7.1 at Station 1 to 7.7 at Station 5 as shown on Figure 6-4.

Alkalinity--Alkalinity is a measure of the buffering capacity of the water. The average alkalinity increased from 200 mg/l as $CaCO_3$ at Station 1 to 240 mg/l as $CaCO_3$ at Station 3 as shown on Figure 6-4. The average concentration then decreased to 215 mg/l as $CaCO_3$ at Station 5.

Suspended Solids--The average total and volatile suspended solids concentrations decreased between Stations 1 and 3 and then increased between Stations 3 and 5. As the water flows into the marsh, suspended solids settle out of the water column and volatile solids (organic matter) are decomposed.

As shown on Figure 6-4, the total solids concentration decreased from 47 mg/l at Station 1 to 7 mg/l at Station 3. The volatile solids concentration was reduced from 15 mg/l at Station 1 to 4 mg/l at Station 3. Due to severe erosion downstream of Station 3, there was a large increase in the total suspended solids concentrations. The average concentrations were 136 mg/l at Station 4 and 732 mg/l at Station 5. The volatile solids concentrations also increased downstream of Pabco Road to 13 mg/l at Station 4 and 58 mg/l at Station 5.

The total suspended solids concentrations at each of the longitudinal stations on November 13, 1980, are presented on Figure 6-5. The concentrations upstream of the treatment plants and in the other surface water sources were extremely low, ranging from 3 to 7 mg/l. Between Station 1 and 1c, the suspended solids concentration increased from 32 to 44 mg/l, apparently due to erosion in the upper channel. When the water enters the marsh below Station 1c, the flows slow down and most of the suspended solids settle out. From Station 2 to Station 3c, the total suspended solids concentration was less than 10 mg/l. Downstream of Station 3c erosion occurring in the lower wash increased the total suspended solids concentration to 234 mg/l at Station 5.

Biochemical Oxygen Demand

The total five-day BOD, (BOD_5) carbonaceous BOD, and nitrogenous BOD concentrations were measured at each of the five wash stations during the routine wash monitoring program and the twenty longitudinal stations during the longitudinal study. The

carbonaceous BOD measures the oxygen demand due to the oxidation of carbonaceous (organic) compounds. The nitrogenous BOD measures the oxygen demand due to the oxidation of ammonia to nitrate. Typically, nitrogenous BOD is not exerted until after a standard five-day BOD test is completed since it takes several days to develop the population of nitrifying bacteria.

Seasonal Distribution. The concentrations of total BOD_5 carbonaceous BOD, and nitrogenous BOD at each of the five routine wash stations are presented on Figure 6-6. The total BOD_5 concentration at Station 1 declined from the fall of 1979 until the summer of 1980. Initially, the concentrations ranged from 17 to 56 mg/l and were generally between 30 and 40 mg/l. During the summer and fall of 1980, the total BOD_5 concentrations ranged from 12 to 19 mg/l. There were no seasonal trends in the data. On the average the BOD_5 at Station 1 was 95 percent carbonaceous and 5 percent nitrogenous.

The total BOD_5 concentration at Station 2 also declined during the study period. During the summer and fall of 1979, the concentrations ranged from 7 to 39 mg/l. During the summer and fall of 1980, the concentrations ranged from 8 to 22 mg/l and were generally between 10 and 15 mg/l. On the average, the BOD_5 at Station 2 was 95 percent carbonaceous and 5 percent nitrogenous.

The total BOD_5 concentrations at Station 3 were much lower than the concentrations at Stations 1 and 2. The total BOD_5 concentrations were generally between 5 and 10 mg/l. The concentrations were higher during the fall of 1979, ranging from 7 to 18 mg/l. On the average, the BOD_5 at Station 3 was 95 percent carbonaceous and 5 percent nitrogenous.

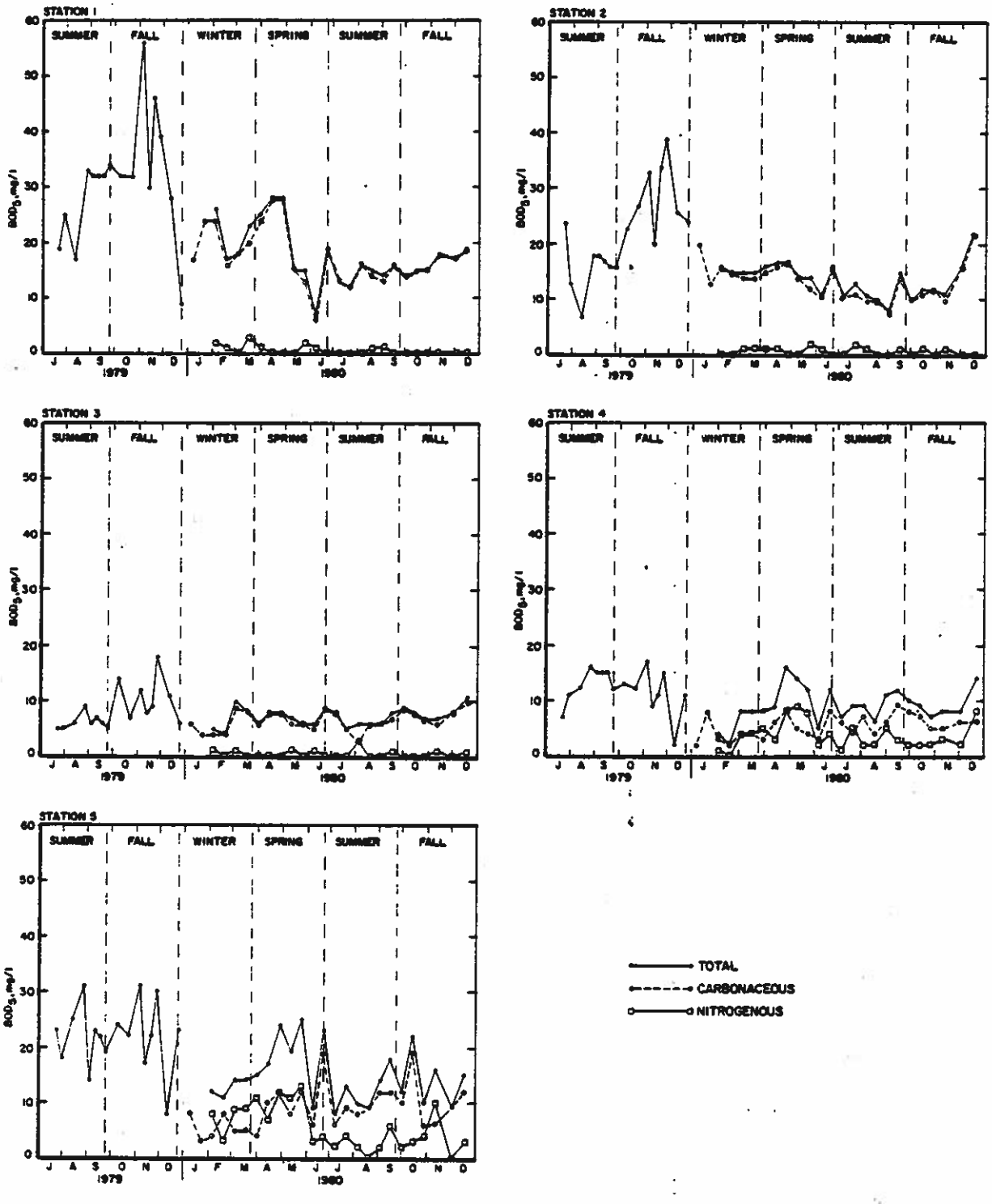


Figure 6-6 BOD_5 Concentrations in Las Vegas Wash

The total BOD_5 concentrations at Station 4 were relatively constant throughout the study. The concentrations ranged from 2 to 17 mg/l. There were no seasonal trends in the data. The nitrogenous BOD concentrations ranged from less than 1 to 9 mg/l and the carbonaceous BOD concentrations ranged from 2 to 9 mg/l. On the average, the BOD_5 at Station 4 was 60 percent carbonaceous and 40 percent nitrogenous.

The total BOD concentrations at Station 5 decreased throughout the study period. During the summer and fall of 1979, the concentrations ranged from 8 to 31 mg/l. The range of concentrations had decreased to 8 to 23 mg/l during the summer and fall of 1980. During the winter and spring of 1980, the nitrogenous BOD concentrations were generally greater than the carbonaceous BOD concentrations. During this time, the nitrogenous BOD ranged from 3 to 13 mg/l and the carbonaceous BOD ranged from 3 to 12 mg/l. During the summer and fall of 1980, the carbonaceous BOD concentrations increased and ranged from 6 to 19 mg/l. The nitrogenous BOD concentrations decreased and ranged from less than 1 to 10 mg/l. During 1980, the total BOD_5 generally consisted of 55 percent carbonaceous BOD and 45 percent nitrogenous BOD. The significance of the changes in nitrogenous and carbonaceous BOD are presented in the spatial distribution section.

Spatial Distribution. The average total, carbonaceous, and nitrogenous BOD concentrations at each station are presented on Figure 6-7. The total BOD_5 decreased rapidly from 23 mg/l at Station 1 to 8 mg/l at Station 3. There was a corresponding decline in both the carbonaceous and nitrogenous BOD concentrations. The decline in the carbonaceous BOD was likely due to sedimentation of particulate BOD and oxidation of

soluble BOD. The ammonia concentration did not change between Stations 1 and 3 so the decrease in the nitrogenous BOD could not be due to decreased nitrification. The samples collected at Stations 2 and 3 may not have contained a well developed population of nitrifying bacteria. Since the nitrogenous BOD test was only run for five days, there may not have been sufficient time for the development of the nitrifying population at Stations 2 and 3. This may have resulted in the lower nitrogenous oxygen demand concentrations simply because all of the nitrogenous BOD was not exerted in five days.

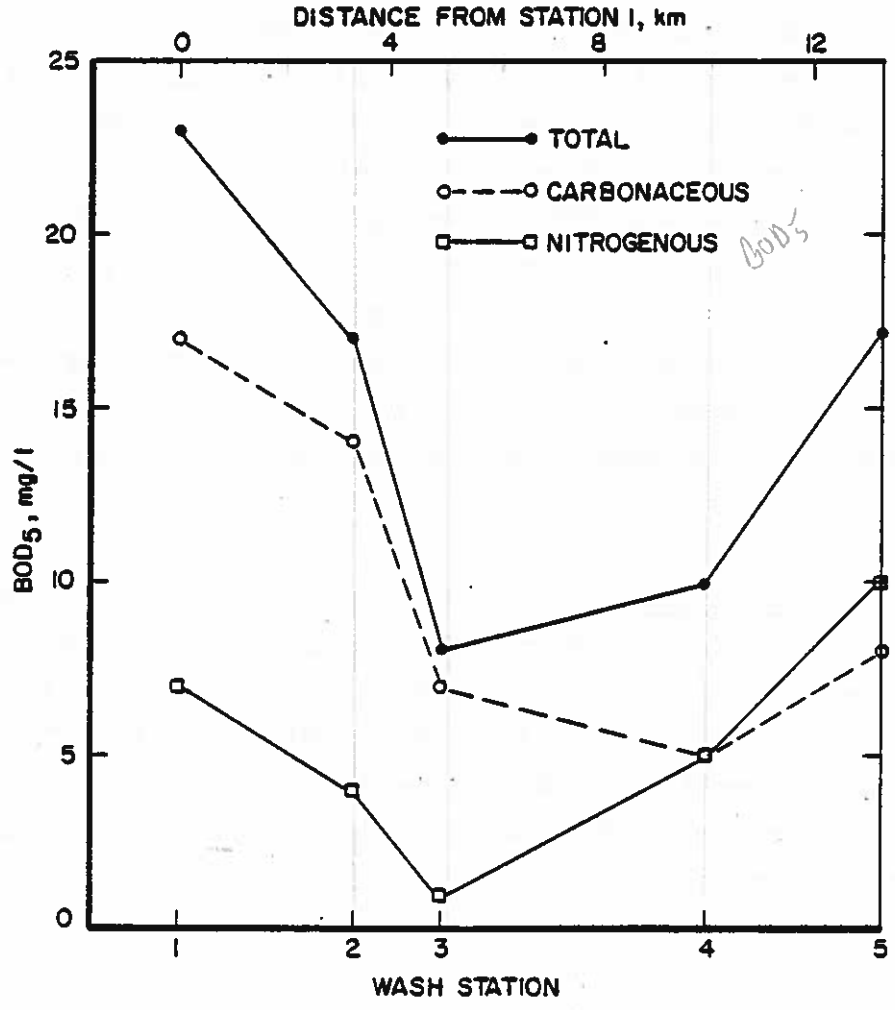


Figure 6-7 Average BOD_5 Concentrations in Las Vegas Wash

There was an increase in the total BOD_5 from 8 to 17 mg/l between Stations 3 and 5. The carbonaceous BOD decreased to 5 mg/l at Station 4 and then increased to 8 mg/l at Station 5. The decrease between Stations 3 and 4 is likely due to further oxidation of organic matter in the ponds and marsh below Pabco Road. The increase between Stations 4 and 5 may be due to the increased concentration of organic materials (volatile solids) due to erosion in the lower wash. The increase in the nitrogenous BOD from 1 mg/l at Station 3 to 10 mg/l at Station 5 corresponds to a decrease in the ammonia concentrations and an increase in the nitrate and nitrite concentrations. These factors indicate that a well developed population of nitrifying bacteria may have been present in the lower wash so some of the nitrogenous BOD was exerted in the five-day BOD test.

The total, carbonaceous, and nitrogenous BOD_5 concentrations at each of the longitudinal stations on November 13, 1980, are presented on Figure 6-8. All of the other surface water sources had total BOD concentrations of 2 to 3 mg/l except Duck Creek which had a concentration of 9 mg/l. In general, the total BOD concentration decreased as the water flowed from Station 1 to the Pabco Ponds (Stations 3a and 3b). The greatest drop in BOD occurred between Stations 1c and 2 as the water flowed into the marsh. As the water flowed through the marsh, the total BOD continued to decrease gradually from 11 mg/l at Station 2 to 5 mg/l at Station 3c. The total BOD increased to 16 mg/l downstream of Station 3c, due mainly to increases in the nitrogenous BOD concentration. As discussed previously, these relatively high nitrogenous BOD concentrations may be due to the presence of a well developed population of nitrifying bacteria in the lower wash that was not present in the marsh.

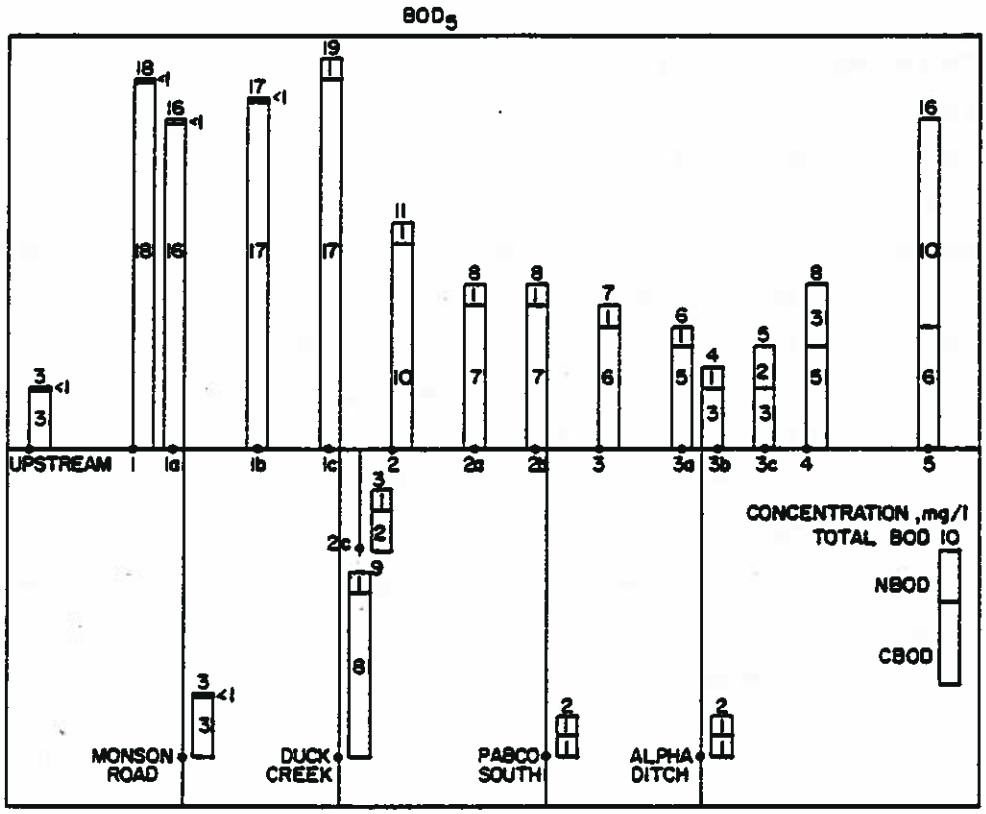


Figure 6-8 Longitudinal Study BOD_5 Concentrations

Nutrients

The phosphorus (P), nitrogen (N), and iron concentrations were measured at each of the five wash stations during the routine wash monitoring program and the twenty longitudinal stations during the longitudinal study.

Seasonal Distribution. The seasonal distribution of phosphorus, nitrogen, and iron are presented in this section.

Phosphorus--The concentrations of total P, dissolved P, and soluble ortho P at each of the five routine wash stations are presented on Figure 6-9. The total P

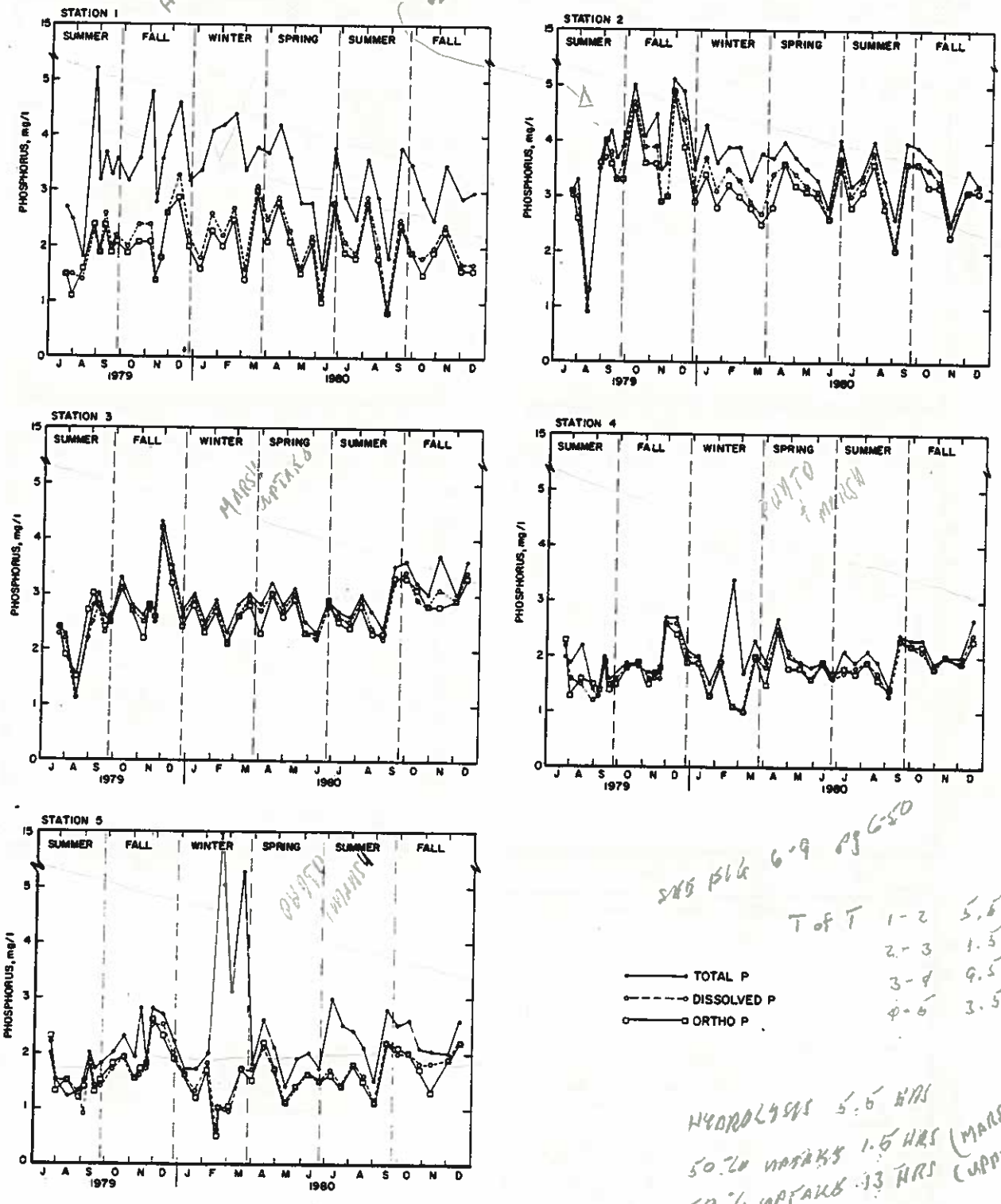


Figure 6-9 Phosphorus Concentrations in Las Vegas Wash

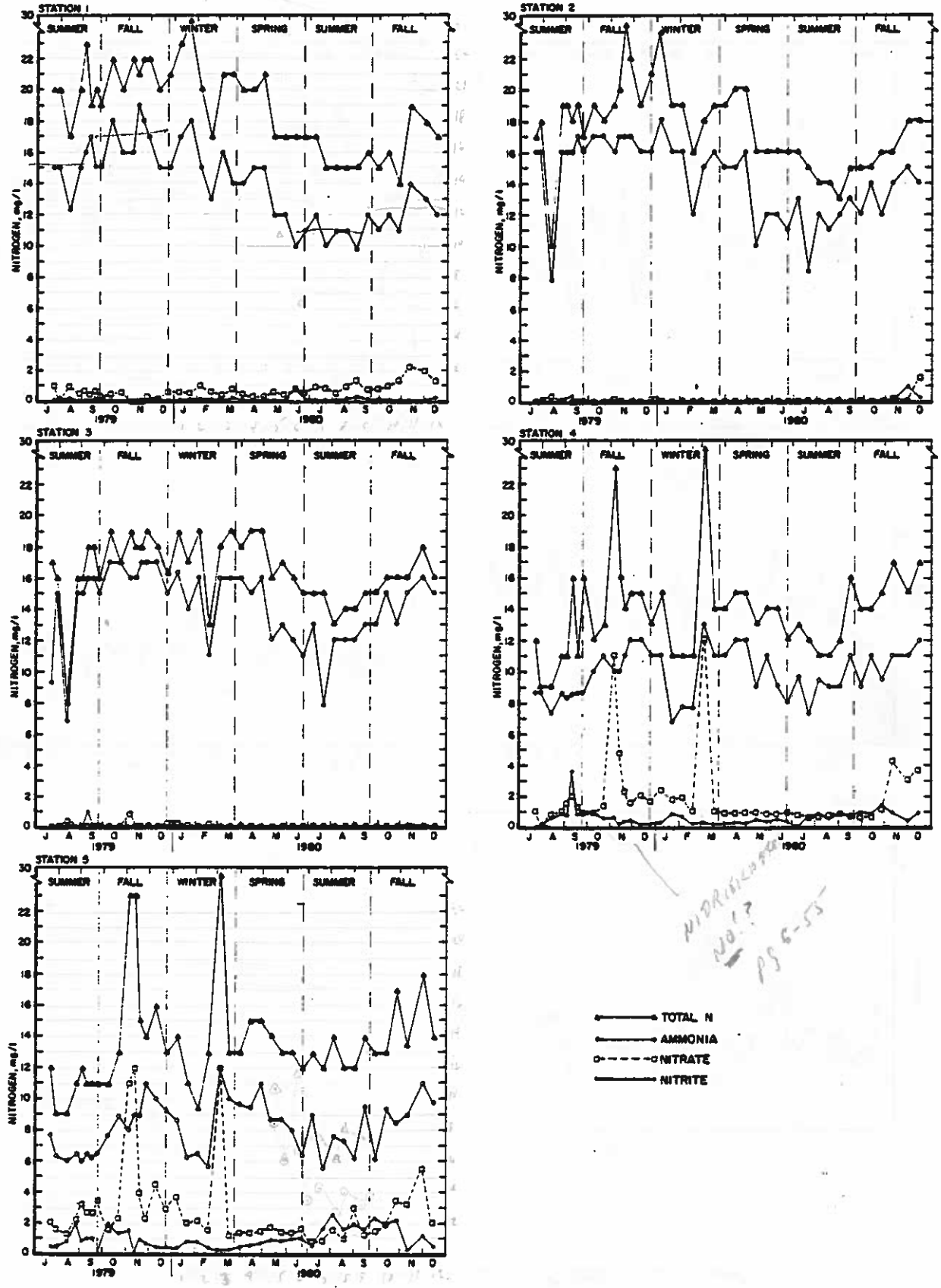


Figure 6-10 Nitrogen Concentrations in Las Vegas Wash

concentrations at Station 1 declined steadily throughout the study as a result of phosphorus removal at the Clark County Sanitation District treatment plant. The total P concentrations ranged from 2 to 7 mg/l during the summer and fall of 1979 and decreased to 2 to 4 mg/l during the summer and fall of 1980. There were no seasonal trends in the data. On the average, 60 percent of the total P was dissolved and 40 percent was particulate. Most of the dissolved P was in the soluble ortho P form.

The total P concentration at Station 2 also declined during the study period. The concentrations initially ranged from 3 to 5 mg/l and had decreased to 2 to 4 mg/l by the summer and fall of 1980. There were no seasonal trends in the data. On the average, 90 percent of the total P was dissolved and 10 percent was particulate. Most of the dissolved P was soluble ortho P.

The total P concentration at Station 3 was generally near 2 to 3 mg/l with higher concentrations occurring during the fall months. The concentrations were not lower in 1980 than in 1979 as they were at Stations 1 and 2. About 95 percent of the total P was dissolved and 5 percent was particulate. Most of the dissolved P was soluble ortho P.

The total P concentration at Station 4 was generally between 1 and 2.5 mg/l. The highest total P concentration of 3.4 mg/l occurred during a storm in February 1980. During this storm, the headcut advanced upstream about 1.4 kilometers causing severe erosion in the wash. The high total P concentration was most likely due to the erosion of sediment containing phosphorus. During normal flows in

the wash about 90 percent of the total P was dissolved and 10 percent was particulate. Only 30 percent of the total P was in the dissolved form during the storm.

There were no seasonal trends in the total P concentrations at Station 5. The concentrations were generally between 1 and 3 mg/l except during February and March 1980. The total P concentration reached 15 mg/l during the February 1980 storm and stayed between 3 and 7 mg/l for about one month following the storm. Prior to the storm, approximately 85 percent of the total P was dissolved and 15 percent was particulate. During the storm, and for about one month after the storm, only 20 to 30 percent of the total P was in the dissolved form. Most of the phosphorus measured during this time was particulate P adsorbed to sediments. After the storm, only 75 percent of the total P was in the dissolved form.

Nitrogen--The concentrations of total N, ammonia, nitrate, and nitrite at each of the five routine wash stations are presented on Figure 6-10. The total N concentration at Station 1 ranged from 17 to 25 mg/l from the summer of 1979 until the end of April 1980. Then there was a sudden drop in the total N concentrations. The concentrations ranged from 14 to 19 mg/l for the remainder of the study. Approximately 75 percent of the total N was in the inorganic N form. Most of the inorganic N was ammonia. The ammonia concentrations showed the same general trend as the total N concentrations. During the first part of the study, the concentrations ranged from 12 to 19 mg/l. After the sharp drop in April 1980, the concentrations ranged from 10 to 14 mg/l. The sudden decline in the total N and

ammonia concentrations at Station 1 occurred about the same time that the solids handling procedures were changed at the Clark County Sanitation District treatment plant. The effluent ammonia concentration decreased when the Zimpro process was shut down. This resulted in lower total N and ammonia concentrations at Station 1. The nitrate and nitrite concentrations at Station 1 were extremely low. The nitrate concentrations were generally less than 1 mg/l except during the last few months of the study when concentrations of 2 mg/l were reached. The nitrite concentrations were generally less than 0.2 mg/l.

The total N and ammonia concentrations at Station 2 showed the same trend as the concentrations at Station 1. The total N concentration ranged from 10 to 26 mg/l from July 1979 until April 1980. There was a sharp drop at the end of April 1980. The concentrations after the drop ranged from 13 to 18 mg/l. Approximately 80 percent of the total N was in the form of inorganic N and most of the inorganic N was ammonia. Before the Zimpro process was shut down in April 1980, the ammonia concentrations ranged from 8 to 18 mg/l and were generally between 16 and 17 mg/l. After the Zimpro process was shut down, the ammonia concentrations ranged from 8 to 15 mg/l. The nitrate and nitrite concentrations were usually less than 0.05 mg/l at Station 2.

The effect of shutting down the Zimpro process was also seen at Station 3. The total N concentrations ranged from 8 to 19 mg/l and were generally between 16 and 19 mg/l prior to the Zimpro process shut down. After the Zimpro process was

shut down, the concentrations ranged from 13 to 18 mg/l and were usually between 14 and 16 mg/l. Approximately 85 percent of the total N was inorganic N. Most of the inorganic N was ammonia. The ammonia concentrations ranged from 7 to 17 mg/l before the Zimpro process was shut down and from 8 to 16 mg/l after the Zimpro process was shut down. The nitrate and nitrite concentrations were extremely low. The nitrate concentrations ranged from less than 0.01 to 0.7 mg/l and were generally near 0.01 mg/l. The nitrite concentrations ranged from less than 0.01 to 1.0 mg/l and were usually near 0.01 mg/l.

The nitrogen pattern at Station 4 was different from the pattern at the upstream stations. The total N concentrations fluctuated from one sampling date to the next, but there were no seasonal trends in the data. The concentrations generally ranged from 9 to 17 mg/l. There was a peak of 23 mg/l in early November 1979 and a peak of 27 mg/l in early March 1980. The nitrate concentrations were much higher than normal on both of these dates. The March 1980 peak was due to a leak in a BMI pipe that transports industrial wastes to lined evaporation ponds in the wash (Franklin Morris, University of Nevada at Las Vegas (UNLV), personal communication)[2]. The UNLV research team typically made physical measurements in Alpha Ditch. On March 4, 1980, the conductivity was unusually high at 33,500 umhos/cm and the pH was unusually low at 5.55. A grab sample was collected and analyzed for all of the routine parameters. The nitrogen concentrations were extremely high. The total N was 575 mg/l, the ammonia was 123 mg/l and the nitrate was 440 mg/l. The total N peak in November 1979 may also have been due to a leak in a BMI pipeline. Approximately

98 percent of the total N was in the form of inorganic N at Station 4. A large amount of the inorganic N was ammonia. The ammonia concentrations at Station 4 ranged from 7 to 13 mg/l throughout the study without any seasonal trends in the data. The nitrate concentrations ranged from less than 0.01 mg/l to 12 mg/l. The concentrations were generally between 1 and 3 mg/l. The nitrite concentrations were normally less than 1 mg/l.

The nitrogen pattern at Station 5 was similar to that at Station 4. The total N concentrations fluctuated from one sampling date to the next, but there were no seasonal trends in the data. The concentrations normally ranged from 9 to 18 mg/l. Peak concentrations of 23 and 27 mg/l occurred in November 1979 and March 1980, respectively. Peak nitrate concentrations occurred at the same time. As discussed previously, the March peak was traced to a leak in a BMI pipeline and the November peak was likely due to the same factor. Inorganic N comprised 85 percent of the total N at Station 5. A large amount of the inorganic N was ammonia. The ammonia concentrations ranged from 6 to 12 mg/l. The summer concentrations were generally lower than the concentrations during the rest of the year. The nitrate and nitrite concentrations were higher at Station 5 than at the other four stations. The nitrate concentration ranged from 1 to 12 mg/l but was generally between 1 and 5 mg/l. The nitrite concentrations ranged from 0.02 to 2.6 mg/l. There were no seasonal trends in the nitrate and nitrite data.

Iron--The concentrations of dissolved iron at each of the five routine wash stations are presented on Figure 6-11.

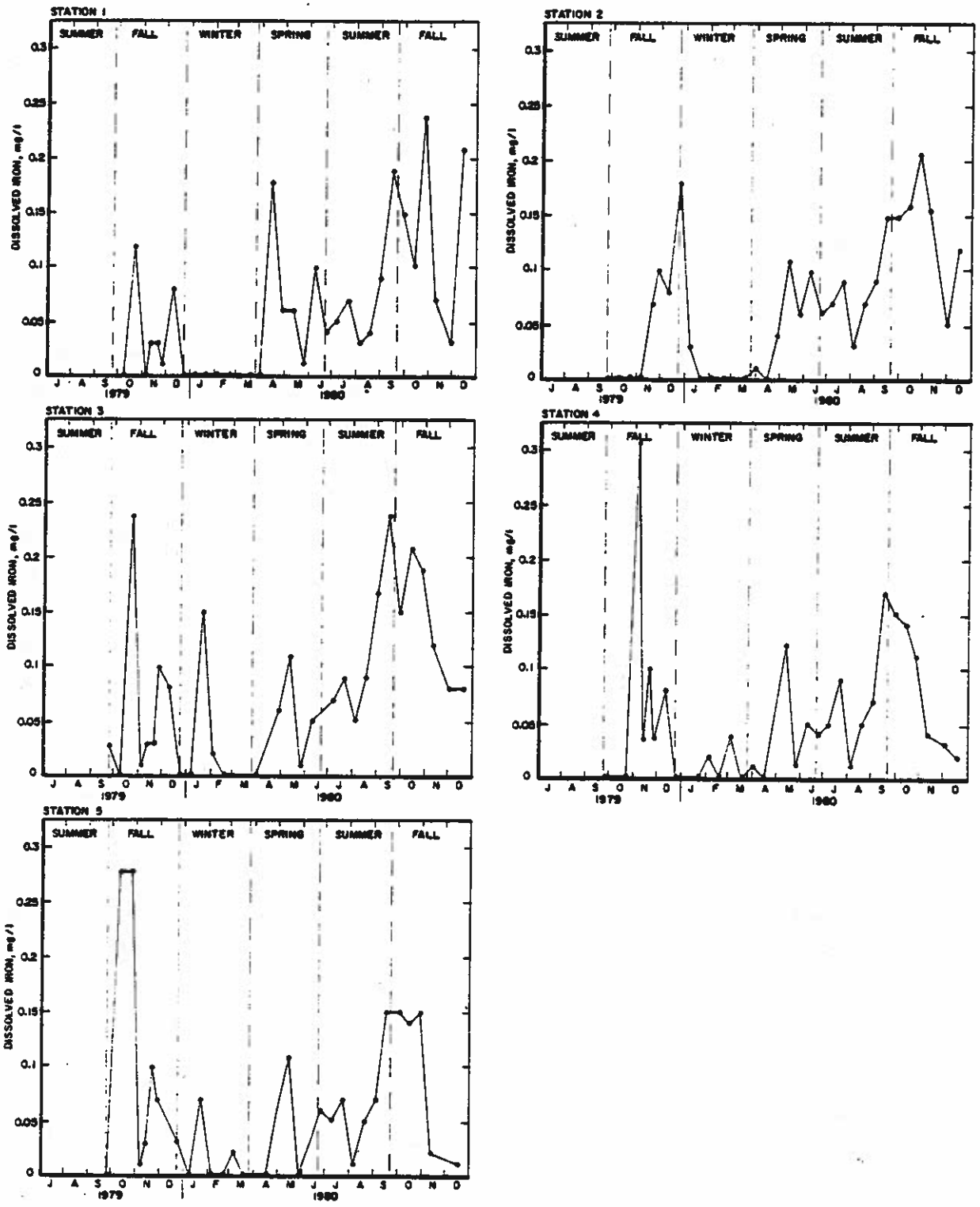


Figure 6-11 Dissolved Iron Concentrations in Las Vegas Wash

The dissolved iron concentrations ranged from the detection limit (less than 0.01 mg/l) to 0.25 mg/l at Stations 1 to 3 and 0.3 mg/l at Stations 4 and 5. There were no apparent trends in the data.

Spatial Distribution. The average concentrations of the nutrients at each station during the 18-month wash study are presented on Figure 6-12.

Phosphorus--The total P concentration increased slightly from 3.4 mg/l at Station 1 to 3.7 mg/l at Station 2. The reason for this increase is unknown but it might be that evapotranspiration of water increased the phosphorus concentration. Another possible explanation is that the cattails were acting as nutrient pumps and pumping phosphorus from the sediments into the water. The dissolved P increased from 2.1 mg/l at Station 1 to 3.3 mg/l at Station 2. The proportions of dissolved P increased and particulate P decreased between these two stations. Between Stations 2 and 4 the total P concentration decreased to 2.0 mg/l and the dissolved P decreased to 1.8 mg/l. This was likely due to biological uptake of phosphorus in the marsh above and below Pabco Road. There was an increase in the total P concentration between Stations 4 and 5 to 2.6 mg/l. The dissolved P concentration continued to decrease to 1.7 mg/l. The increase in the total P concentration is probably related to the erosion of sediments in the lower wash. Phosphorus adsorbed to sediments is measured as total P but is not detected in the dissolved P measurement.

The total and dissolved P concentrations at each of the longitudinal stations on November 13, 1980, are presented on

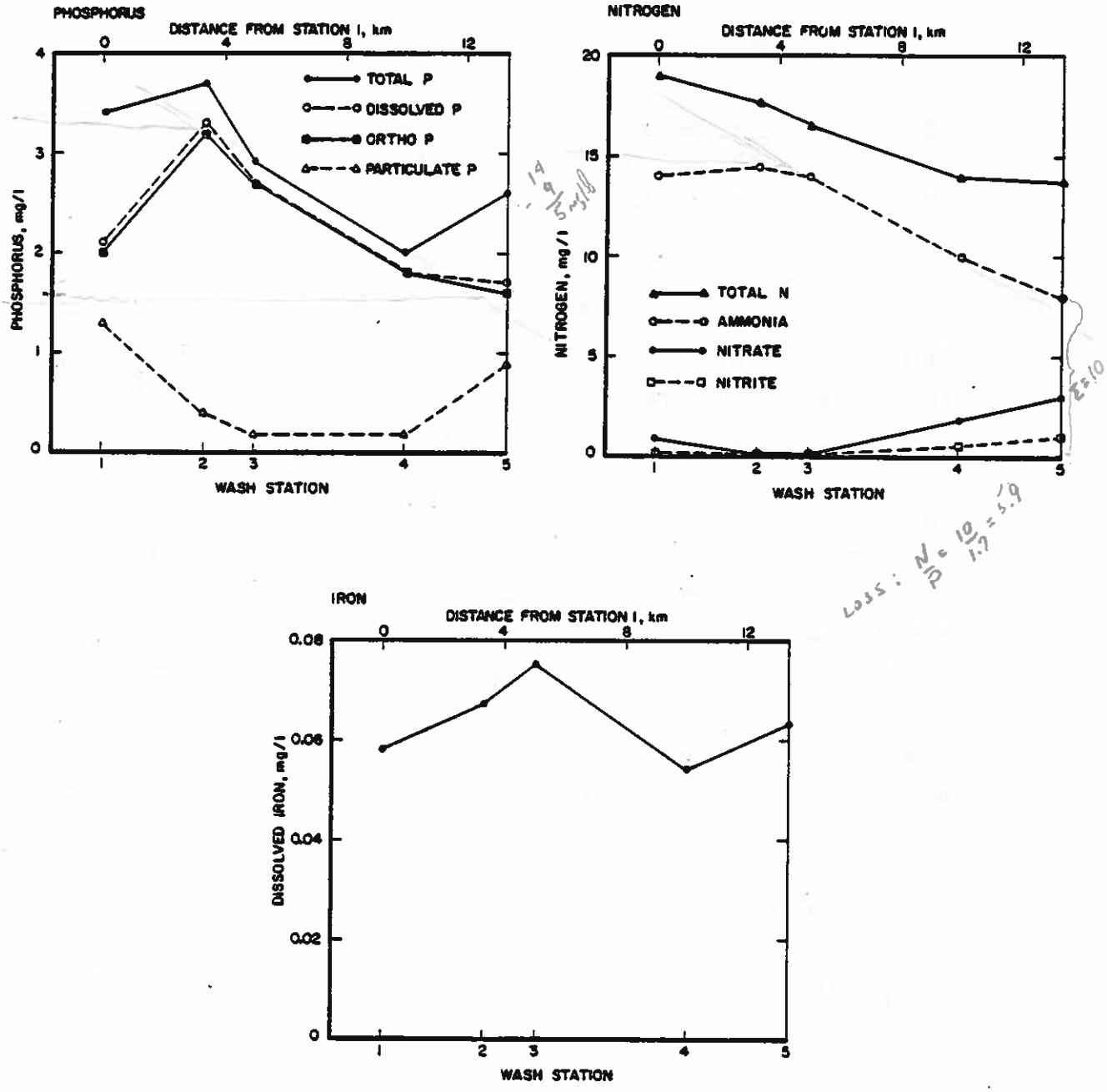


Figure 6-12 Average Nutrient Concentrations in Las Vegas Wash

Figure 6-13. The total P concentrations upstream of the treatment plants and in the other surface water sources were much lower than in the main flow of the wash. The concentrations ranged from 0.17 mg/l at Alpha Ditch to 0.89 mg/l at Pabco South. In general, the total P concentrations decreased gradually as the water flowed through the wash. The total P concentration did not change appreciably in the upper channelized portion of the wash between Stations 1 and 1c; however, the proportion of dissolved P increased slightly. As the water entered the marsh, the total P and dissolved P concentrations decreased to 2.5 mg/l at Station 2. All of the particulate P associated with suspended solids settled out as the flows slowed down in the marsh. During the longitudinal study, the total P concentration increased from 2.5 mg/l at Station 2 to 3.7 mg/l at Station 3. There was normally a decrease of about 1 mg/l between Stations 2 and 3 during the routine monitoring program. However, during the last three months of the study, the decrease between Stations 2 and 3 was usually less than 0.5 mg/l; and on several occasions, the concentration at Station 3 was greater than at Station 2. This may be due to the dying off of the cattails during the fall months, although this loss of removal capacity in the marsh was not seen during the fall of 1979.

The total P concentration decreased steadily downstream of Pabco Road from 3.7 mg/l at Station 3 to 2.1 mg/l at Station 5. Almost all of the removal occurred in the pond and marsh between Stations 3 and 3c. The total P concentration in the lower Pabco Pond was 1.8 mg/l This shows that the total P concentration can be reduced significantly with greater retention times in the ponds. On the

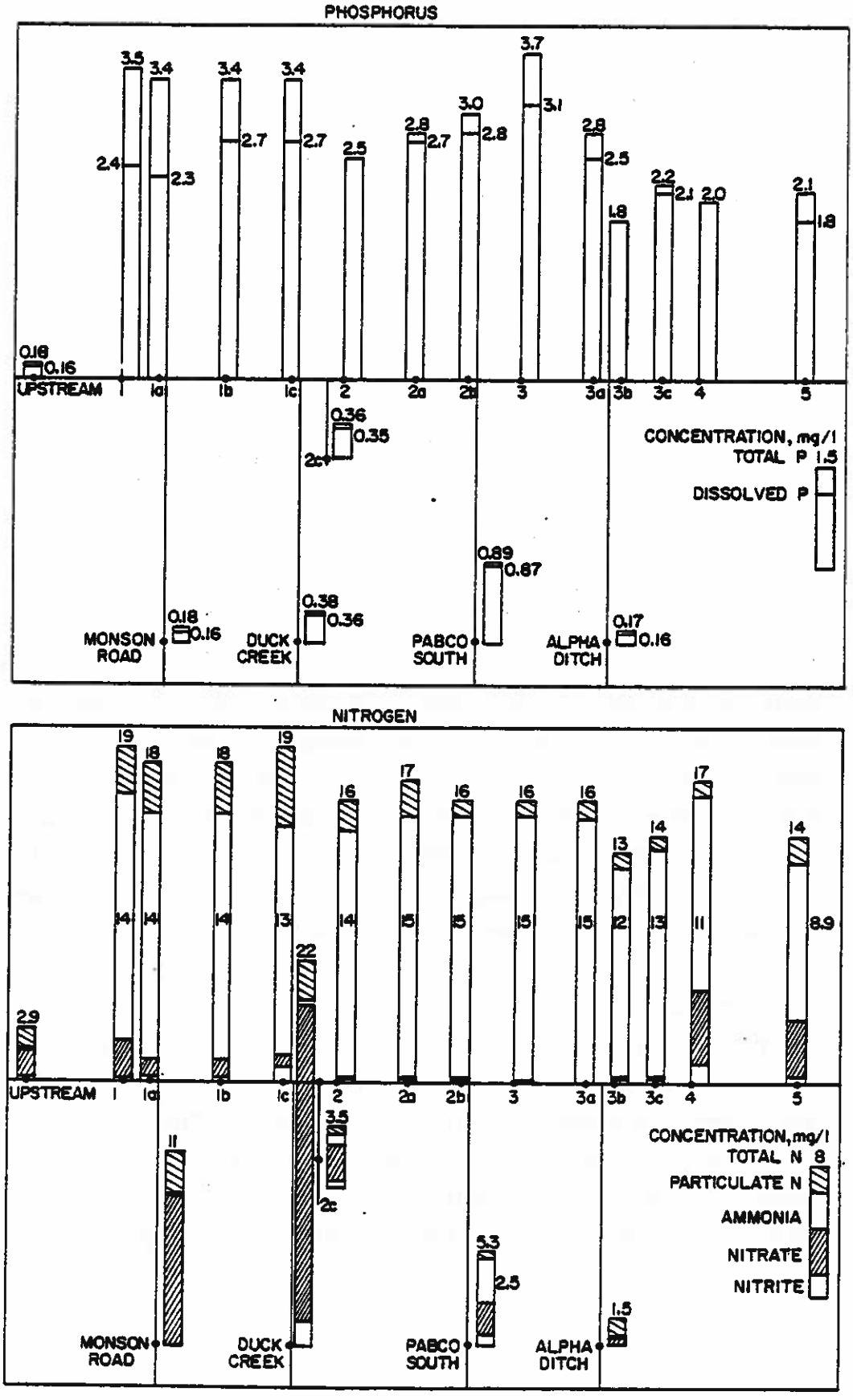


Figure 6-13 Longitudinal Study Nutrient Concentrations

southern side of the marsh at Station 2c, the total P concentration was 0.36 mg/l. The dye study showed that the main flow of the wash was on the northern side of the marsh. This low total P concentration at Station 2c illustrates that the effluent from the treatment plants does not reach the southern side of the marsh.

Nitrogen--The average total N, ammonia, nitrate, and nitrite concentrations at each of the five wash stations are shown on Figure 6-12. The total N concentration decreased steadily from 19 mg/l at Station 1 to 14 mg/l at Station 5. The average ammonia concentrations remained between 14 and 14.5 mg/l between Stations 1 and 3. Then the concentration decreased to 10 mg/l at Station 4, and 8 mg/l at Station 5. The nitrate and nitrite concentrations decreased between Stations 1 and 2, remained extremely low between Stations 2 and 3, and then increased in the lower wash. At Station 5, the average nitrate concentration was 3.0 mg/l and the average nitrite concentration was 1.0 mg/l.

The total N, ammonia, nitrate, and nitrite concentrations at each of the longitudinal stations on November 13, 1980, are presented on Figure 6-13. The total N concentrations upstream of the treatment plants, at Alpha Ditch and at Pabco South, were much lower than in the main flow of the wash. The total N concentrations ranged from 1.5 mg/l at Alpha Ditch to 5.3 mg/l at Pabco South. The total N concentration at Monson Road Floodway was 11 mg/l and at Duck Creek it was 22 mg/l. Most of the total N was in the form of nitrate. The total N concentration was reduced by about 25 percent as the water

flowed through the wash. In the upper channelized portion of the wash between Stations 1 and 1c, the total N and ammonia concentrations were relatively constant. The nitrate concentration decreased by 1.5 mg/l, the nitrite concentration increased by 0.8 mg/l, and the particulate N increased by 1.7 mg/l. As the water flowed into the marsh, the total N concentration was reduced from 19 to 16 mg/l. The reduction was due mainly to particulate nitrogen settling out with the suspended solids in the marsh. Between Station 2 and Pabco Road, the total N concentration remained at 16 mg/l, and the nitrate and nitrite concentrations were reduced to below the detection limit (0.01 mg/l). The only removal that occured upstream of Pabco Road was settling out of particulate N. Downstream of Pabco Road, the total N concentration decreased from 16 mg/l at Station 3 to 14 mg/l at Station 3c. The ammonia concentration was also reduced by 2 mg/l. The ammonia concentration was reduced by 2 mg/l between Stations 3c and 4; however, the total N concentration increased by 3 mg/l. The increase in total N was due to an increase in the nitrate concentration of 4 mg/l and an increase in the nitrite concentration of 1 mg/l. Between Stations 4 and 5, the total N concentration was reduced by 3 mg/l to 14 mg/l due to a reduction of 2 mg/l of ammonia and 1 mg/l of nitrate.

The possible explanations for the changes in the nitrogen species in the wash will be discussed in more detail in the analysis section of this chapter. The decrease in the ammonia concentration may be due to ammonia adsorption to clays, nitrification of ammonia to nitrate and

nitrite, or biological uptake of ammonia. It is probably a combination of all of these factors acting together. The increase in the nitrate concentration may be due to the inflow of nitrate laden groundwater or to the conversion of ammonia to nitrate. The presence of nitrite in the lower wash indicates that nitrification may be occurring.

Iron--The average dissolved iron concentrations in Las Vegas Wash are shown on Figure 6-12 Iron concentrations were measured in the wash because at times iron may limit aquatic plant growth in Las Vegas Bay. The average dissolved iron concentrations in the wash were quite high, ranging from 0.054 mg/l at Station 4 to 0.074 mg/l at Station 3. In general, the concentrations in the upper wash were higher than in the lower wash.

Bacteria

Total and fecal coliform concentrations were measured at each of the five wash stations during the routine wash monitoring program.

Seasonal Distribution. The concentrations of total and fecal coliforms at each of the five routine wash stations are presented on Figure 6-14. In general, the total and fecal coliform concentrations increased between Stations 1 and 2, and then decreased between Stations 2 and 4. The concentrations at Stations 4 and 5 were similar. Both the total and fecal coliform concentrations were generally greater than 240,000/100 ml at Station 1 during 1979. The concentrations of total coliforms ranged from 8 to

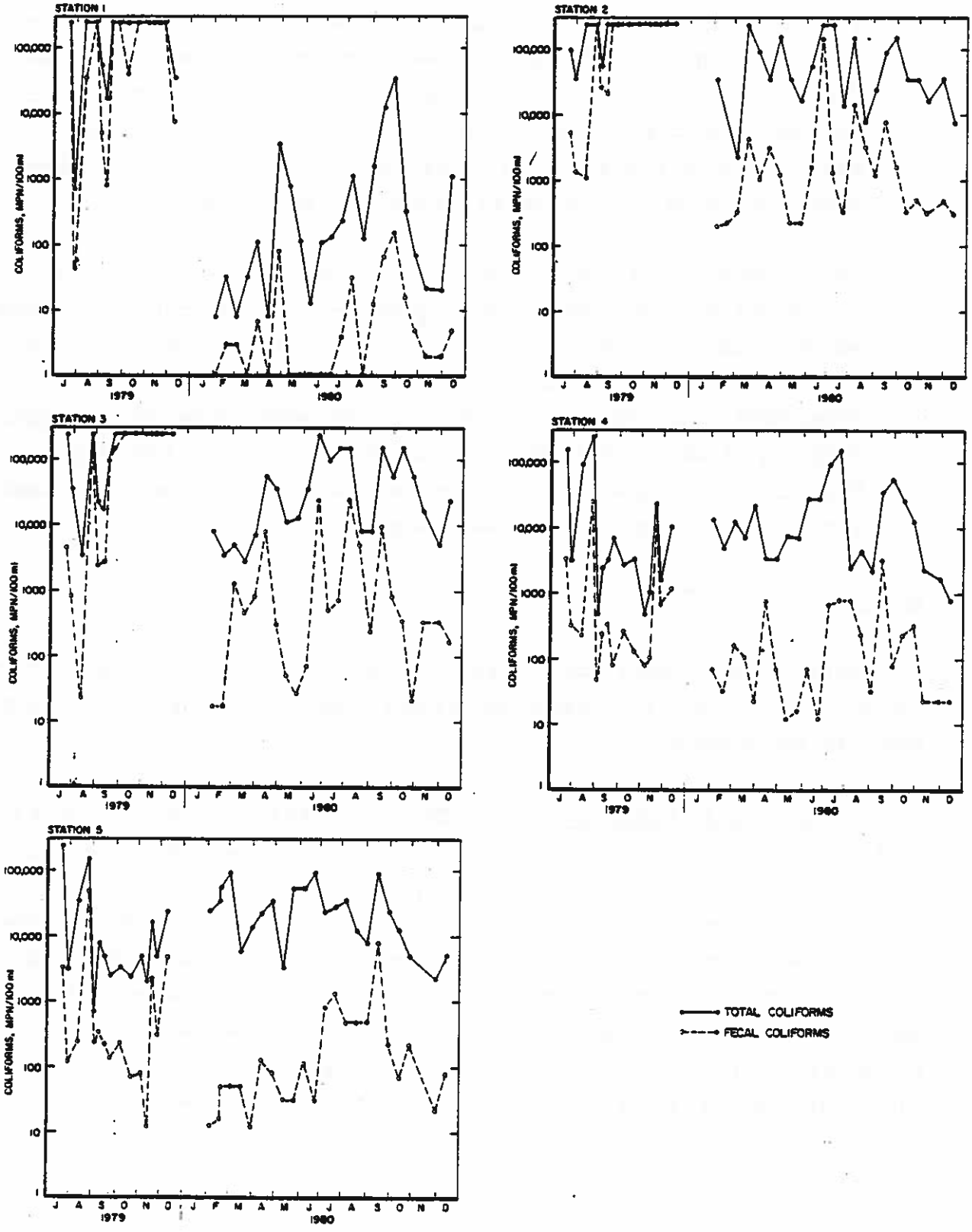


Figure 6-14 Coliform Concentrations in Las Vegas Wash

35,000/100 ml, and the fecal coliforms ranged from less than 2 to 170/100 ml during 1980. In 1979, the total and fecal coliform concentrations were generally lower at Station 5 than at Station 1. The total coliforms ranged from 700 to 240,000/100 ml and were generally less than 100,000/100 ml at Station 5. The fecal coliforms ranged from 13 to 50,000/100 ml. During 1980, both the total and fecal coliforms were greater at Station 5 than at Station 1. The total coliforms ranged from 2,200 to 92,000/100 ml and the fecal coliforms ranged from 13 to 7,900/100 ml at Station 5.

Spatial Distribution. The geometric mean total coliform and fecal coliform concentrations in the wash are presented on Figure 6-15. The standards and effluent limitations for coliform bacteria are based on geometric means in most cases. The total and fecal coliforms at Station 1 were quite low. The total coliform concentration was 80/100 ml and the fecal coliform concentration was 1.7/100 ml. Both the total and fecal coliform concentrations increased dramatically between Stations 1 and 2 and then remained high at Stations 3, 4, and 5. The average concentrations at Station 2 were 46,000 total coliforms/100 ml and 800 fecal coliforms/100 ml.

Other Surface Water Sources Sampling Program

Samples were collected from Las Vegas Wash upstream of the treatment plants, Monson Road Floodway, Duck Creek, Alpha Ditch, and a small stream entering the wash at the southern end of the marsh near Pabco Road (Pabco South) during the last four sampling trips of the routine wash monitoring program. The flow in these streams was low compared to the flow in the wash downstream of the treatment plants. The total average flow

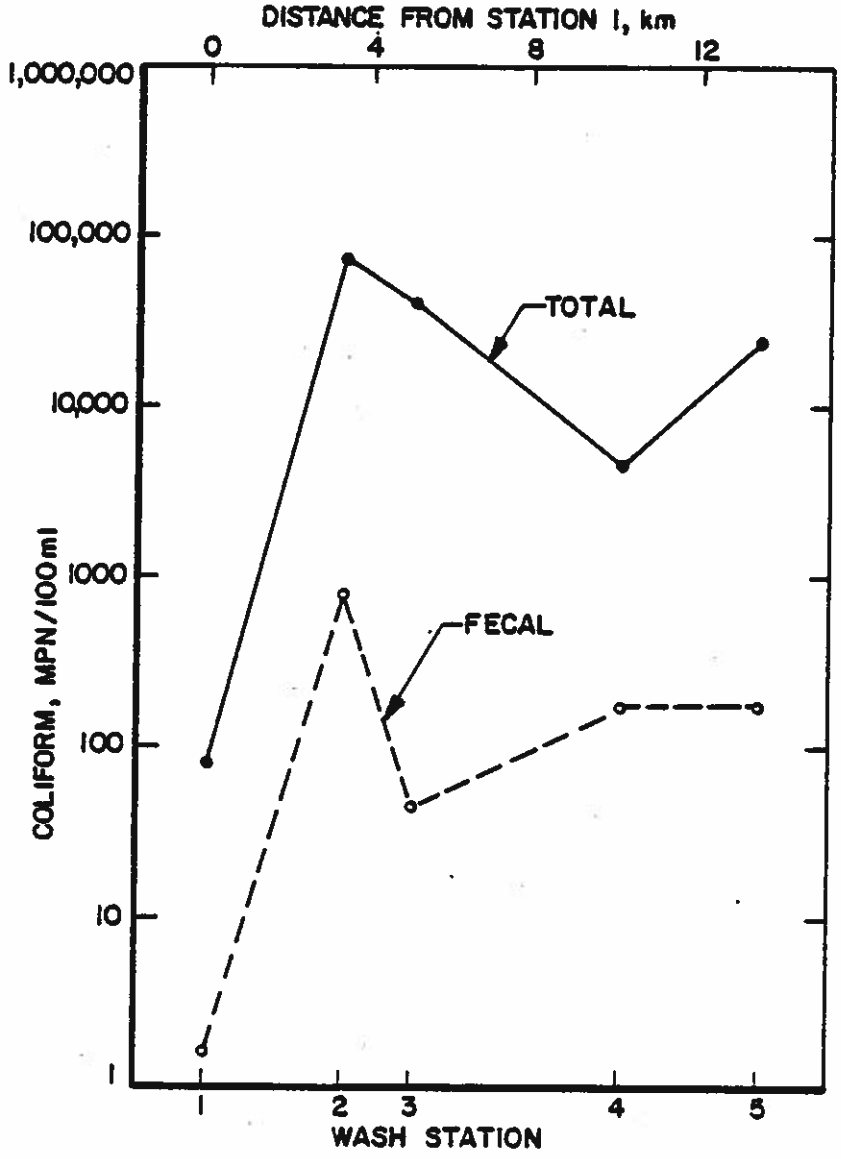


Figure 6-15 Average Coliform Concentrations in Las Vegas Wash

from these streams during the sampling period (October 28 to December 18, 1980, was 18 cfs. The average flow in the individual streams ranged from 0.7 cfs in Monson Road Floodway to 9.3 cfs in Alpha Ditch. No data were collected on storm flows in these streams. The physical characteristics of these streams are summarized on Figure 6-16. The average pH, temperature, conductivity, and DO concentrations of the other surface water sources are compared to the average values of these parameters at the routine wash stations during the sampling period. With the exception of Alpha Ditch, the conductivity of the other surface water sources was higher than the conductivity of the routine stations. The dissolved oxygen concentrations were high in all of the streams except Pabco South. The average DO concentration was 2.7 mg/l in this stream.

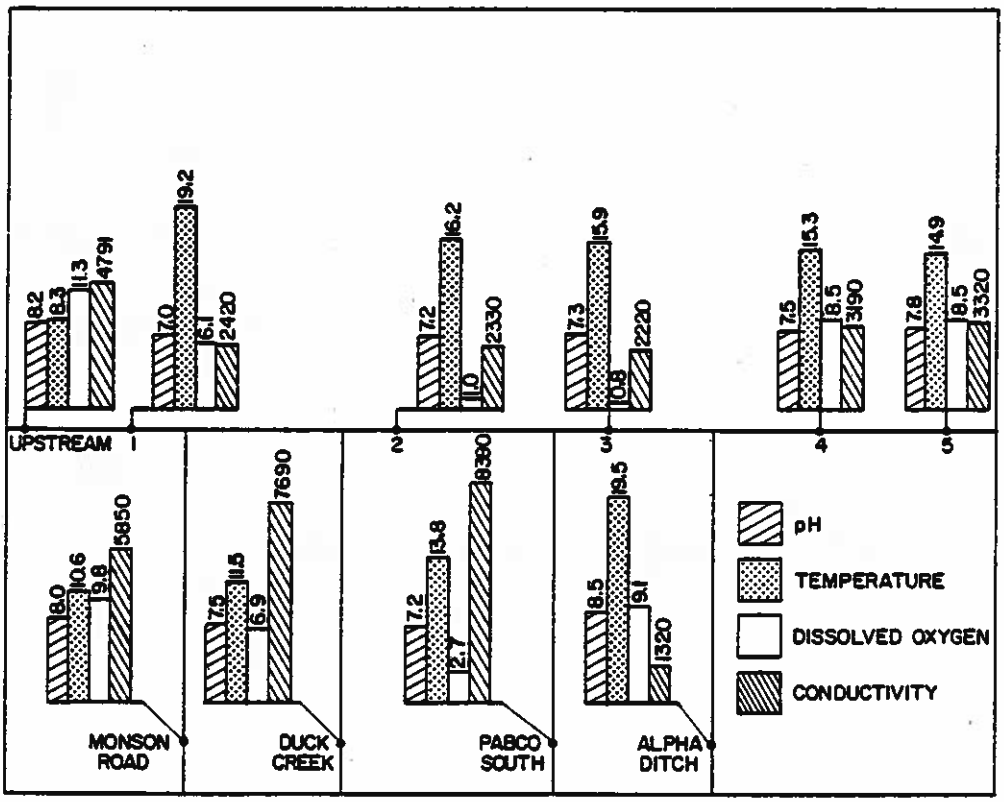


Figure 6-16 Comparison of Physical Characteristics of Other Surface Water Sources to Routine Station Characteristics

The carbonaceous, nitrogenous, and total BOD_5 concentrations at the routine stations and the other surface water sources stations are shown on Figure 6-17. The BOD_5 concentrations of the other streams were considerably lower than the BOD_5 concentrations in Las Vegas Wash. A small amount of nitrogenous BOD was found in Monson Road Floodway, but none was found in the other streams.

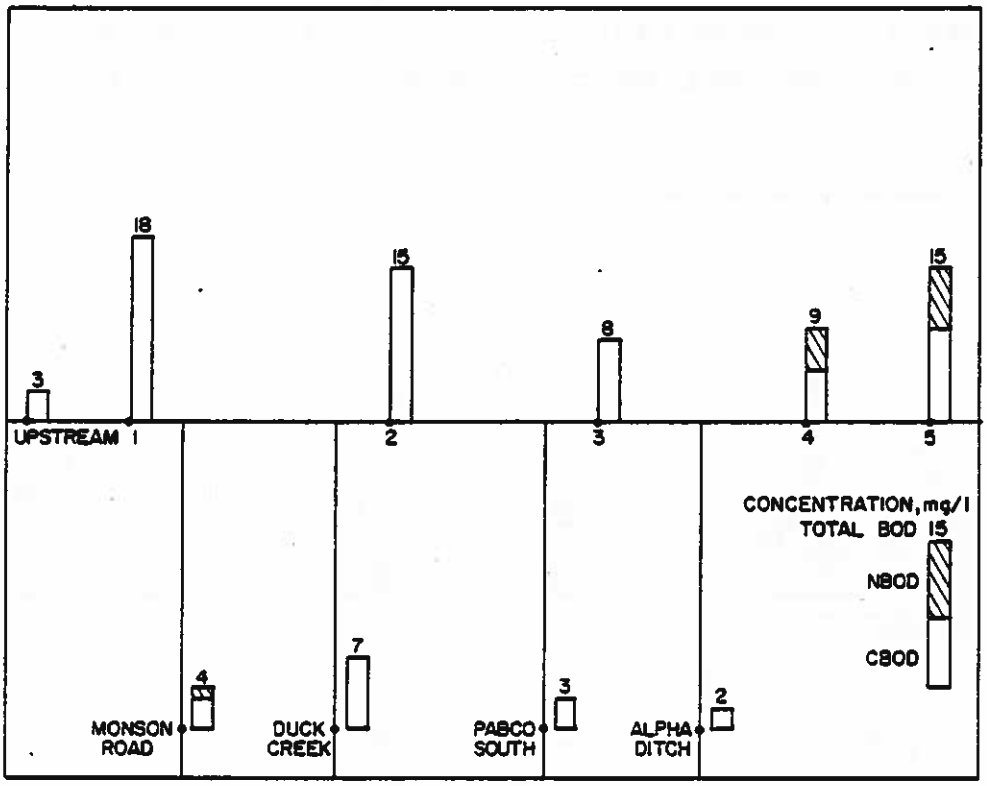


Figure 6-17 Comparison of BOD Concentrations in Other Surface Water Sources to Routine Station Concentrations

The average phosphorus concentrations in the other streams and in Las Vegas Wash during the last four sampling runs are shown on Figure 6-18. The phosphorus concentrations in the other streams and the wash upstream of the treatment plants were low compared to the concentrations at the routine stations. With the exception of Pabco South, all of the streams had phosphorus concentrations less than 0.5 mg/l. The average concentration at Pabco South was 1.0 mg/l. Most of the phosphorus in these streams was in the dissolved form.

The average nitrogen concentrations are shown on Figure 6-18. The total nitrogen concentrations in Monson Road Floodway and Duck Creek were comparable to the total N concentrations at the routine stations. Most of the nitrogen at the routine stations was in the form of ammonia, whereas nitrate comprised most of the total N in Monson Road Floodway and Duck Creek. The total N concentrations were much lower in upstream Las Vegas Wash, Pabco South, and Alpha Ditch.

Dye Study

To determine the major flow paths and travel times in Las Vegas Wash, three separate dye releases were made in the wash on November 11 and 12, 1980. One release was made just below the confluence of the effluent discharges from the Clark County Sanitation District and City of Las Vegas wastewater treatment plants (Station 1), another was at Pabco Road (Station 3), and the final release was below the marsh downstream of Pabco Road (Station 3c). There is a large diurnal fluctuation in flows in the wash. All releases were made near the minimum flows for the day.

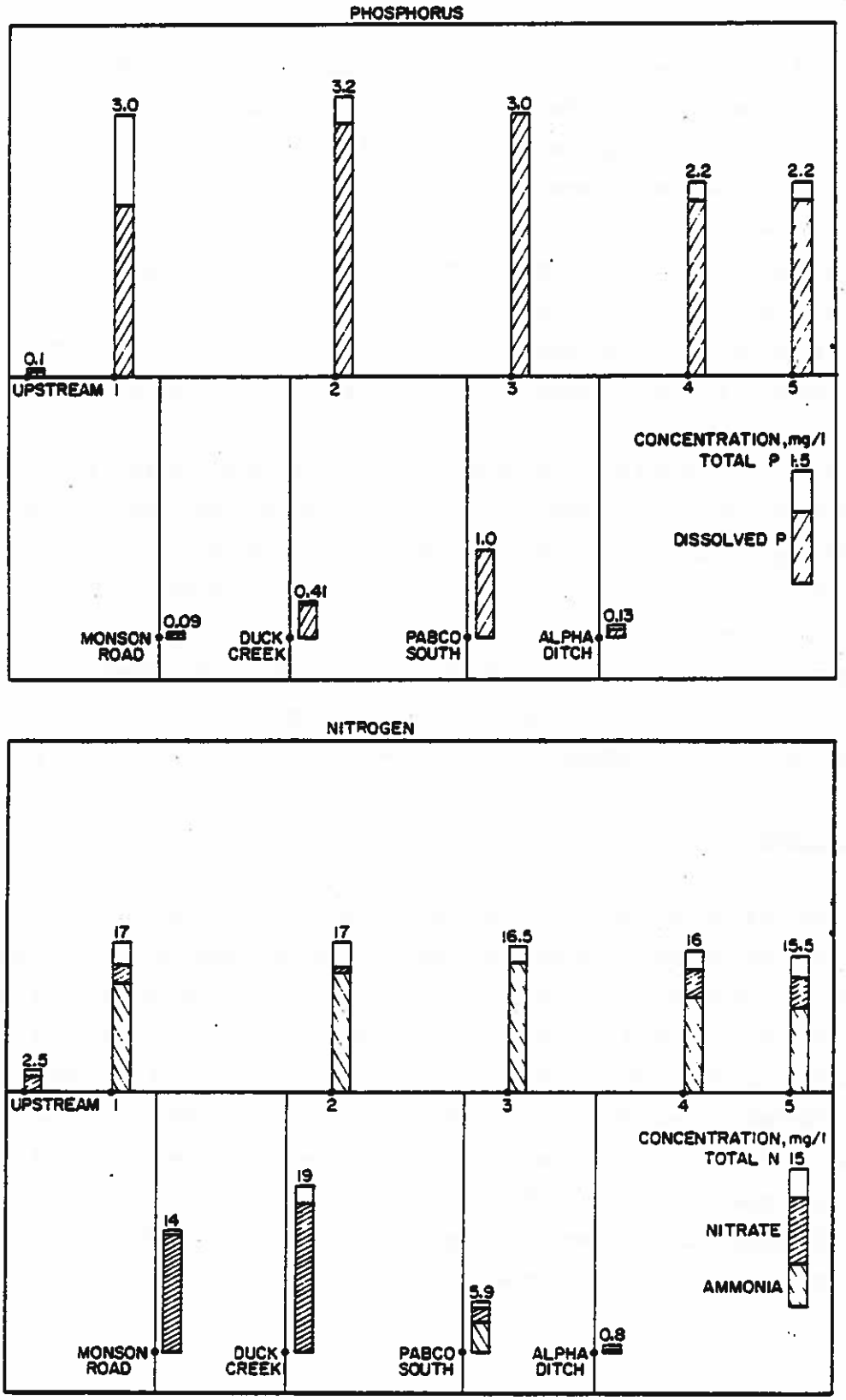


Figure 6-18 Comparison of Nutrient Concentrations in Other Surface Water Sources to Routine Station Concentrations

The total cumulative travel time for the 15 kilometers between the confluence and Lake Mead was 11.5 hours for the leading edge of the dye, and 18.2 hours for the peak concentration. The marshes and ponds located near Pabco Road had the effect of diluting the dye and increasing the longitudinal dispersion considerably.

Travel times are summarized on Figure 6-19. Dye released near the confluence showed that the major flow of treated wastewater remained on the north side of the marsh upstream of Pabco Road, rather than through the center of the marsh. This showed that Station 2 was in the main stream of the wash flow through the marsh. Some dye was detected in the flow emptying the central and southern portions of the marsh area; however, dye concentrations were roughly twenty times less than those on the north side. The travel time from the confluence to Pabco Road was 5.5 hours for the leading edge and 7 hours for the peak. The travel time of the peak through just the marsh portion was roughly 6 hours.

There are two ponds, separated by cattails, just downstream of Pabco Road. Dye released at Pabco Road started flowing out of the culvert emptying the first pond after 1 hour and the peak passed after an additional 20 minutes. Dye was still detected emptying out of the pond 12 hours later. Dye was detected at the culvert emptying the second pond approximately 5.5 hours after release and the peak passed after 9.5 hours. Dye was still detectable the next morning, 30 hours after release. The marsh below the ponds retained and diluted the dye a great deal. Trace amounts of dye were detectable just below the marsh at Station 3c, 3 hours after release from Pabco Road; however, the peak did not pass until after an additional 4 hours.

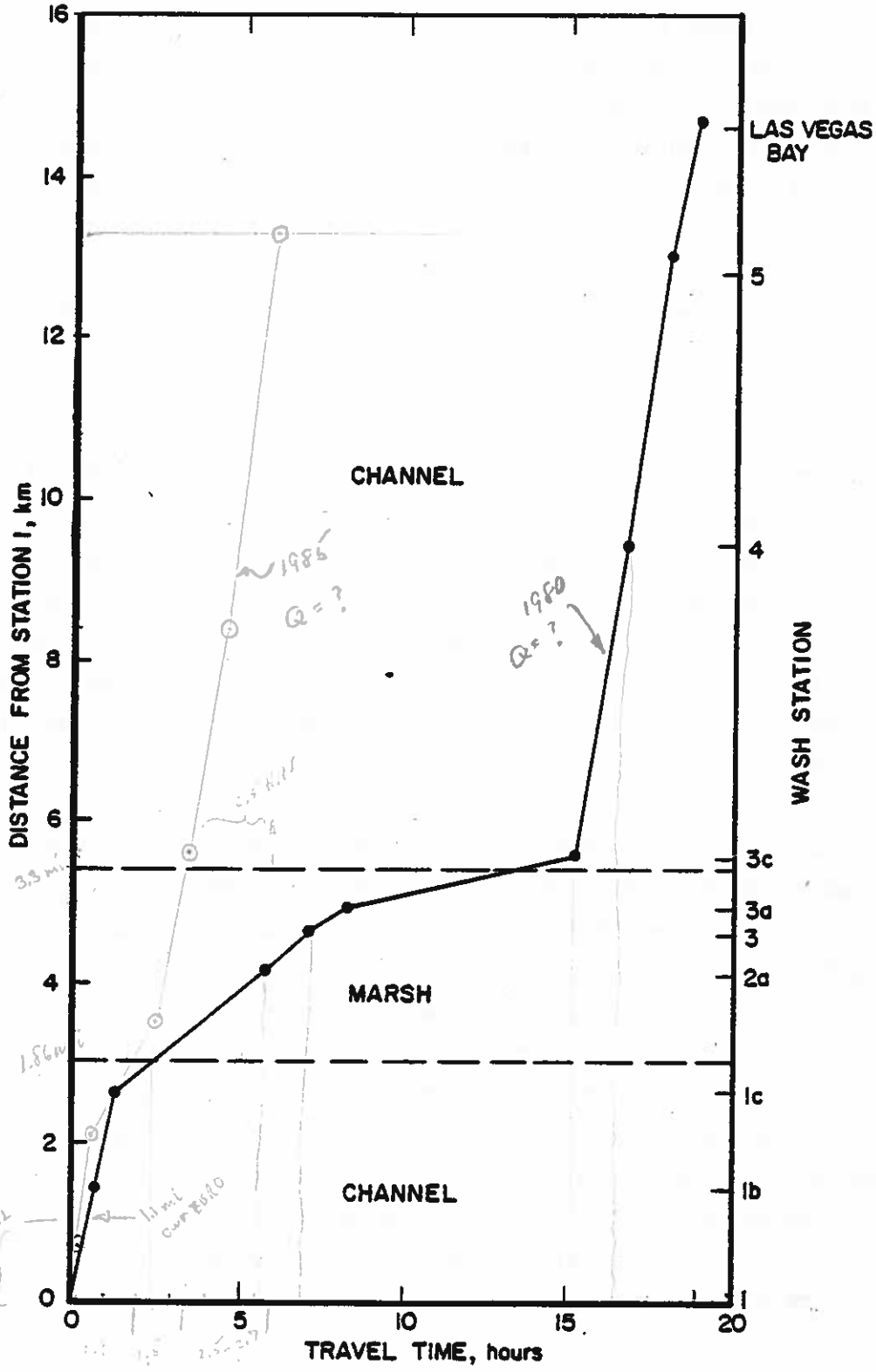


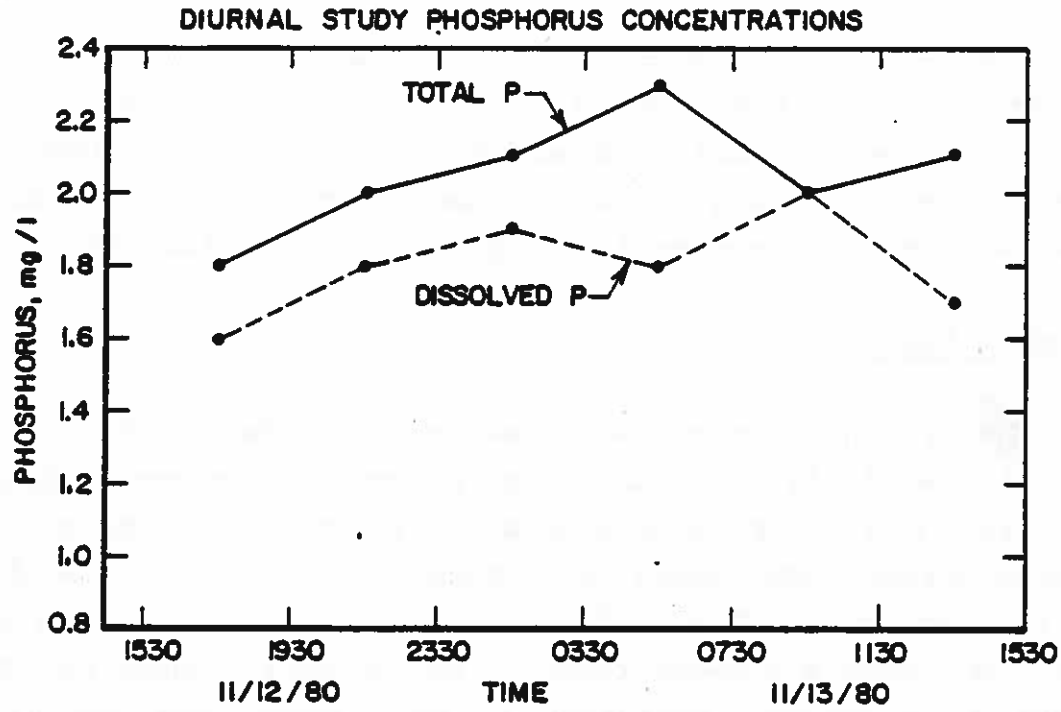
Figure 6-19 Travel Times in Las Vegas Wash

Dye released from Station 3c passed Station 4 1.5 hours after release and passed Northshore Road approximately 3 hours after release. Based on dye measurements made during the Hydraulic Study, travel time from Northshore Road to Las Vegas Bay in Lake Mead is approximately 40 minutes.

Diurnal Study

The diurnal study was designed to determine if there are large daily fluctuations in pollutant concentrations and loads at Northshore Road. Phosphorus and nitrogen concentrations are shown on Figure 6-20. During the 24-hour period, the total P concentration varied from 1.8 to 2.3 mg/l and the total N ranged from 12 to 15 mg/l. This represents about a 25 percent variation in both phosphorus and nitrogen concentrations. The lowest concentrations occurred early in the evening and the peak concentrations occurred early in the morning. The inorganic N concentration showed the same pattern as total N.

During the week of the intensive wash studies, temperature and dissolved oxygen measurements were taken at various sites throughout the wash whenever it was possible to do so. Since the field work was generally conducted from 6 a.m. to 6 p.m., there are no measurements during the night. Figure 6-21 presents the results of this survey at the routine stations. For the few measurements that were taken, the DO concentrations remained relatively constant at 5 to 6 mg/l at Station 1, 1 mg/l at Station 2, and 1 to 2 mg/l at Station 3. The DO concentrations were generally near 7 mg/l at Station 4 and 8 mg/l at Station 5.



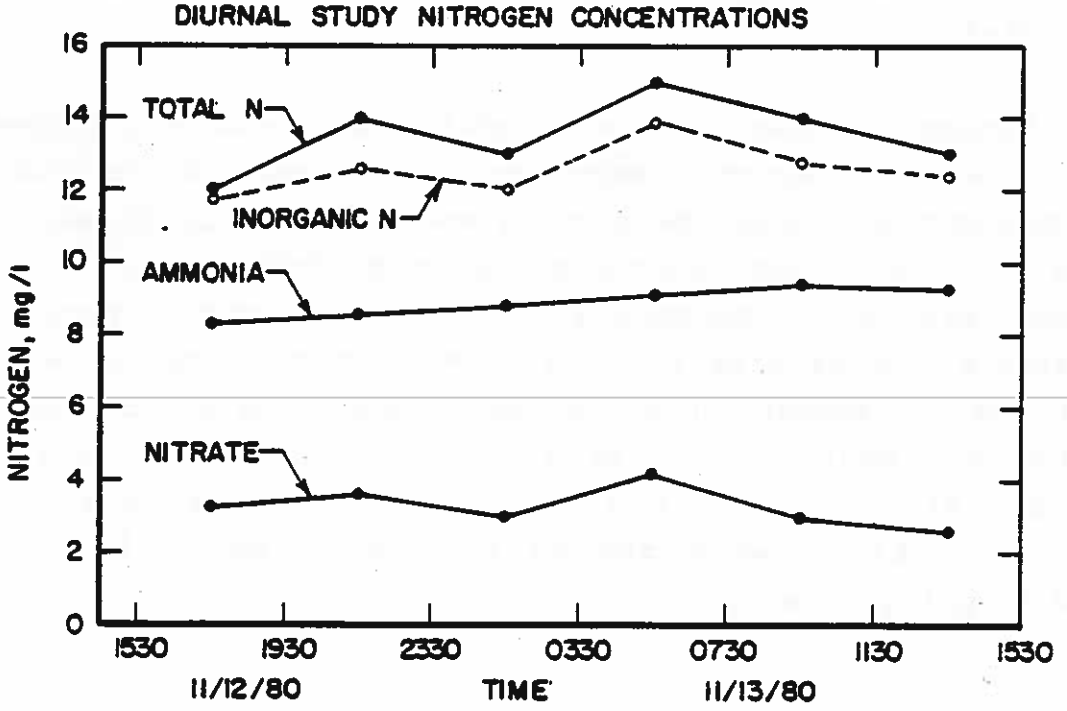


Figure 6-20 Phosphorus and Nitrogen Concentrations at Northshore Road During the Diurnal Study

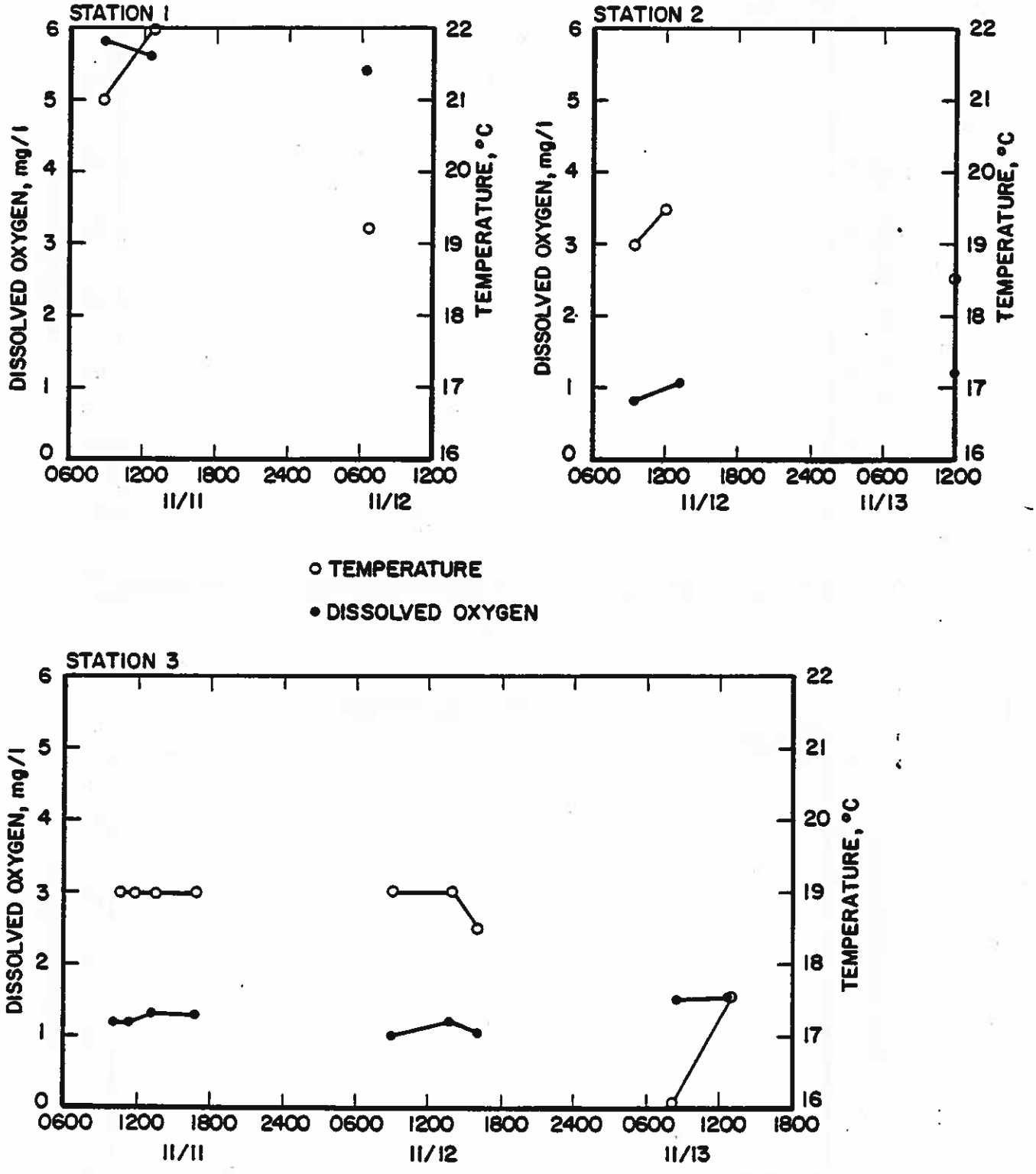


Figure 6-21 Diurnal Dissolved Oxygen and Temperature Survey

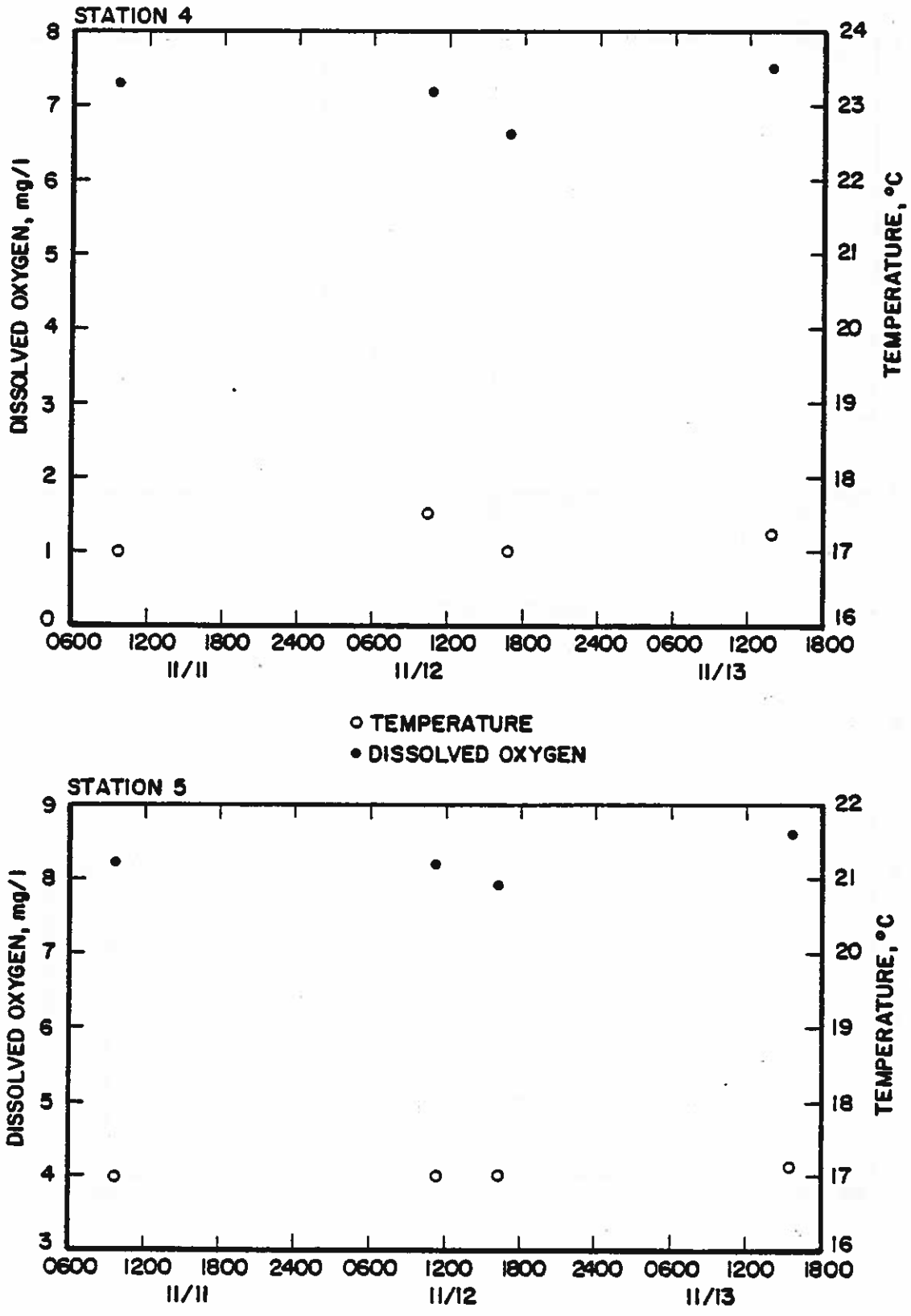


Figure 6-21 (Continued) Diurnal Dissolved Oxygen and Temperature Survey

Groundwater Sampling Program

A limited groundwater sampling program was conducted in January 1981. Six wells located throughout the wash were sampled three times. The samples were analyzed for physical parameters and dissolved nutrients. Figure 6-22 presents the average nutrient concentrations measured in the wells. The soluble orthophosphorus and dissolved phosphorus concentrations were always less than 0.01 mg/l in all of the wells. The low phosphorus concentrations were expected since phosphorus sorbs onto soil particles. The mean nitrate concentration ranged from 0.08 mg/l to 14 mg/l. The higher nitrate concentrations were found downstream of Pabco Road and in the vicinity of Duck Creek. The mean nitrite concentrations ranged from less than 0.01 mg/l to 0.15 mg/l. The higher nitrite concentrations were also found in the lower wash.

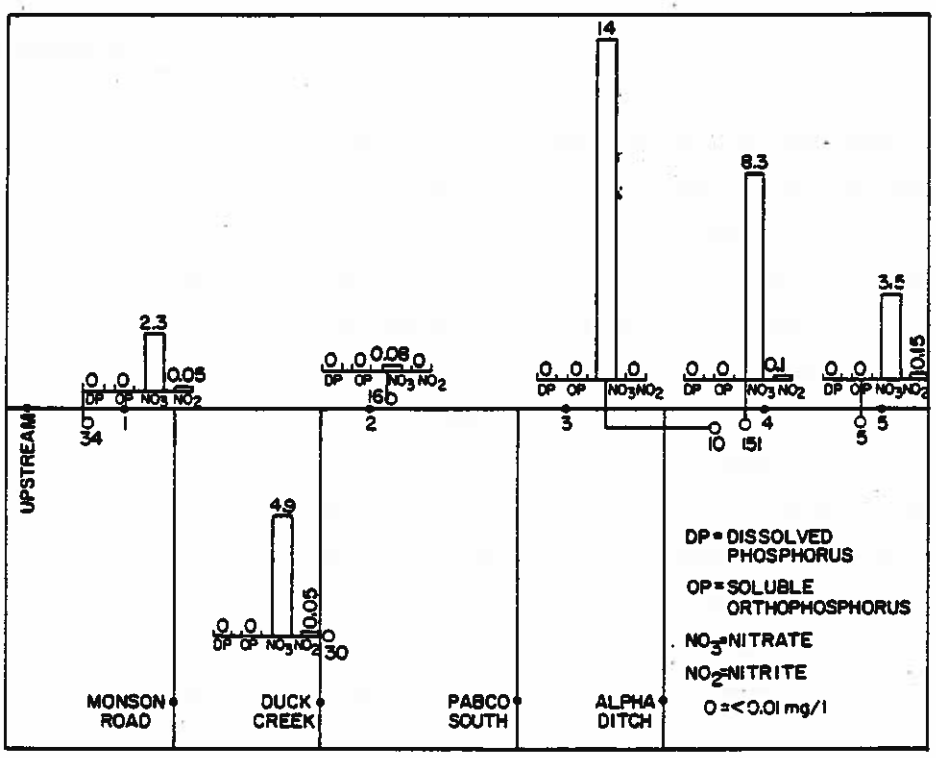


Figure 6-22 Average Groundwater Nutrient Concentrations

Ammonia Adsorption/Nitrification Study

Two experiments were conducted to determine if the Las Vegas Wash sediments would adsorb ammonia. In the first experiment, sediments from the stream bed and from the cliff above the water level were mixed with wash water. A control sample that contained wash water without sediment was also set up. Table 6-4 shows the mixtures of wash water and sediment used in the first experiment.

Table 6-4. Sediment Concentrations Used in First Ammonia Adsorption Experiment

Number of samples	Volume of wash water, mls	Concentration of sediment, mg/l	Source of sediment
2	250	0	
2	250	2,000	Cliff
2	250	2,000	Streambed

The samples were mixed in 500 ml polyethylene bottles and shaken on a mechanical shaker for 2 minutes each day for 8 days. The samples were stored at 20°C throughout the study. The ammonia concentration of each sample was determined initially, after 2 days, and after 8 days. Figure 6-23 presents the results of the experiment. The change in ammonia concentration in the control sample was equal to the change in the two samples containing sediment. This indicates that the decrease in the ammonia concentration in the wash water was not due to ammonia adsorption to sediment. The decrease in the ammonia concentration occurred primarily between the second and eighth days. The ammonia concentration should have decreased more rapidly if ammonia adsorption was a major removal mechanism.

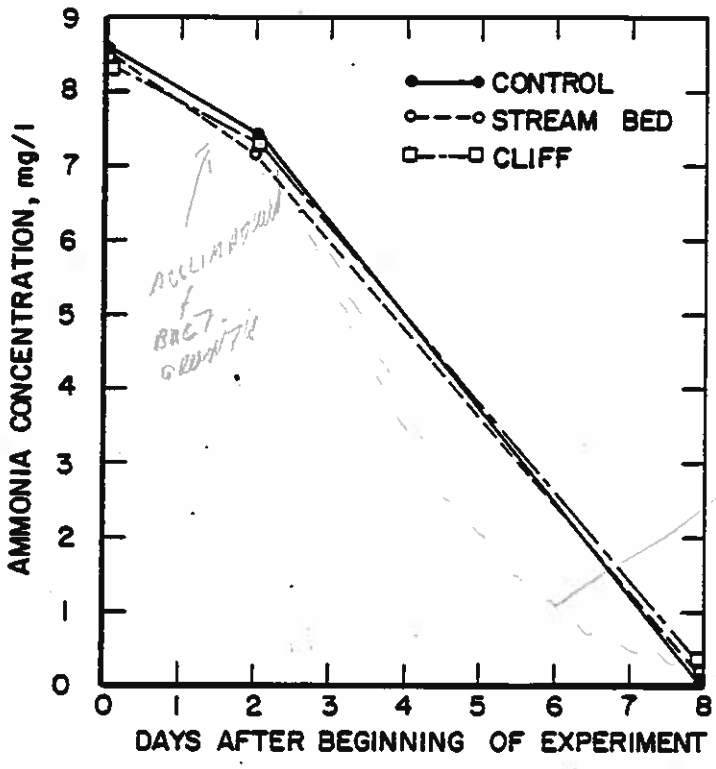


Figure 6-23 Results of First Ammonia Adsorption Experiment

In the second experiment, different concentrations of sediment from the streambed and the cliff above the stream were mixed with wash water from Station 4 as shown in Table 6-5.

Table 6-5. Sediment Concentrations Used in Second Ammonia Adsorption Experiment

Number of samples	Volume of wash water, mls	Concentration of sediment, mg/l	Source of sediment
1	250	0	Cliff
1	250	2,050	Cliff
1	100	4,890	Cliff
1	250	5,330	Cliff
1	250	103,000	Streambed
1	250	2,140	Streambed
1	100	4,580	Streambed
1	250	4,750	Streambed
1	250	93,400	Streambed

The ammonia concentration of each sample was determined twice on the first and second days and once on the third day of the experiment. The nitrate and nitrite concentrations of each sample were measured initially and on the second and third days of the experiment. Figure 6-24 shows the changes that occurred in the ammonia and nitrate plus nitrite concentrations over the three-day period. In each of the eight samples, the ammonia concentration decreased and the nitrate plus nitrite concentrations increased proportionately. The largest decrease in the ammonia concentration and increase in the nitrate plus nitrite concentration occurred in the cliff and streambed samples that had the highest sediment concentrations.

These two experiments indicate that ammonia adsoption is not currently the mechanism for ammonia removal in the lower wash. Nitrification, rather than ammonia adsorption, occurred in the laboratory over a three-day period. Up to 2 mg/l ammonia was converted to nitrate and nitrite in the first day. Since the travel time in the wash is about 20 hours, some amount of nitrification could be occurring in the wash.

SEE FIG 6-18

ANALYSIS

The data collected on Las Vegas Wash that were described in the Results section of this chapter are analyzed and discussed in this section.

1. The sources and sinks of water in the wash are described and a rough estimate of the wash water balance during 1980 is presented.

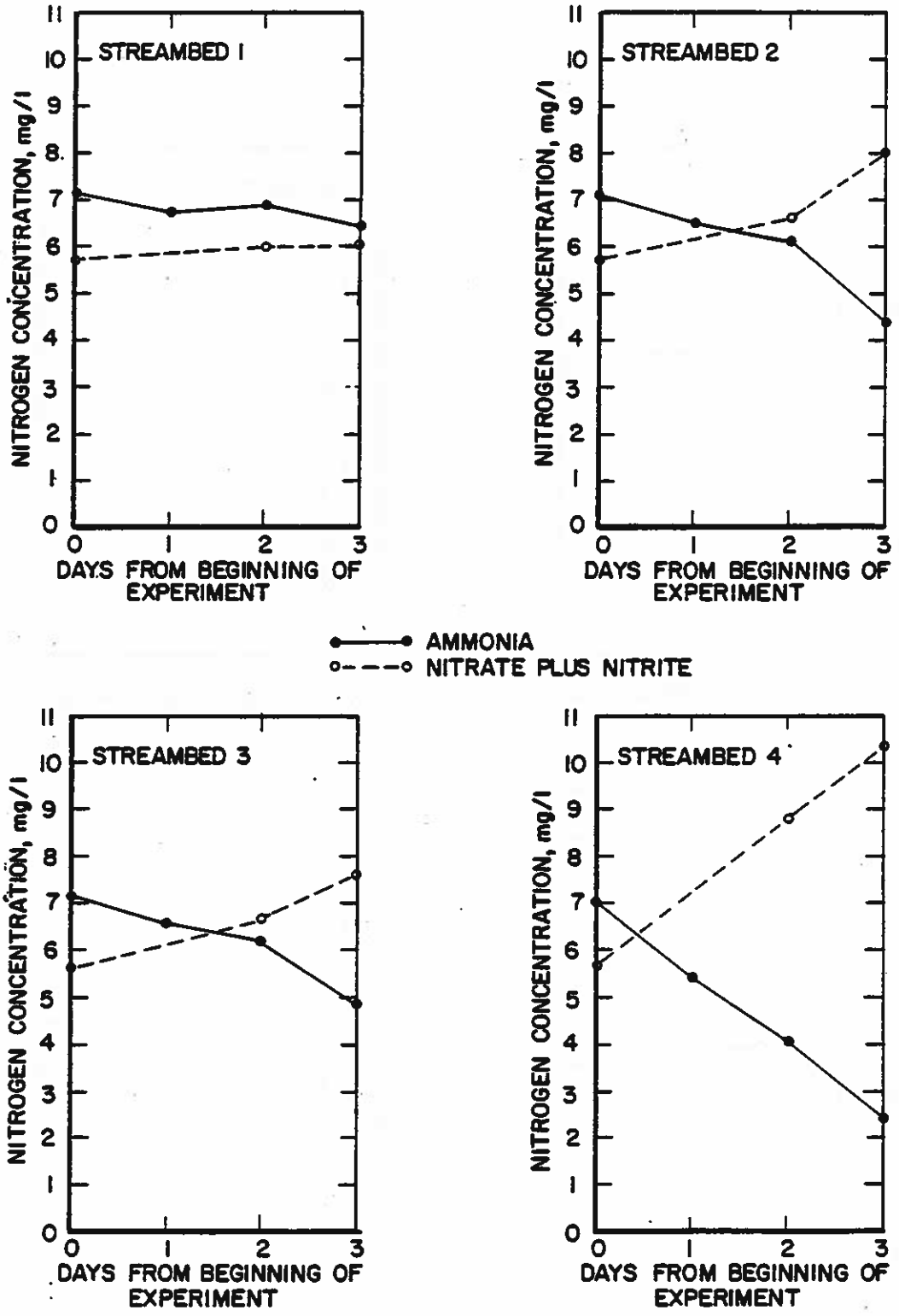


Figure 6-24 Results of Second Ammonia Adsorption Experiment

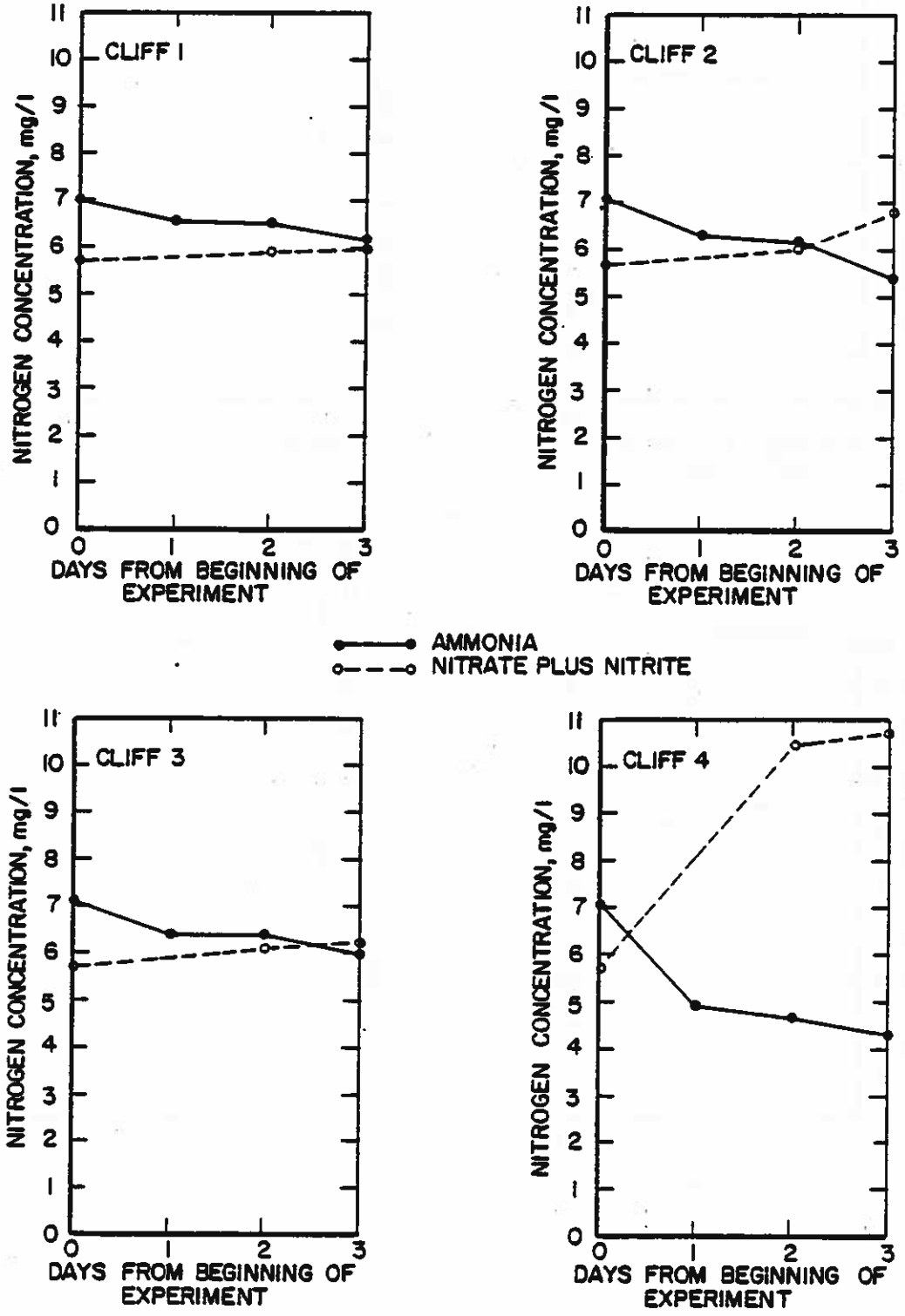


Figure 6-24 (Continued) Results of Second Ammonia Adsorption Experiment

2. The nutrient loads entering the wash from the wastewater treatment plants, other surface water sources, and groundwater are discussed.

3. The pollutant loads discharged to Las Vegas Bay from the wash at Northshore Road are described.

4. Pollutant removal in the wash and potential removal mechanisms are discussed.

5. Changes in salinity, temperature, and fecal coliform concentrations are discussed.

Water Balance

Treated wastewater effluent, surfacing groundwater, industrial cooling water, surface water, and stormwater runoff from the Las Vegas Valley all discharge to Las Vegas Wash. The industrial cooling water, surface water runoff and stormwater runoff enter the wash through the five other surface water sources (upstream Las Vegas Wash, Monson Road Floodway, Duck Creek, Pabco South, and Alpha Ditch) previously discussed. The major loss of water from the wash is evapotranspiration or consumptive use by wash plants.

Figure 6-25 is a schematic of water sources and sinks in the wash. Much of the information presented in this figure is from other sources since the WQSS was not designed to determine a water balance for Las Vegas Wash. During 1980, the average flows reported by the USGS were 83 cfs at Pabco Road and 102 cfs at Northshore Road.[3] The City and County Sanitation District

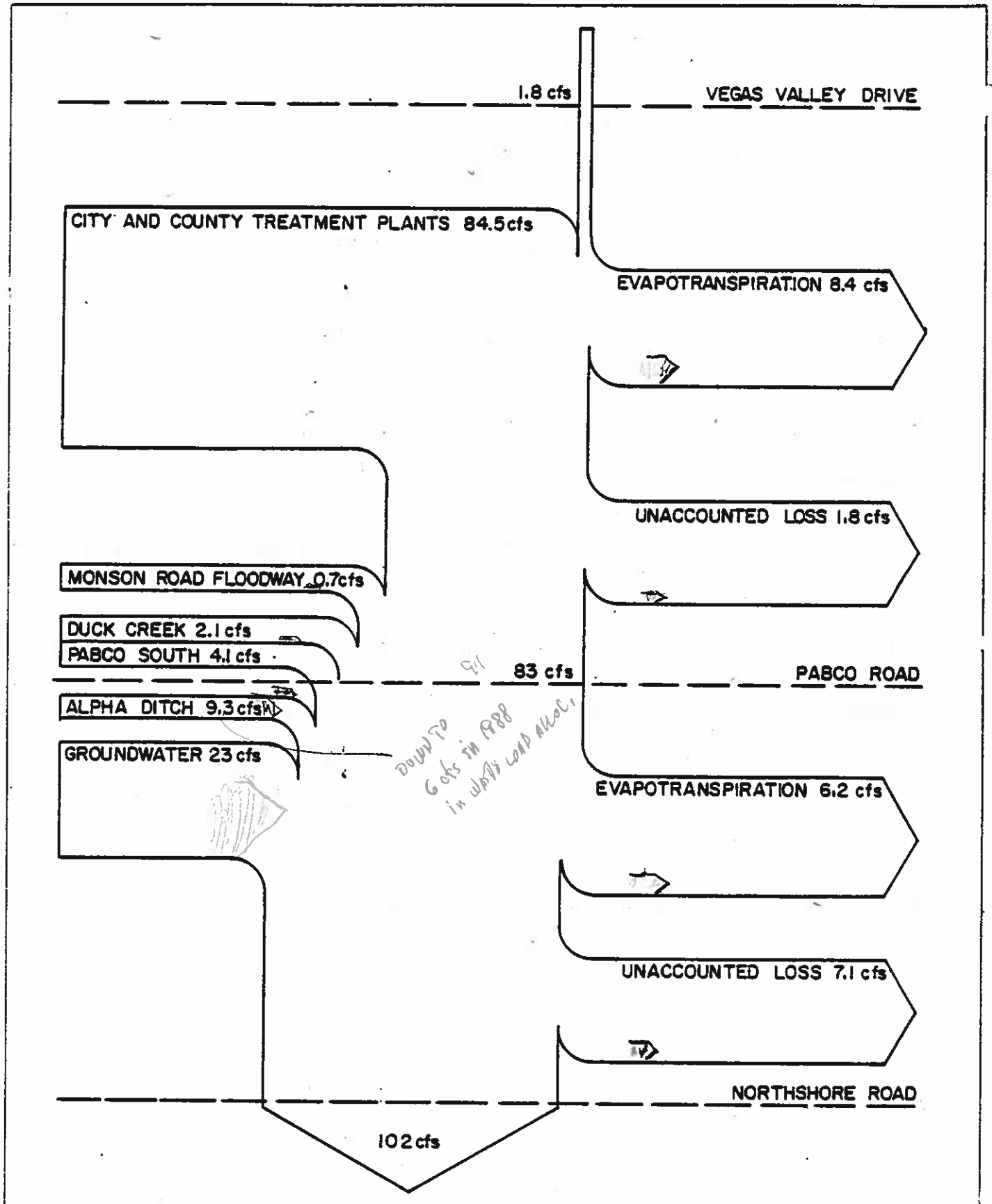


Figure 6-25 Las Vegas Wash Water Balance

treatment plants discharged 84.5 cfs to the wash during 1980.[4,5] Based on four measurements made between October and December 1980, the other surface water sources contributed 8.7 cfs above Pabco Road and 9.3 cfs downstream of Pabco Road. An estimate of 23 cfs of groundwater flowed into the wash downstream of Pabco Road in 1980. The URS Company reported that 13,100 acre feet/year or 18 cfs of groundwater flowed into Las Vegas Wash in 1975.[6] An estimate of 20,300 acre feet/year or 28 cfs is given for groundwater flow in 1985. By linear extrapolation it was estimated that 23 cfs of groundwater flowed into Las Vegas Wash in 1980. URS estimated evapotranspiration as 8.4 cfs above Pabco Road and 6.2 cfs below Pabco Road in 1976.[7] The extent of marsh vegetation has been drastically reduced by headcutting since 1976 but better estimates of evapotranspiration are not available. As shown on Figure 6-23 when the sources and sinks are added up, there is an unaccounted loss of 1.8 cfs above Pabco Road and 7 cfs below Pabco Road. As stated previously, many sources of information were used in this water balance and it is simply a rough estimate of the flows to and from the wash.

The wastewater treatment plants are the most significant source of water to Las Vegas Wash. The flows discharged to the wash from the treatment plants have increased steadily since 1970 as shown on Figure 6-26.[4,5,8] The flows discharged to the wash from the treatment plants increased from 37 cfs in 1970 to 85 cfs in 1980. The flows at Pabco Road and Northshore Road have also increased steadily with the increasing flows from the treatment plants. In 1980, the flows were 83 cfs at Pabco Road and 102 cfs at Northshore Road.

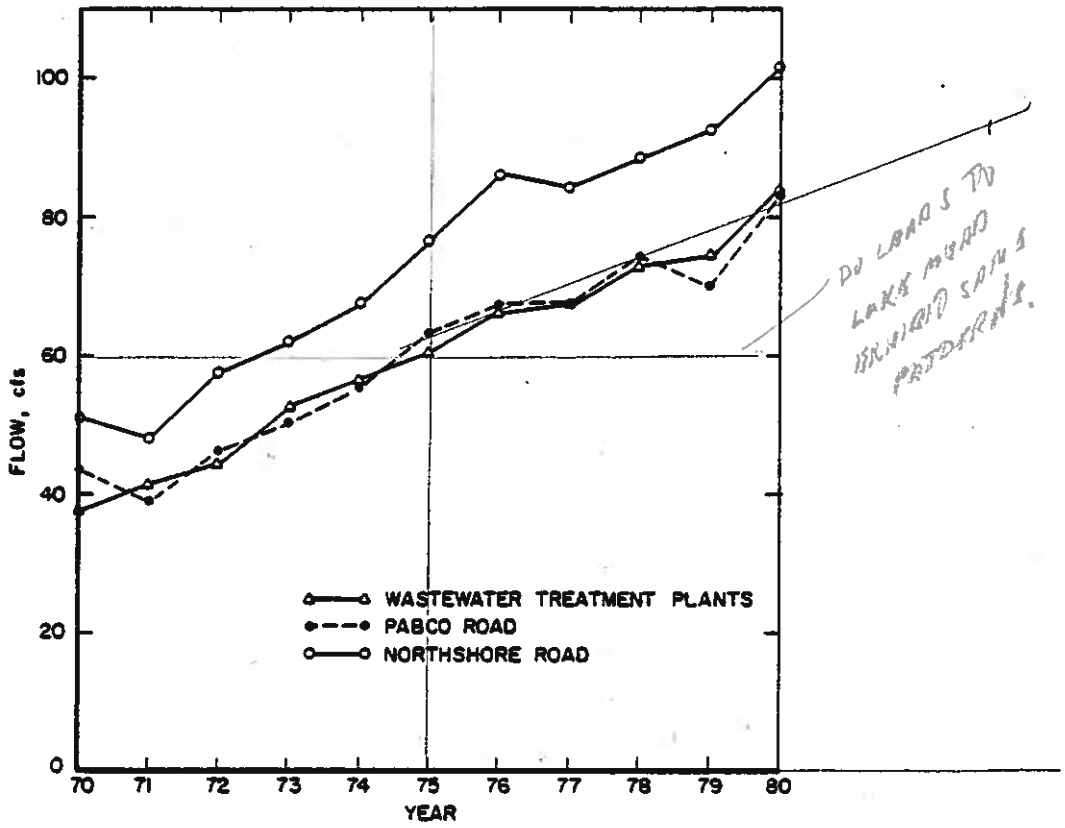


Figure 6-26 Average Annual Flows in Las Vegas Wash

Loads Entering Las Vegas Wash

Nitrogen and phosphorus enter Las Vegas Wash from the City and County Sanitation District wastewater treatment plants, other surface waters flowing into the wash, and groundwater. The basis for computing loads from these sources is presented in this section.

Wastewater Treatment Plant Loads. The City of Las Vegas and Clark County Sanitation District provided effluent nutrient concentrations and daily flows from the treatment plants each month during the study.[4,5] The amount of effluent diverted for reuse each month was also provided. The amount diverted for

reuse was subtracted from the effluent flow to determine an average daily flow to the wash for each week of the study. The average daily flow for each week was multiplied by the average weekly concentration to obtain an average daily load for each week of the study. Average daily loads for each month were calculated by taking the mean of the daily loads for the weeks in each month. The annual average daily loads were calculated by taking the mean of the daily loads for each month of the year.

The historical total P and total N loads from the treatment plants were calculated from the historical flows presented in the Phase I Treatment Facilities Study (TFS-I) report, adjusted for reuse, and from the average effluent concentrations of 7.2 mg/l P and 19 mg/l N reported by the URS Company.[6] The amount of reuse was assumed to be constant at 13 cfs from 1970 through 1978. This estimate was based on data provided by the Clark County Department of Comprehensive Planning[9] and EPA.[10] The historical reuse of 13 cfs is comparable to the 1979 reuse of 19 cfs and the 1980 reuse of 13 cfs. This method of calculating loads was used for every year between 1970 and 1978 for which no load data were available. Total P loads for 1971, 1972, and 1974 were presented by the URS Company.[7] According to the URS Company the average effluent ammonia concentration was 90 percent of the total N concentration.[6] During the WQSS, ammonia was typically about 80 percent of the total N concentration rather than the 90 percent reported by the URS Company. To calculate historical loads, the effluent ammonia concentration was assumed to be 85 percent of the total N concentration or 16 mg/l.

Figure 6-27 presents the total P loads from the treatment plants from 1970 to 1980. The total P load increased steadily from 640 kg/day in 1970 to 1,300 kg/day in 1978. The Clark County Sanitation District began adding chemical to reduce the BOD and suspended solids concentrations of the treatment plant effluent in 1979. The chemical addition also decreased the total P concentration of the effluent to 2 to 3 mg/l. This reduced the total P load from the wastewater treatment plants to the 1972 level of 850 kg/day in 1979 and 800 kg/day in 1980.

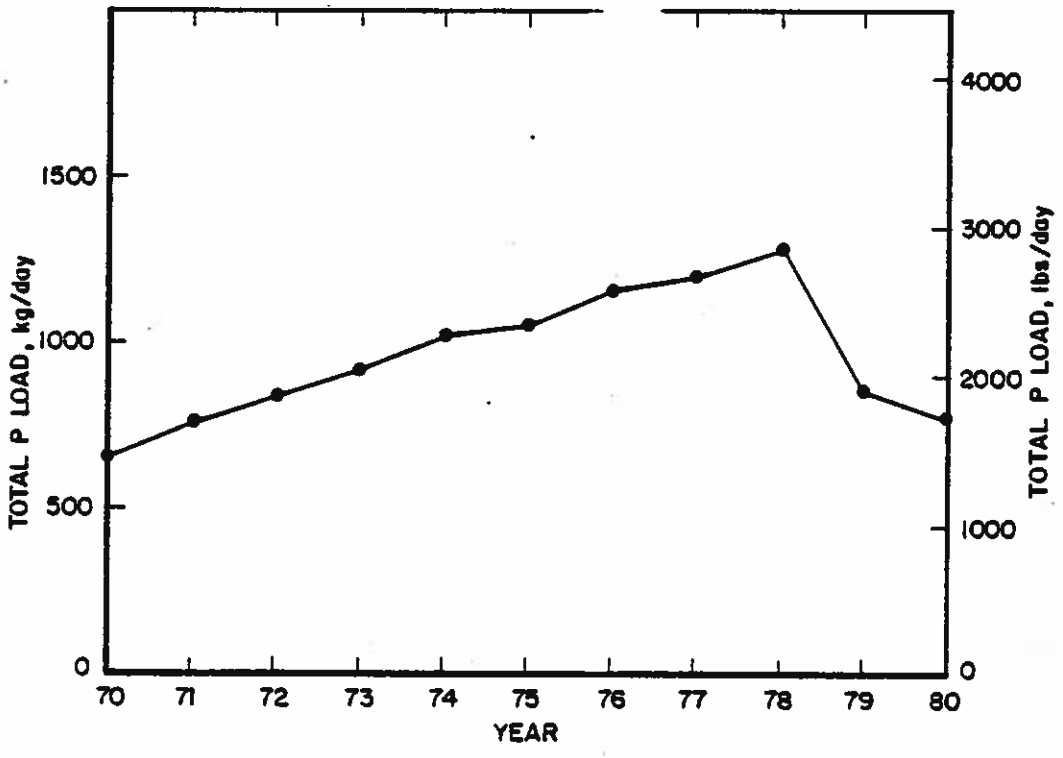


Figure 6-27 Total Phosphorus Loads to Las Vegas Wash from City and County Sanitation District Treatment Plants

The total nitrogen and ammonia loads from the wastewater treatment plants are presented on Figure 6-28. The total N loads increased steadily from 1,700 kg/day in 1970 to 4,100 kg/day in 1980. The ammonia loads increased from 1,400 kg/day in 1970 to 2,900 kg/day in 1978 and then decreased slightly in 1979. This apparent decrease is probably due to the method of calculating the historical loads. When the actual concentrations were used to calculate the load in 1979, there appeared to be a decrease in the ammonia load between 1978 and 1979. The ammonia load increased to 3,400 kg/day in 1980.

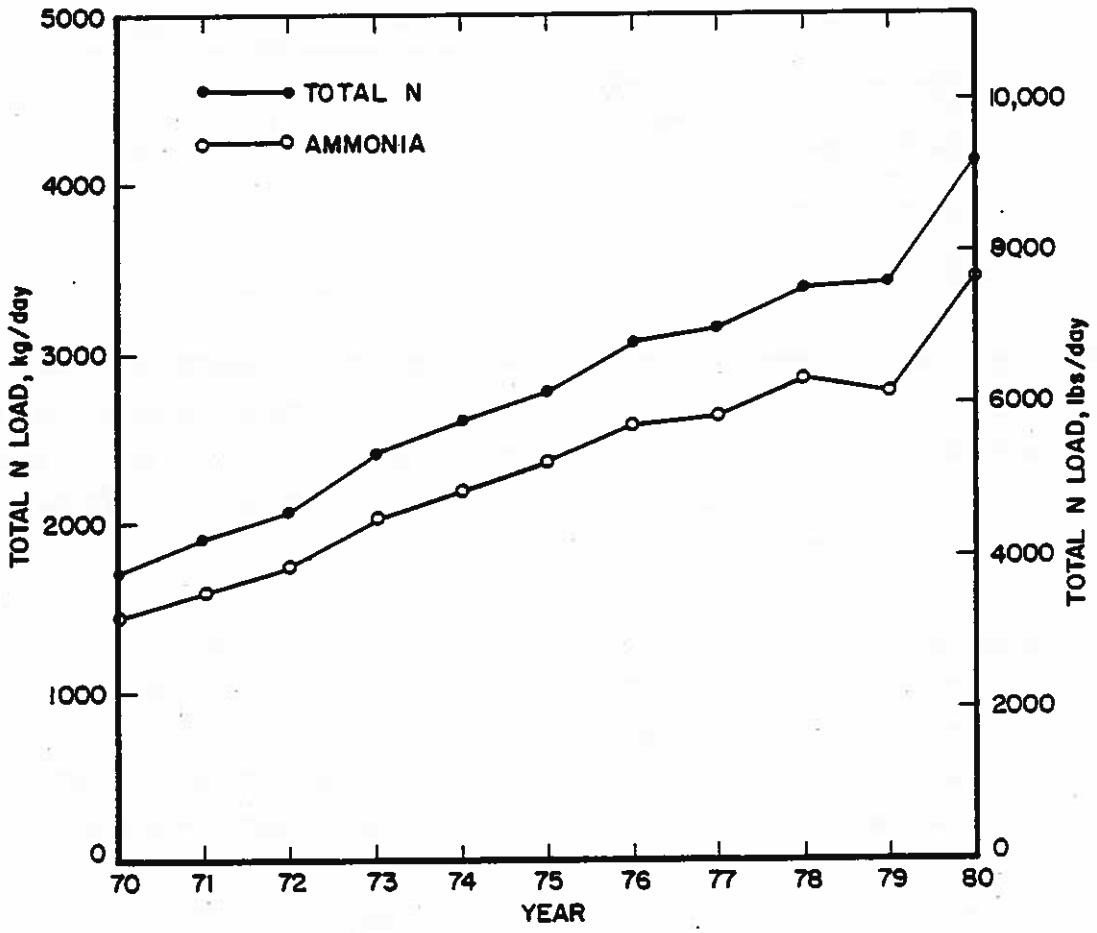


Figure 6-28 Total Nitrogen and Ammonia Loads to Las Vegas Wash from City and County Sanitation District Treatment Plants

Other Surface Water Sources Loads. Samples were collected four times from upstream Las Vegas Wash, Monson Road Floodway, Duck Creek, Pabco South, and Alpha Ditch in the fall of 1980. The nutrient concentrations and flows from each sampling trip were averaged and average total P and total N loads were calculated for each stream. The loads are presented in Table 6-6.

Table 6-6. Nutrient Loads From Other Surface Water Sources

Stream	Load, kg/day	
	Total P	Total N
Upstream Las Vegas Wash	0.5	10
Monson Road Floodway	0	24
Duck Creek	2	100
Pabco South	9	57
Alpha Ditch	3	16
Total	14.5	207

The nutrient loads entering the wash from these streams were extremely low during the fall of 1980. Since samples were not collected during other times of the year or during storm events, the annual contribution of nutrients to the wash from these sources is unknown.

Groundwater. This study was not designed to determine the nutrient loads to the wash from groundwater; however, an estimate of the loads was made from the limited data available. As discussed previously, it was assumed that 23 cfs of groundwater flowed into the wash downstream of Pabco Road in 1980. The average concentrations of nutrients in the three wells downstream of Pabco Road were used to calculate the load from groundwater. The dissolved P concentrations in the three

wells were always less than the detection limit (0.01 mg/l). It was assumed that the total P concentration in groundwater was 0.01 mg/l. This concentration was multiplied by the flow of 23 cfs to obtain a total P load of 1 kg/day. The average nitrate concentration in the three wells was 8.6 mg/l and the average nitrite concentration was 0.09 mg/l. It was assumed that no other forms of nitrogen were present in the groundwater so the total N concentration in the groundwater was assumed to be 8.7 mg/l. This concentration was multiplied by the flow of 23 cfs to obtain a total N load of 480 kg/day.

Table 6-7 summarizes the total P and total N loads from the three major sources of nutrients to Las Vegas Wash in 1980. The surface water and groundwater loads are rough estimates in comparison to the treatment plant loads which were calculated from a large data base. The wastewater treatment plants contributed 98 percent of the phosphorus and 86 percent of the nitrogen to Las Vegas Wash during 1980. Other surface water sources contributed 2 percent of the phosphorus and 4 percent of the nitrogen, and groundwater contributed 10 percent of the nitrogen.

Table 6-7. Nutrient Loads Entering Las Vegas Wash in 1980

Source	Total P		Total N	
	Load, kg/day	Percent of total load	Load, kg/day	Percent of total load
Treatment plants	788	98	4,146	86
Surface water	15	2	207	4
Groundwater	1	0	480	10
Total	804	100	4,833	100

Loads at Northshore Road

Northshore Road has historically been the regulatory control point for water quality standards for Las Vegas Wash. Prior to the Consent Decree there was a phosphorus load standard of 400 lbs/day at Northshore Road.[11] This standard was established to protect the beneficial uses of Lake Mead.

This section presents the methods used to calculate loads at Northshore Road during the WQSS. The WQSS loads and the historic loads at Northshore Road and removals in the wash are presented. A detailed discussion of pollutant removals in the wash during the WQSS is presented in the following section, Water Quality Transformations.

Methodology. The USGS flow data and the WQSS nutrient and BOD concentration data at Northshore Road were used to calculate the nutrient and BOD loads to Lake Mead. Flow was continuously monitored by USGS at Northshore Road throughout the WQSS with a few exceptions when the equipment malfunctioned. No flow measurements are available during the Februry 1980 storm because the gaging station was destroyed by the high flows. Nutrient and BOD concentrations were generally determined every two weeks from July 1979 through December 1980. The USGS and WQSS data and data collected during the Clark County stormwater monitoring program[12] were analyzed to determine the most appropriate method of calculating pollutant loads since continuous concentration data were not available. A detailed description of this analysis is presented in Appendix E and a summary of the analysis is presented in this section.

A number of factors were considered in determining the most appropriate method of calculating pollutant loads to Las Vegas Bay.

1. Diurnal variations in flows and concentrations.

2. Weekly variations in flows and concentrations.

3. Pollutant loads during storms.

Each of these factors was analyzed. The results of the analysis are presented below.

Diurnal Variations--During the WQSS sampling program, hourly samples were collected at Northshore Road with an Isco automatic sampler and composited to produce a 24-hour composite sample. Flow proportional samples were not collected. The diurnal study total N and total P data were analyzed to determine if the flow proportional loads differed from the load determined by averaging the concentrations in the six diurnal samples and multiplying by the daily flow. The flow proportional load was determined by multiplying the concentration during a four-hour period by the flow during that period. The loads calculated by both methods were equal for both total N and total P. This indicates that under normal flow conditions the composite sample collected during the WQSS produced representative concentration data.

Weekly Variations--The flow data collected during the week of the intensive study (November 9 to November 15, 1980) indicate that during normal flow conditions the same general flow pattern exists each day of the week. Samples were not collected every day of the week for nutrient analyses, so it was not possible to determine if there were weekly

variations in nutrient loads. If the relationship between nutrient concentrations and flows found during the diurnal study applies during normal flow conditions, the flow data is indicative of the general pattern in nutrient loads.

Pollutant Loads During Storms--The stormwater data collected by the Clark County Department of Comprehensive Planning and data collected during storms as part of the routine wash monitoring program were analyzed to determine if there was a consistent relationship between the pollutant concentrations and flows that could be used to predict pollutant concentrations during storms for which there were no data. The dissolved nutrients were consistently lower than average during the storms. The total P and total N were lower than average during some storms and higher than average during others. It was concluded that there was no consistent relationship between concentrations of pollutants and stormwater flows.

Most samples were collected under normal flow conditions, during the routine wash monitoring program. Samples were rarely collected during storms. If the pollutant loads were calculated by multiplying the concentration on the sampling day by the flow on the sampling day, the pollutant loads during storms would be excluded from the load calculation. It was determined that the most appropriate method of calculating loads was to multiply the average concentration during the month by the average monthly flow. This method includes storm flows; however, the concentration data were usually collected during normal flow conditions.

Water Quality Standards Study Loads. The phosphorus, nitrogen, and BOD loads during the WQSS are presented in this section.

Phosphorus--The average daily total P and dissolved P loads during each month of the WQSS are presented on Figure 6-29. The total P loads fluctuated from month to month and there was an overall increasing trend in the loads during the study. The average monthly total P loads were generally between 300 and 500 kg/day during 1979 and between 400 and 700 kg/day during 1980. During February and March 1980, there were severe storms that washed large amounts of particulate P out of the wash. The total P load during these two months increased to 1,200 kg/day in February and 1,450 kg/day in March, but the dissolved P load remained near 400 kg/day. The monthly loads of total, dissolved, and soluble orthophosphorus are presented in Table 6-8.

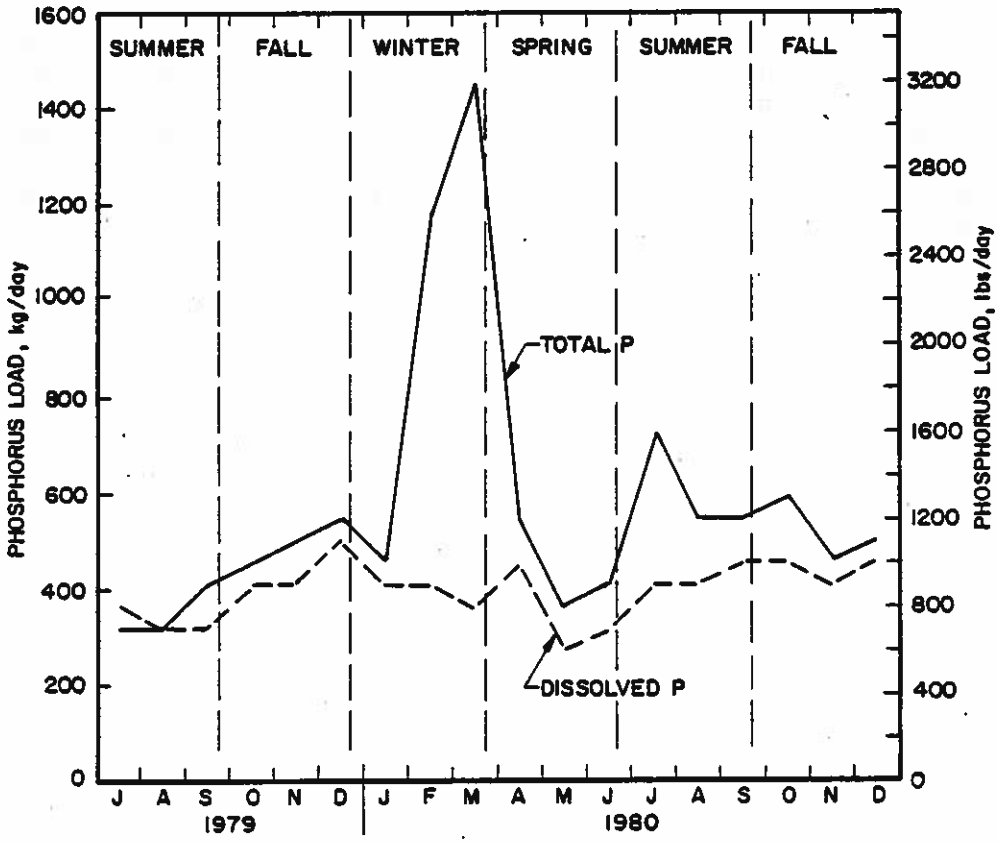


Figure 6-29 Phosphorus Loads at Northshore Road During the WQSS

Table 6-8. Average Daily Phosphorus Loads at Northshore Road

Month	Total phosphorus load		Dissolved phosphorus load		Soluble orthophosphorus load	
	lbs/day	kg/day	lbs/day	kg/day	lbs/day	kg/day
07/79	800	350	800	350	800	350
08/79	700	300	700	300	700	300
09/79	900	400	700	300	700	300
10/79	1,000	450	900	400	900	400
11/79	1,100	500	900	400	900	400
12/79	1,200	550	1,100	500	1,100	500
01/80	1,000	450	900	400	800	350
02/80	2,600	1,200	900	400	900	400
03/80	3,200	1,450	800	350	800	350
04/80	1,200	550	1,000	450	1,000	450
05/80	800	350	600	250	600	250
06/80	900	400	700	300	700	300
07/80	1,600	700	900	400	800	350
08/80	1,200	550	900	400	800	350
09/80	1,200	550	1,000	450	1,000	450
10/80	1,300	600	1,000	450	1,000	450
11/80	1,000	450	900	400	700	300
12/80	1,100	500	1,000	450	1,000	450
WQSS average	1,250	550	900	400	850	350

Nitrogen--The average daily total N, ammonia, and nitrate loads during each month of the WQSS are presented on Figure 6-30. The total N load increased during the first few months of the study and then fluctuated between 2,800 and 4,000 kg/day for the remainder of the study. The February and March storms that washed so much particulate P into the wash had no effect on the total N load. In general, the ammonia load increased during the study period. The load ranged from 1,400 to 2,700 kg/day. The highest loads occurred during the winter and spring. The nitrate

load ranged from 200 to 1,600 kg/day. The highest load occurred during November 1979, and may have been due to a leak in a BMI pipline. The total and inorganic nitrogen, ammonia, nitrate, and nitrite monthly loads are presented in Table 6-9.

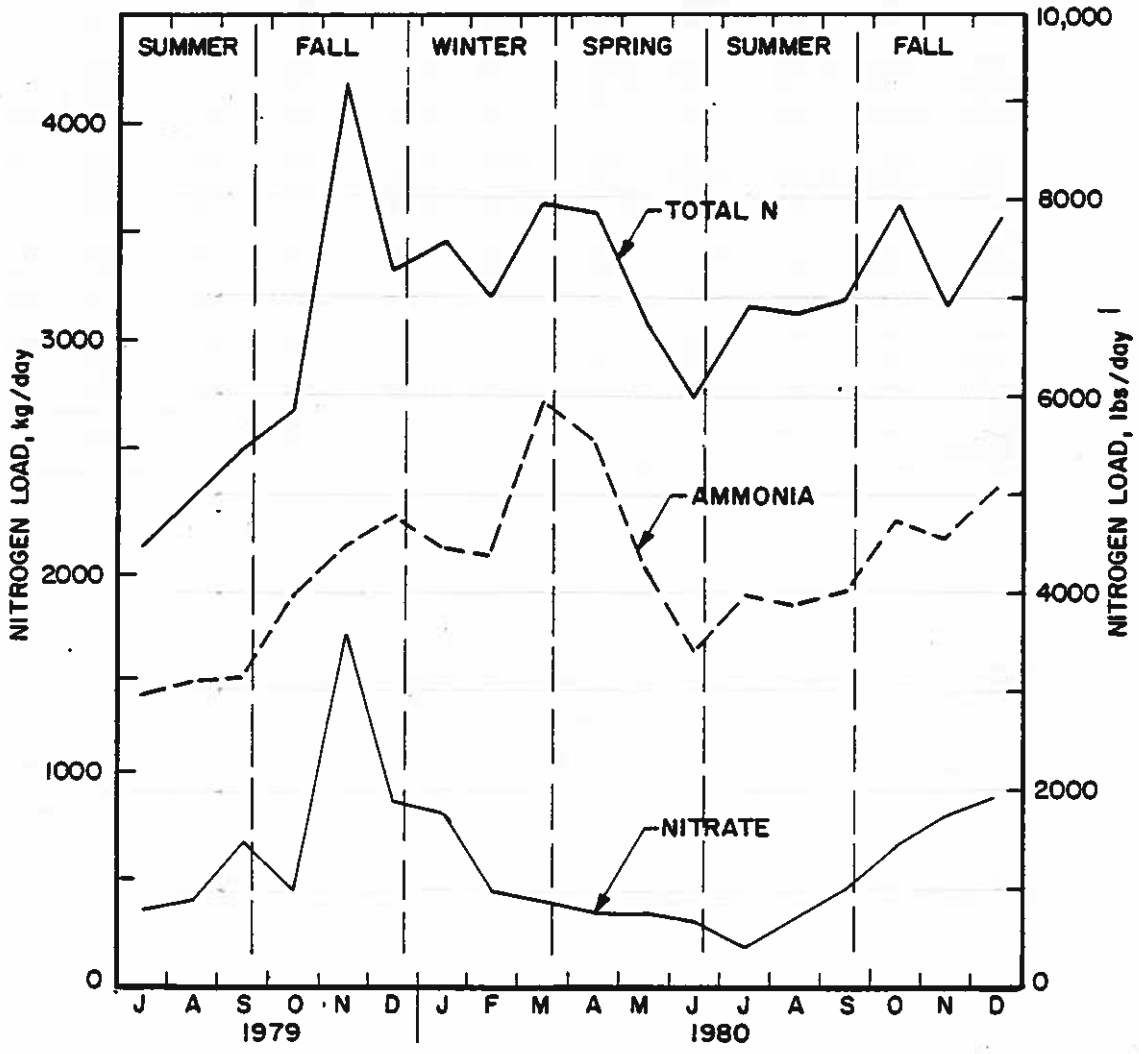


Figure 6-30 Nitrogen Loads at Northshore Road During the WQSS

Table 6-9. Average Daily Nitrogen Loads at Northshore Road

Month	Total nitrogen load		Inorganic nitrogen load		Ammonia load		Nitrate load		Nitrite load	
	lbs/day	kg/day	lbs/day	kg/day	lbs/day	kg/day	lbs/day	kg/day	lbs/day	kg/day
07/79	4,500	2,000	4,000	1,800	3,000	1,350	800	350	200	100
08/79	5,000	2,250	4,700	2,100	3,100	1,400	900	400	700	300
09/79	5,500	2,500	4,900	2,250	3,100	1,400	1,500	650	400	200
10/79	5,900	2,650	5,800	2,600	4,000	1,800	1,000	450	800	350
11/79	9,200	4,150	8,500	3,800	4,500	2,000	3,600	1,600	400	200
12/79	7,300	3,300	6,900	3,150	4,800	2,150	1,900	850	300	150
01/80	7,600	3,400	6,700	3,000	4,500	2,000	1,800	800	400	200
02/80	7,000	3,150	5,800	2,600	4,400	2,000	1,000	450	300	150
03/80	8,000	3,600	7,100	3,200	6,000	2,700	900	400	200	100
04/80	7,900	3,550	6,700	3,000	5,600	2,500	800	350	300	150
05/80	6,800	3,050	5,500	2,500	4,300	1,950	800	350	400	200
06/80	6,000	2,700	4,700	2,100	3,400	1,550	700	300	600	250
07/80	6,900	3,100	5,100	2,250	4,000	1,800	400	200	600	250
08/80	6,800	3,050	5,500	2,550	3,900	1,750	700	300	1,100	500
09/80	7,000	3,150	6,100	2,750	4,000	1,800	1,000	450	1,100	500
10/80	8,000	3,600	7,300	3,300	4,800	2,150	1,400	650	1,100	500
11/80	6,900	3,100	6,400	2,900	4,600	2,050	1,700	750	200	100
12/80	7,800	3,500	7,300	3,350	5,100	2,300	1,900	850	400	200
WQSS average	6,900	3,100	6,100	2,750	4,300	1,950	1,300	550	500	250

BOD--The average daily total BOD_5, carbonaceous BOD, and nitrogenous BOD loads during each month of the WQSS are presented on Figure 6-31. The total BOD load decreased steadily during the study period. During the summer and fall of 1979, the total BOD_5 load ranged from 3,500 to 6,300 kg/day. During the summer and fall of 1980, the

total BOD load ranged from 2,200 to 3,900 kg/day. The carbonaceous BOD fluctuated from one sampling trip to the next, but there were no seasonal trends in the data. The carbonaceous BOD load ranged from 1,200 to 3,000 kg/day. The nitrogenous BOD load ranged from 250 to 2,700 kg/day. The lowest loads were found during the summer of 1980. The monthly loads of total, carbonaceous, and nitrogenous BOD are presented in Table 6-10.

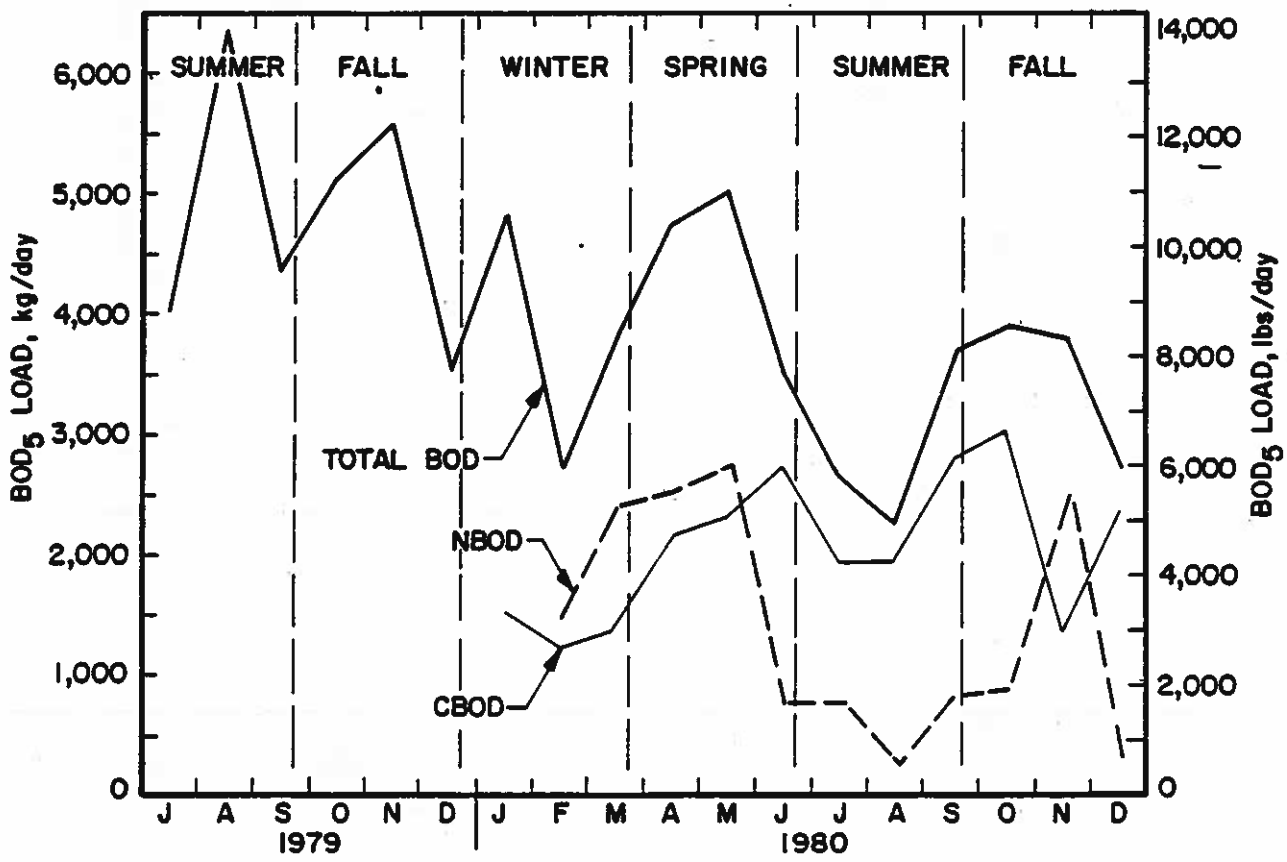


Figure 6-31 BOD_5 Load at Northshore Road

Table 6-10. Average Daily BOD_5 Loads at Northshore Road

Month	Total BOD load		Carbonaceous BOD load		Nitrogenous BOD load	
	lbs/day	kg/day	lbs/day	kg/day	lbs/day	kg/day
07/79	8,800	3,950				
08/79	13,950	6,250				
09/79	9,500	4,300				
10/79	11,200	5,050				
11/79	12,200	5,500				
12/79	7,800	3,500				
01/80	10,600	4,750	3,300	1,500		
02/80	5,900	2,650	2,700	1,200	3,200	1,450
03/80	8,400	3,750	3,000	1,350	5,300	2,400
04/80	10,400	4,650	4,800	2,150	5,500	2,500
05/80	11,000	4,950	5,000	2,250	6,000	2,700
06/80	7,600	3,450	6,000	2,700	1,700	750
07/80	5,800	2,650	4,200	1,900	1,700	750
08/80	4,800	2,200	4,300	1,950	500	250
09/80	8,000	3,550	6,100	2,750	1,800	800
10/80	8,500	3,850	6,700	3,000	1,900	850
11/80	8,300	3,800	2,900	1,300	5,500	2,500
12/80	5,900	2,600	5,100	2,300	700	300
WQSS average	8,800	3,950	4,500	2,000	3,100	1,400

Historic Loads and Removal. The average daily loads of nitrogen at Northshore Road from 1974 to 1980 and phosphorus from 1973 to 1980 were calculated from the USGS flow and nutrient data. Average daily loads were calculated for each month that data were available. The average monthly values were then used to calculate the average daily load for each year. The loads at Northshore Road are compared to the historic treatment plant loads to determine the amount of removal that historically occurred in the wash.

Historic Loads--Figure 6-32 shows the phosphorus loads from 1973 to 1980 at Northshore Road. The total P load increased from 700 kg/day in 1973 to 900 kg/day in 1977. The load decreased steadily to 500 kg/day in 1979 and then increased to 700 kg/day in 1980. The total nitrogen, ammonia, and nitrate loads from 1974 to 1980 at Northshore Road are presented on Figure 6-32. The total N load decreased from 2,400 kg/day in 1974 to 1,500 kg/day in 1977 and then increased dramatically to 3,700 kg/day in 1980. The ammonia load was relatively constant at 100 kg/day from 1974 to 1976, increased to 200 kg/day in 1977 and then increased steadily to 2,100 kg/day in 1980. During this period, the nitrate load decreased steadily from 1,700 kg/day in 1974 to 500 kg/day in 1980.

Data Comparisons--The USGS nutrient data were used to calculate the loads during 1979 and 1980, as shown on Figure 6-32, for the sake of consistency even though WQSS data were available. The annual average WQSS phosphorus and nitrogen loads are shown on Figure 6-32 for comparison. The total P loads calculated from WQSS data were only slightly lower than the loads calculated from the USGS data. The WQSS total N load was about 15 percent higher than the USGS load in 1979 and about 15 percent lower than the USGS load in 1980. The ammonia, nitrate, and nitrite loads calculated from the WQSS data were almost identical to the USGS loads during 1979 and 1980

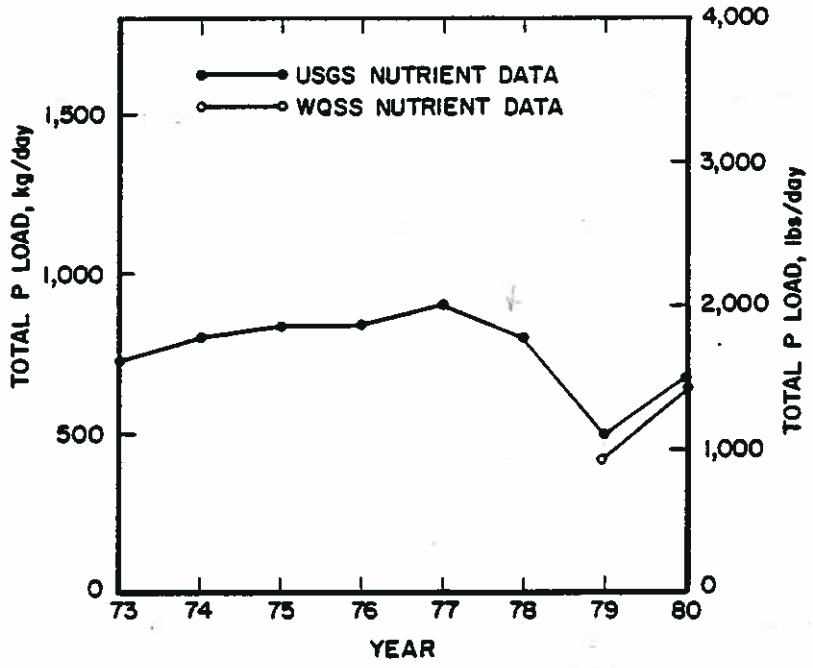
Historic Removal--The nutrient loads discharged to Lake Mead at Northshore Road are considerably lower than the nutrient loads discharged to Las Vegas Wash from the treatment plants. The wash has historically provided some degree of pollutant removal as illustrated by Figure 6-33.

Since 1973, an annual average of 200 to 500 kg/day of phosphorus have been removed in the wash, resulting in a 16 to 28 percent reduction in the phosphorus load. The total N removal has been more variable. Since 1974, 200 to 1,600 kg/day of nitrogen have been removed in the wash, resulting in a 7 to 51 percent reduction in the total N load. Between 1974 and 1977, 92 to 96 percent of the ammonia load was removed in the wash. The ammonia removal capacity has decreased since 1977. In 1980, only 40 percent of the ammonia load was removed in the wash.

Water Quality Transformations

Over the annual cycle, the wash has historically provided some degree of nutrient removal. The wash removed an annual average of 27 percent of the total P, 29 percent of the total N, and 76 percent of the ammonia load discharged from the treatment plants between 1974 and 1980. In this section the 1979 and 1980 removals are examined to determine if there were seasonal variations in the removal capacity of the wash. Potential removal mechanisms are also discussed.

To examine removals in the wash, the nutrient and BOD loads were calculated at Stations 1, 3, and 5 by multiplying the concentration measured on each sampling date by the USGS average daily flow on that date. Nutrient and BOD data collected at the treatment plants were not always collected on the same day that samples were collected in the wash. The treatment plants' samples were also analyzed by different laboratories than the wash samples. For these reasons, removals in the wash were calculated between Stations 1 and 5 rather than between the treatment plants and Station 5. Since Station 1 is located



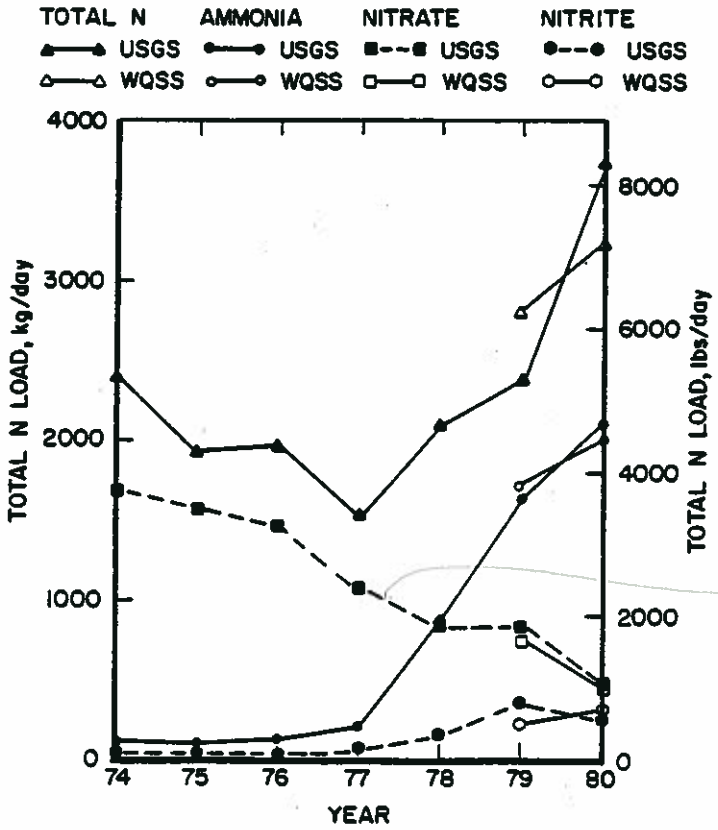


Figure 6-32 Nutrient Loads at Northshore Road

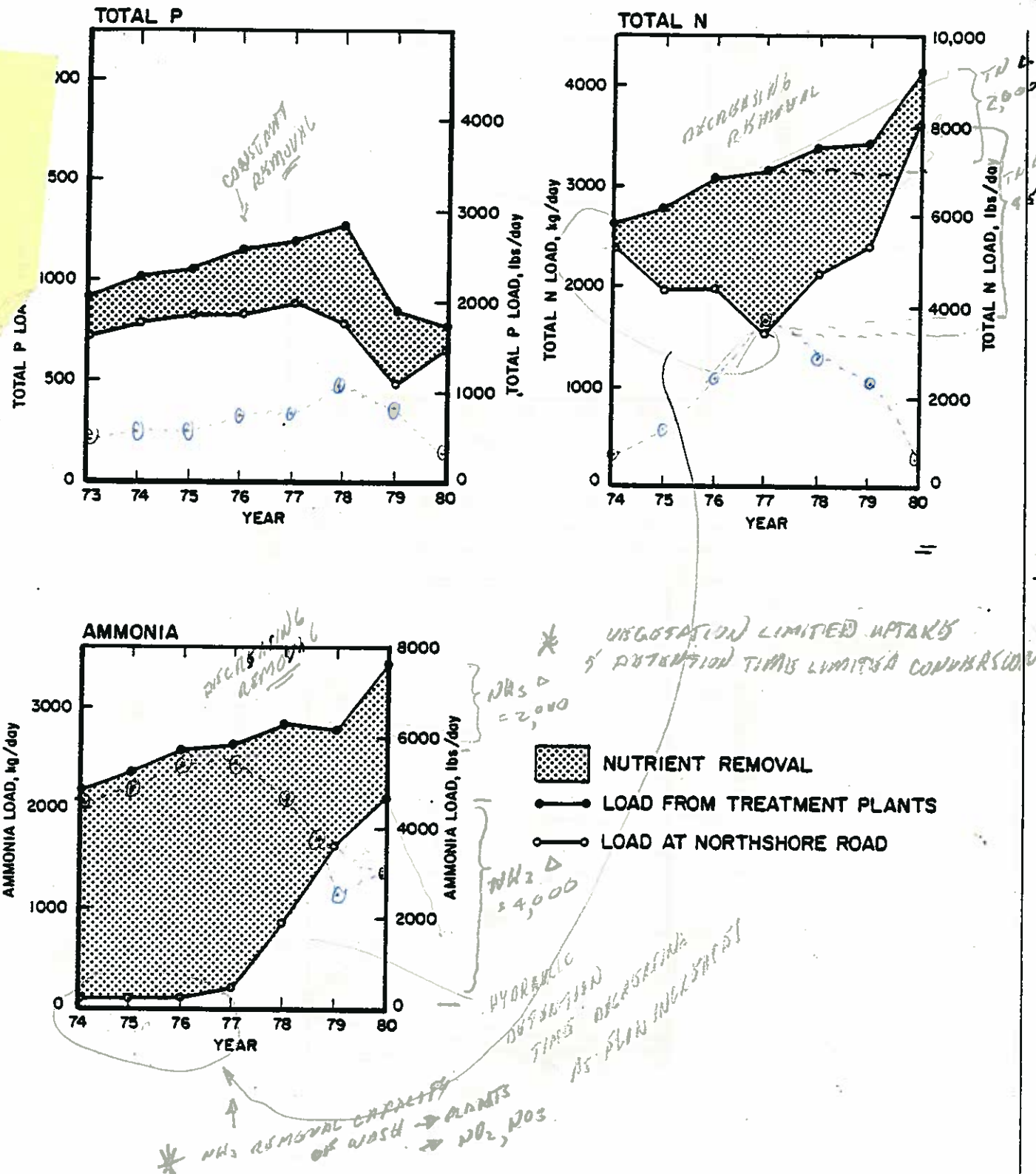


Figure 6-33 Historic Nutrient Removal in Las Vegas Wash

in a fast-flowing channel 100 yards downstream of the confluence of the treatment plant discharges, there should be little change in the quality of the water between the treatment plants and Station 1.

Phosphorus Removal. There are several mechanisms that are potentially transforming and removing phosphorus in Las Vegas Wash. The following mechanisms reduce the concentration of total P:

1. Assimilation of dissolved P by macrophytes and epiphytes removes P from the water column.

2. Soluble ortho P forms insoluble complexes with ions, particularly with iron, in the presence of dissolved oxygen. This permanently removes P from the water column.

3. Sedimentation of particulate P out of the water column reduces the total P concentration.

The following mechanisms convert phosphorus from one form to another:

1. Assimilation of dissolved P by phytoplankton converts dissolved P to particulate.

2. Adsorption of dissolved P onto suspended sediments converts dissolved P to particulate P.

3. Organic P can be converted to inorganic P in the soil or water column.

The amounts of total and dissolved P removed in the wash during the study are presented on Figure 6-34. During the summer and fall of 1979 and the first part of the winter of 1980, approximately 250 kg/day of total P were removed between Stations 1 and 5. However, there was a net contribution of 750 kg/day of total P in March 1980. Large amounts of particulate P were discharged from the wash during the active headcutting period that occurred after the February 1980 storm. During the remainder of the study, the total P removal was reduced to approximately 150 kg/day.

Most of the total P removal occurred between Stations 1 and 3, however, little dissolved P was removed between these two stations. On most sampling dates, the dissolved P load was actually greater at Station 3 than it was at Station 1. The large decrease in the total P load between Stations 1 and 3 was likely due to the settling of particulate P out of the water column, since the particulate P load decreased significantly between these two stations. Some amount of organic P may also be converted to dissolved P in the marsh. The total P removal between Stations 1 and 3 was greater in 1979 than in 1980. The decrease in total P removal in the upper wash during 1980 may be related to the fact that there was less particulate P at Station 1 than there was during 1979. Some of the particulate P was being removed at the Clark County Sanitation District treatment plant rather than in the upper wash.

There was a small amount of total P removal and a large amount of dissolved P removal between Stations 3 and 5. The dissolved P removal was likely due to the adsorption of soluble ortho P to sediments. There may be some removal by biological uptake in the marsh downstream of Pabco Road and by complexation of soluble orthophosphorus with ions.

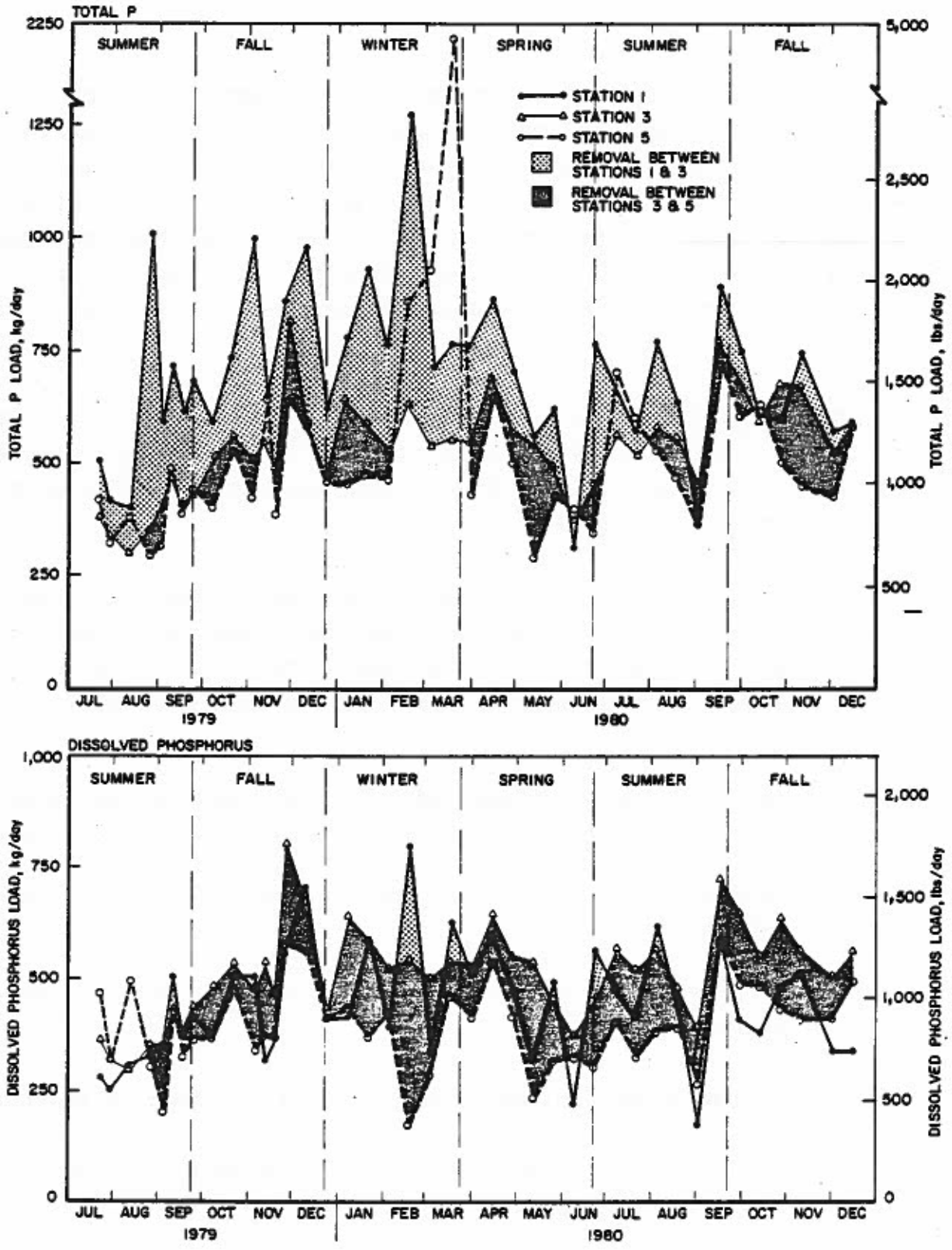


Figure 6-34 Phosphorus Removal in Las Vegas Wash

Over the annual cycle, total P is effectively removed by the wash, although the removal capacity of the wash decreased during this study. This may be due to the fact that more of the easily removable particulate P was removed by the Clark County Sanitation District treatment plant in 1980. During the WQSS, the average total P load at Northshore Road was 550 kg/day (1,250 lbs/day) and on the average 20 percent of the total P was removed in the wash.

Nitrogen Removal. There are a number of mechanisms that could potentially be transforming and removing nitrogen in Las Vegas Wash. The following mechanisms reduce the concentration of total N:

1. Denitrification is the major N sink in many wetlands.[13] Nitrate is converted to N gas under anaerobic conditions and is lost from the wetland. This may occur in the upper wash where DO concentrations were generally quite low.

2. Assimilation of dissolved N by macrophytes, epiphytes, and phytoplankton removes N from the water column.

3. Sedimentation of particulate N removes N from the water column.

4. Volatilization of ammonia removes ammonia from the water column.

The following mechanisms convert N from one form to another:

1. Assimilation of dissolved N by phtoplankton converts dissolved N to particulate N.

2. Ammonification is the process by which organic N is converted to ammonia by bacterial decomposition of organic matter.

3. Nitrification is the process by which ammonia is converted to nitrate by bacterial action. Oxygen is required for this process. Nitrification may be occurring in the lower wash.

4. Ammonia adsorption to sediments has been proposed as a removal mechanism in the wash.[1]

The amounts of total N, ammonia, and nitrate removed in the wash during the study are presented on Figure 6-35. The total N removal showed the same general pattern as the total P removal. During the summer and fall of 1979 and the first part of the winter of 1980, approximately 1,300 kg/day of total N were removed between Stations 1 and 5. There was a net contribution of 1,500 kg/day of total N in March 1980, following the storm and severe headcutting that occurred in February 1980. After the storm, the total N removal was reduced to approximately 450 kg/day.

Between Stations 1 and 3, most of the total N removal occurred, the nitrate load was reduced to near zero, and a small amount of ammonia was removed. The reduction in the nitrate load was probably due to a combination of denitrification and biological assimilation. The dissolved oxygen concentrations in the marsh were often near zero which favors denitrifying bacteria that convert nitrate to nitrogen gas. The reduction in the ammonia load may be due to biological assimilation and perhaps adsorption to sediments. These factors combined with

reductions in the particulate N by settling out of the water column result in a significant decrease in the total N load between Stations 1 and 3.

There was a large increase in the nitrate load and a large decrease in the ammonia load between Stations 3 and 5. Overall there was a small decrease in the total N load between these two stations. The increase in the nitrate load was most likely mainly due to the inflow of nitrate-laden groundwater to the lower wash. The nitrification of ammonia may also contribute to the increased nitrate load. The loss of ammonia between Stations 3 and 5 may be due to adsorption to sediments or to nitrification. As discussed previously, Goldman and Deacon suggested that ammonia is adsorbed to clay particles exposed by the headcutting in the lower wash.[1] Between 1974 and 1977 over 90 percent of the ammonia was removed in the wash.[1] If ammonia adsorption is the key removal mechanism, the explanation for the lowered removals during the last three years could be that the headcut has cut deeper into sediments that do not contain as much clay as the sediments that were cut through historically. Another possible explanation for the reduction in ammonia in the lower wash is that ammonia is converted to nitrate through nitrification. Nitrite is an intermediary product in the nitrification reaction. The relatively high nitrite concentrations in the lower wash indicate that nitrification may be occurring. Nitrification was observed in the laboratory experiment discussed previously. If nitrification is the key removal mechanism, the explanation for the lowered removals during the last three years could be that the headcut has decreased the travel time in the lower wash, resulting in less time for nitrification to occur.

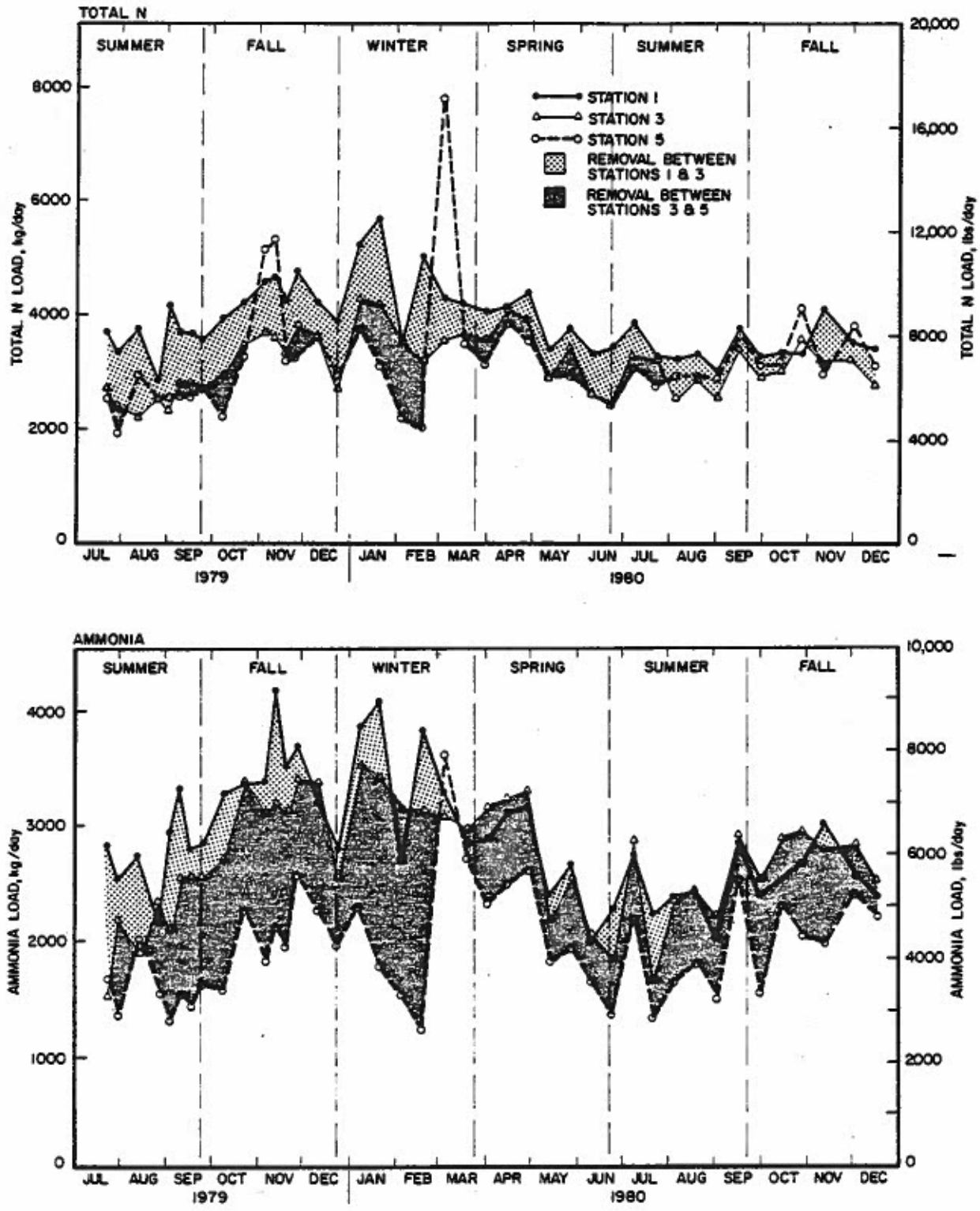


Figure 6-35 Nutrient Removal in Las Vegas Wash

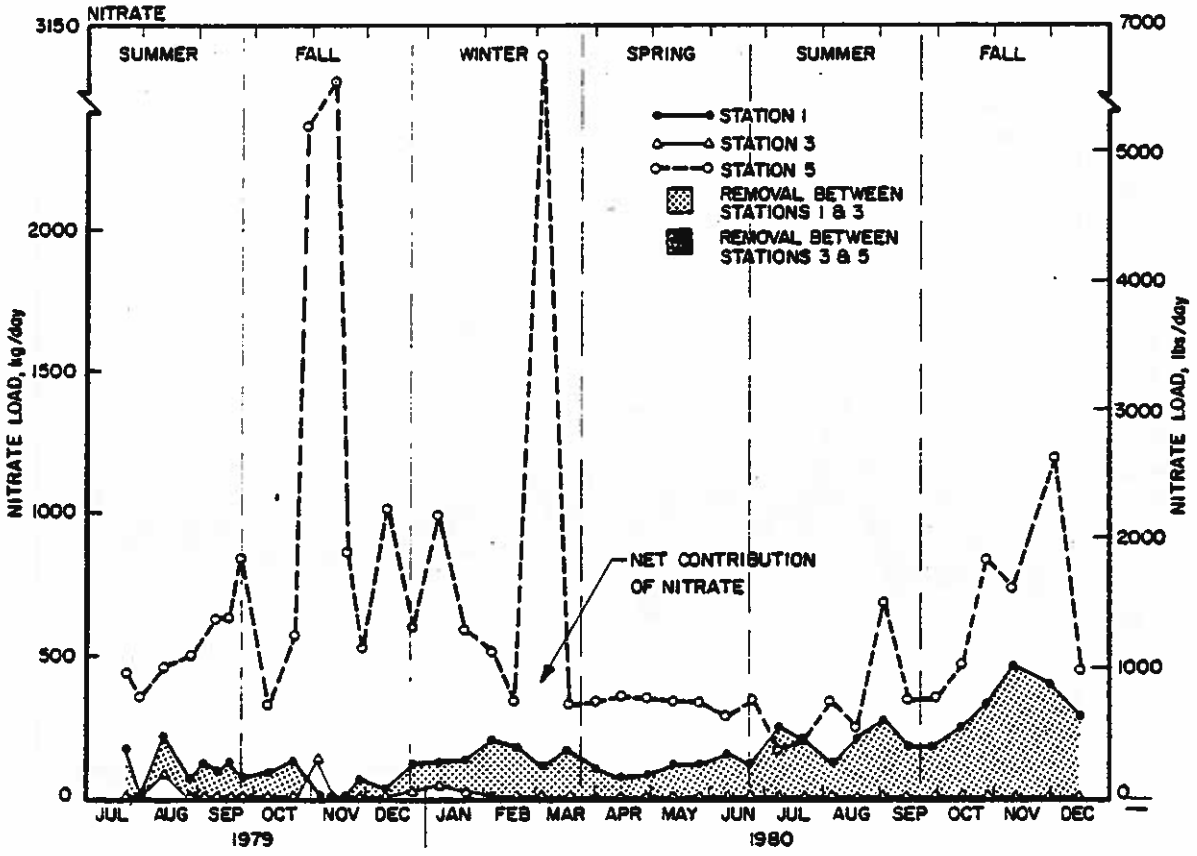


Figure 6-35 Nutrient Removal in Las Vegas Wash (Continued)

Over the annual cycle, total N is effectively removed by the wash, although the removal capacity of the wash decreased during this study. This is probably related to the decrease in marsh acreage due to the erosion that is occurring in both the upper and lower wash. During the WQSS, the average total N and ammonia loads at Northshore Road were 3,100 kg/day (6,900 lbs/day), and 1,950 kgs/day (4,300 lbs/day), respectively. An average of 20 percent of the total N and 40 percent of the ammonia was removed in the wash.

This study was not designed to determine the exact removal mechanisms that are responsible for the reductions in the nitrogen and phosphorus loads in the wash. The study did show, however, that both nitrogen and phosphorus are currently removed

in the wash; however, the nitrogen and phosphorus removal capacities of the wash are being reduced. This reduction in the removal capacities is likely related to the reduction in the marsh acreage by the headcutting that is occurring in both the upper and lower wash. The amount of nutrient removal that occurred in the wash is quite remarkable considering that the travel time is only 18 hours and the flow is channelized through most of the wash. If the flow was slowed down by spreading the water throughout the marsh or imponding in a series of ponds, much greater nutrient removal would be expected to occur.

BOD Removal. There are two mechanisms that could potentially be removing BOD in Las Vegas Wash:

1. Sedimentation of particulate oxygen demanding materials removes BOD from the water column.

2. Oxidation of carbonaceous and nitrogenous oxygen demanding materials reduces the BOD concentration in the water column.

The amount of total BOD_5 removed in the wash during the study is presented on Figure 6-36. The amount of BOD_5 removed in the wash decreased during the study. In 1979, approximately 450 kg/day of BOD_5 were removed. During 1980, the average removal was 400 kg/day. There was a large amount of BOD_5 removal between Stations 1 and 3. The BOD_5 load at Station 5 was always greater than the load at Station 3 and it was often greater than the load at Station 1. As discussed previously, the BOD_5 data may not represent actual conditions in the wash. The greater BOD loads at Stations 1 and 5 may be due to the presence of nitrifying bacteria in these areas of the wash. The lower BOD loads at Station 3 may be due to the absence of nitrifying bacteria in the marsh. Since the ammonia

concentrations are similar at Stations 1 and 3, the nitrogenous BOD concentrations should be similar. During the WQSS, the average total BOD_5 load at Northshore Road was 1,400 kg/day (3,100 lbs/day). An average of 20 percent of the total BOD_5 was removed in the wash.

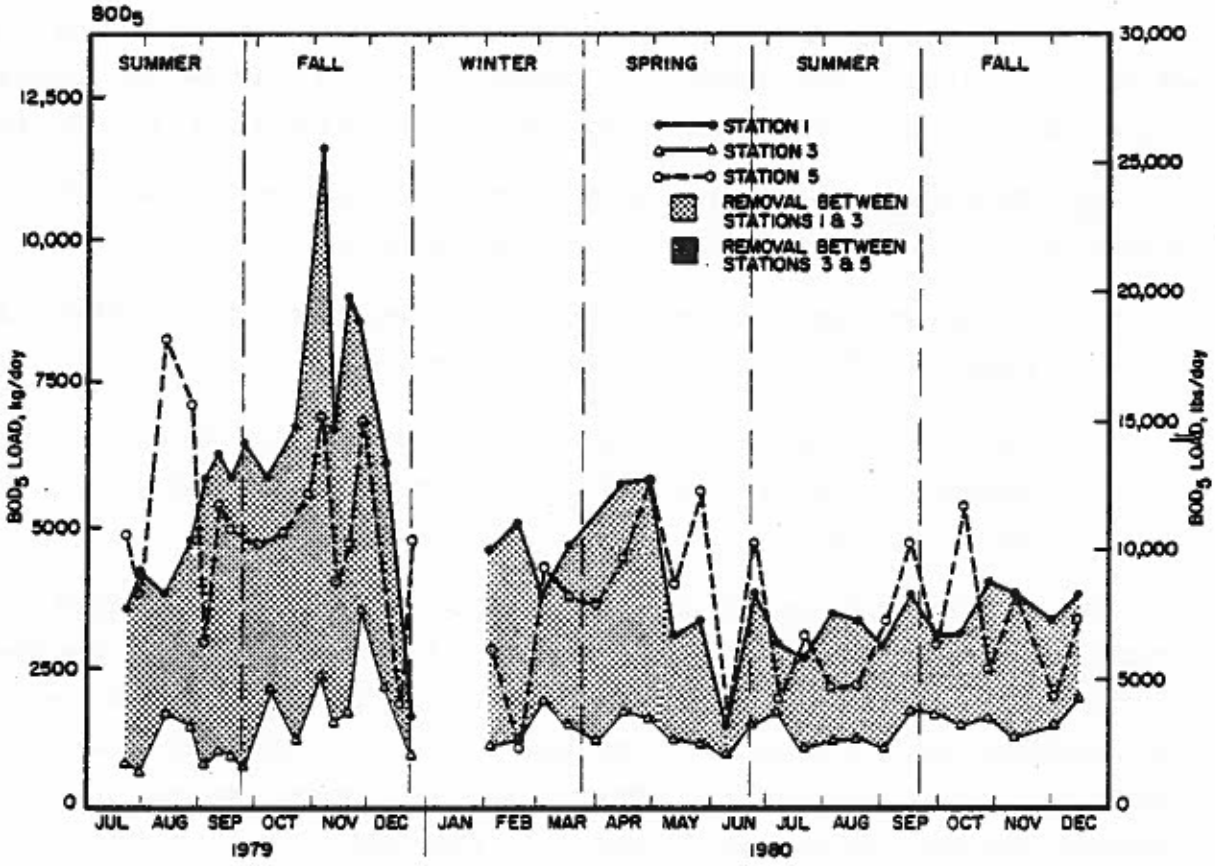


Figure 6-36 BOD_5 Removal in Las Vegas Wash

Salinity Changes in Las Vegas Wash

The U.S. Congress ordered the USBR to reduce salinity in the Colorado River. During the WQSS, Las Vegas Wash contributed 205,000 metric tons of total dissolved solids (TDS) to the

Colorado River each year. Several methods of controlling salinity in the wash have been proposed by USBR. Their impacts will be evaluated as part of the Phase II Treatment Facilities Study (TFS-II). To evaluate the effectiveness of salinity control strategies, the USBR has proposed construction of a pipeline to convey industrial cooling water discharges from the Pittman area which currently flow in the Alpha Ditch. The USBR estimated that this measure would result in a reduction in total dissolved solids of approximately 18,000 metric tons/year at Northshore Road.[14] Based upon results of the Pittman Verification Program, the USBR may pursue salinity control measures which may eliminate virtually all of the TDS increase which occurs as water flows through the wash. As presently conceived, this long-term measure involves bypassing wastewater treatment plant effluent around the upper wash and discharging below the Pabco Road area. This could have severe consequenees with respect to nutrient removal in the wash.

The WQSS total dissolved solids data and the USGS flow data were used to calculate a total dissolved solids balance for the wash during the WQSS. The average TDS concentrations at Stations 1, 3, and 5 were multiplied by the USGS average flows at these stations during the study. Estimates of the loads from the other surface water sources were made based on the limited data collected during October through December 1980. This rough balance is presented on Figure 6-37. There was only a slight increase in the TDS load between Stations 1 and 3 (11,500 kg/day). This increase was lower than the load from the other surface water sources discharging to the wash between these two stations. Based on this balance, 78,500 kg/day of TDS are lost in the upper wash. There was a large increase in TDS between Stations 3 and 5, amounting to 219,400 kg/day. A small

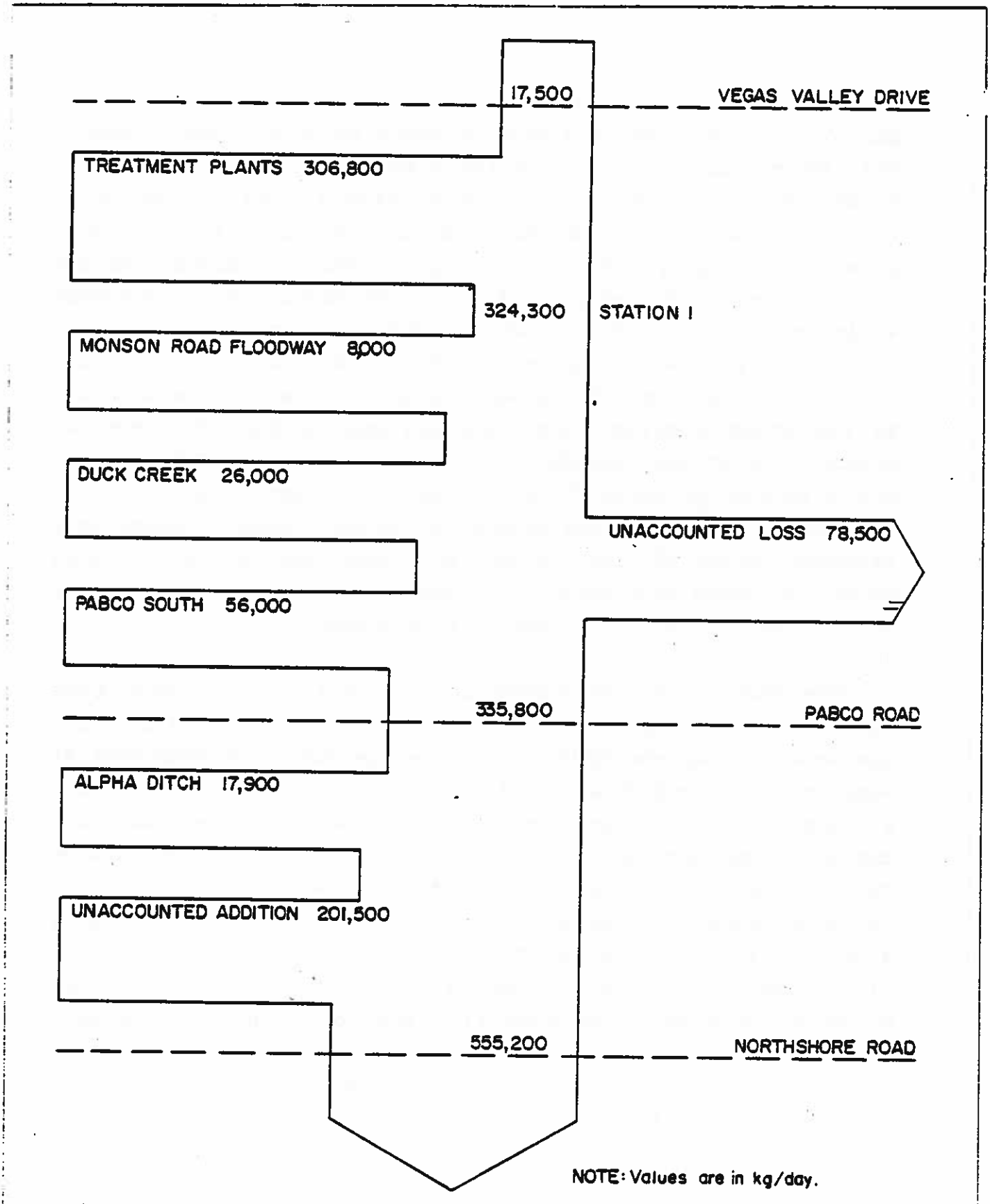


Figure 6-37 Total Dissolved Solids Balance for Las Vegas Wash

amount of the increase comes from Alpha Ditch (17,900 kg/day). The large unaccounted addition of 201,500 kg/day may be due to highly saline groundwater flowing into the wash or the wash flow passing over soils with a high salt content.

Based on this preliminary analysis, it appears that the upper wash acts as a sink for a portion of the total dissolved solids entering the wash upstream of Pabco Road. The salt removal mechanisms are unknown; however, precipitation of ($CaCO_3$) and uptake of sulfate by sulfur bacteria are two possible mechanisms. Precipitation of $CaCO_3$ and the presence of sulfur bacteria have been observed in the wash.[2]

Temperature Changes in the Las Vegas Wash

The results of the Hydraulic Study showed that temperature is much more important than salinity in controlling the position of the Las Vegas Wash plume in the lake. The USBR has proposed diverting the effluent from the treatment plants around the upper wash to a point below the proposed salinity control barrier upstream from Station 4. The effect that this would have on Las Vegas Bay is unknown. There would almost certainly be less nutrient removal in the wash if the marsh is bypassed. Furthermore, the impact on the temperature of the wash water, and hence, the position of the plume in the bay is unknown. During the WQSS, the temperature dropped rapidly in the wash. As discussed previously, the average temperature at Station 1 was 21.5°C. This decreased to 18.6°C at Station 2 and then decreased to 17.9°C at Station 5. There was an average drop in temperature of 3.6°C in the wash with most of the cooling occurring in the 3 kilometers between Stations 1 and 2.

The temperature measurements taken at Stations 1 and 5 during the WQSS do not really reflect the actual change in temperature that occurs in the wash, since these measurements

were typically made within a few hours of each other. The travel time between Stations 1 and 5 is 18 hours. The USGS data at Northshore Road and the WQSS data at Station 1 were analyzed to determine the actual change in temperature between these two points. The points that were compared in this analysis were temperature measurements at Station 1 and measurements taken 18 hours later at Northshore Road. The difference in temperature was calculated for each date that samples were collected at both stations. Figure 6-38 presents the results of this analysis. The change in temperature ranged from 1.8°C in May 1980 to 10°C in November 1979. The smallest change in temperature (1.8 to 4.8°C) occurred during the spring and summer months when the plume position in the lake is the most important with respect to water quality conditions in Las Vegas Bay. With the one exception in November 1979, the change in temperature during the fall and winter ranged from 3.8 to 6.5°C. There currently are insufficient data to determine what the effect diverting wastewater flow around the upper wash would be on changes in temperature in the wash.

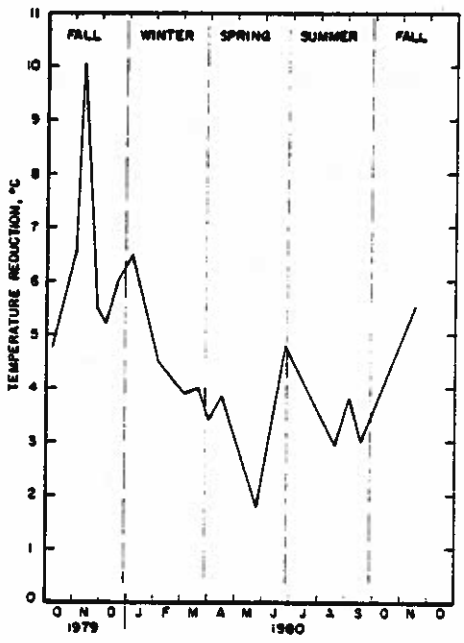


Figure 6-38 Reduction in Temperature of a Water Particle as it Passes Through Las Vegas Wash

Sources of Fecal Coliforms in Las Vegas Wash

The total and fecal coliform data presented in the Results section of this chapter show that fecal coliform concentrations were often quite high in the wash. Examination of the data from the treatment plants shows that the discharges consistently complied with the effluent limitation of 200/100 ml. Although coliforms are harmless to man, they indicate that pathogenic organisms may also be present if the source of the coliforms is human. The ratio of fecal coliform to fecal streptococci is an indication of whether the pollutant source is human or animal. The fecal coliform/fecal streptococci (FC/FS) ratio for man is 4.4. The ratio for other warm-blooded animals is 0.6 or less.[15] The FC/FS ratios at each of the five wash stations during the study are presented on Figure 6-39. The FC/FS ratios were usually less than 0.6 at all five stations. There were a few values at Stations 2 and 3 and one value at Station 5 that exceeded 4.4. These ratios indicate that the fecal coliforms in the wash are primarily from non-human sources, such as birds and other warm-blooded animals.

The bacteriological data collected at the five other surface water sampling stations were examined. The range of fecal coliform concentrations and the FC/FS ratios are presented below:

Stream	Fecal coliform range MPN/100 ml	FC/FS
Upstream Las Vegas Wash	240 - 330	0.18-0.49
Monson Road Floodway	<2 - 330	0.25-1.00
Duck Creek	170 -1,400	0.13-0.72
Pabco South	2 - 7	0.06-0.27
Alpha Ditch	<2 - 11	0.03-0.08

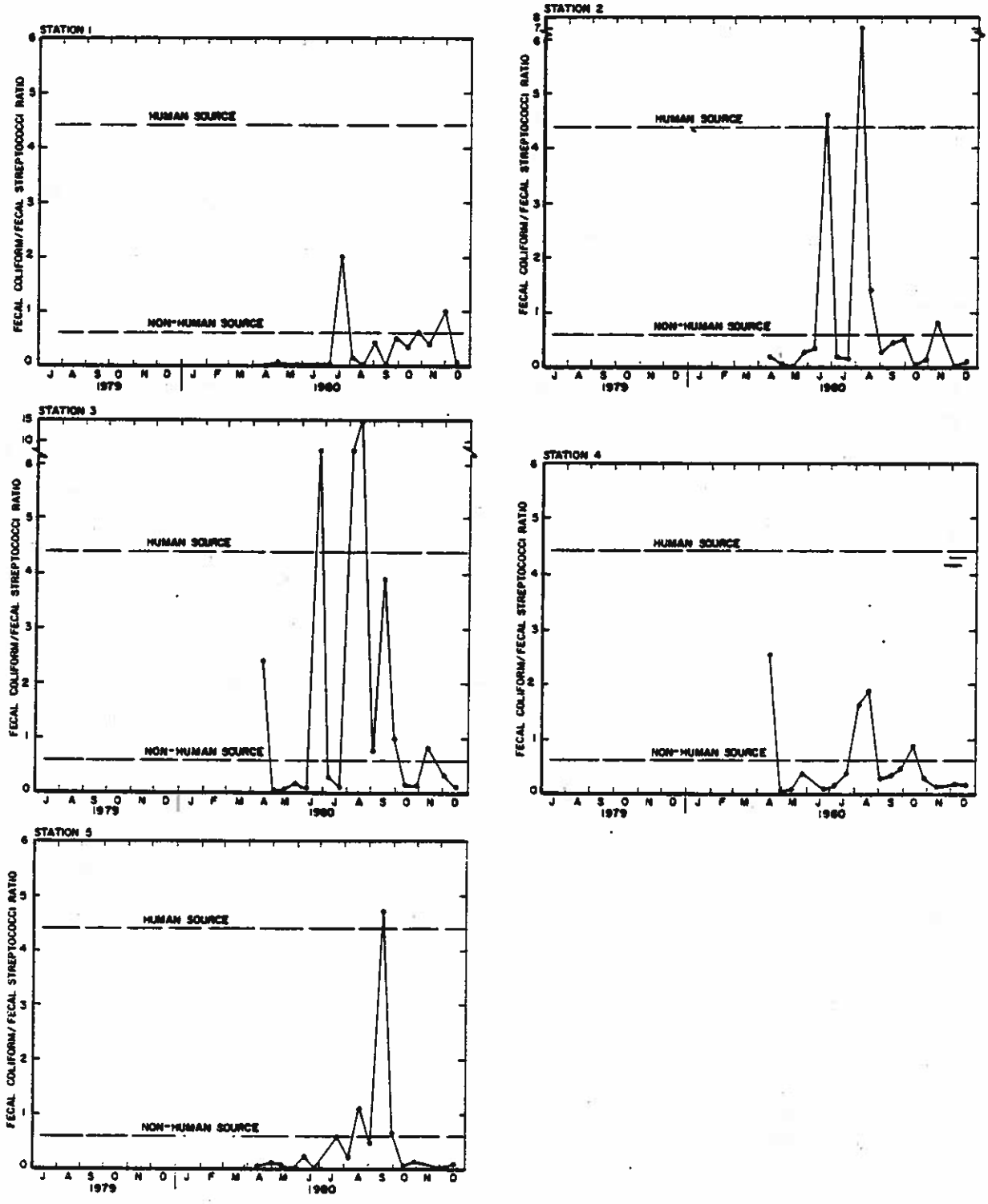


Figure 6-39 Fecal Coliform / Fecal Streptococci Ratios in Las Vegas Wash

The concentrations were relatively low compared to concentrations found at the routine wash stations. The FC/FS ratios indicate that the source of coliforms in the other surface waters was also non-human.

EFFECT ON BENEFICIAL USES

The currently designated beneficial uses of Las Vegas Wash are aesthetics and recreation, irrigation, stock watering, fish, and wildlife. These uses are discussed in detail in Chapter 4. The uses are discussed briefly in this chapter and recommendations are presented. Actual conditions in the wash are compared to the existing standards for the wash and to criteria published by the State of Nevada, EPA, and the National Academy of Sciences (NAS).

Beneficial Uses

Our recommendations regarding the beneficial uses of Las Vegas Wash are presented below.

Aesthetics and Recreation. Current aesthetic and recreational uses of the wash are birdwatching, hiking, and hunting. These uses are expected to increase if the wetlands park is established. Body-contact recreation (swimming) and boating are not current uses of the wash. Water quality conditions and physical constraints make it infeasible for body-contact recreation in the wash. The wash flow consists primarily of treated wastewater with minimal dilution from other flows and as such is incompatible with body-contact recreation. Boating does not occur because most of the wash is too shallow and fast-flowing; most ponded areas are inaccessible due to

heavy marsh vegetation. Because of these physical and water quality constraints, the thrust of the wetlands park is towards enhancement of non-water contact uses. Thus, it is recommended that the use of aesthetics and recreation be maintained, but it should be qualified to exclude body-contact recreation.

Irrigation. Irrigation is not presently a use of the wash, although, according to the Clark County Department of Comprehensive Planning, it is planned to use wash water to irrigate grass at the proposed Stadium Park.[9] Use of the wash for irrigation is not significantly constrained by any physical factors and it is generally compatible with existing water quality conditions. Thus, it is recommended that irrigation be maintained as a use in the wash.

Stock Watering. No systematic use of wash water for stock watering is conducted, although there may be some consumption of wash water by horses on equestrian trails. Since equestrian trails are planned as part of the wetlands park, this use may increase in the future. It is recommended that stock watering be maintained as a use in the wash.

Fish. Limited information is available on fish species inhabiting the wash presently or in the past. A review of the few available reports and conversations with fisheries biologists are described in Chapter 4. That information indicates that the wash did not in the past, and does not today, support a substantial fishery. At present, mosquito fish (*Gambusia affinis*) appear to be the only fish inhabiting the wash in any significant number, although there have been a few random sitings of goldfish and sunfish.

Both water quality conditions and physical limitations prevent the wash from being able to support a fishery. Based on the data presented previously in this chapter, a diverse fishery could not survive in the wash under current water quality conditions of low dissolved oxygen, high un-ionized ammonia, high nitrite and high turbidity. The mosquito fish appear to be well adapted to the water quality conditions found in the wash. Unlike most other fish, mosquito fish do not depend on dissolved oxygen in the water as they obtain oxygen directly from the air at the air-water interface. Most of the wash is unsuitable as a habitat for fish since it is too shallow and fast-flowing or is heavily laden with silt. Upstream of the treatment plants, there is insufficient flow to support fish. The only portion of the wash that appears to be suitable as a fish habitat is the ponded area near Pabco Road. Expansion of the current limited fish habitat would require major physical modifications to the wash and alteration of flow patterns.

Since the wash does not contain an appreciable area with suitable habitat to support a diverse fishery, it is recommended that fish be deleted as a beneficial use. Despite the current physical and water quality constraints, it is likely that mosquito fish and small numbers of other fish will continue to inhabit the wash in the ponded areas near Pabco Road.

Wildlife. The wash presently provides a diverse terrestrial animal and bird habitat. This use would be expanded if the proposed wetlands park is established. Thus, it is recommended that wildlife be maintained as a use in the wash. However, erosion that has been occurring in the wash for several years is gradually destroying portions of the wildlife habitat. To maintain adequate wildlife habitat, the wetlands park concept

must include steps to control erosion and alter current flow patterns in the wash.

Criteria and Standards

In this section, the wash data are compared to various water quality criteria and standards. The data are compared to the existing standards for Las Vegas Wash at Northshore Road,[11] the Nevada Water Pollution Control Regulations Water Quality Criteria for Designated Beneficial Uses[16], the EPA Quality Criteria for Water[17], and the NAS Water Quality Criteria.[18] Water quality standards recommendations are developed for the key parameters.

Temperature. The temperature of the Las Vegas Wash water affects the beneficial uses of fish and wildlife. Excessively high temperatures can be detrimental to wildlife and aquatic life. Fish have a temperature range in which they can survive and reproduce. Temperatures beyond the range inhibit reproduction and are lethal if sufficiently high or low. Temperature also affects the toxicity of some substances. The current temperature standards for Las Vegas Wash at Northshore Road are:

June 1 to September 30—

Monthly mean—Not more than 27°C
Single value in 90 percent of samples—
Not more than 31°C

October 1 to May 31—

Monthly mean—Not more than 23°C
Single value in 90 percent of samples—
Not more than 27°C

The State of Nevada recommends that the temperature should not exceed 30°C for the protection of warmwater aquatic life. The State does not recommend a criterion for the protection of wildlife. As shown on Figure 6-40, the existing standards and the state warmwater aquatic life criterion were consistently met at all of the wash stations. The temperatures of the discharges from the wastewater treatment plants were often close to the existing wash standard during the summer months; however, the temperature drops rapidly in the wash as shown on Figure 6-4. It is recommended that the existing standards be retained. It is possible that the upper temperature limit may occasionally be exceeded in the area immediately downstream of the treatment plant discharges.

pH. The pH of the Las Vegas Wash water affects the beneficial uses of fish and wildlife. The pH of the water affects the use of the water by wildlife as a drinking water source and affects the food supply. The pH also affects the toxicity of some chemicals to aquatic life. Outside of the natural pH range, fish suffer adverse physiological effects. The current pH standards for Las Vegas Wash at Northshore Road are:

> Monthly median—within range 6.5 to 8.5
> Single value in 90 percent of samples—within range 6.5 to 8.5

The State of Nevada recommends a pH range of 7.0 to 9.2 for the protection of wildlife. The State and EPA recommend a pH range of 6.5 to 9.0 for the protection of aquatic life and the NAS recommends a range of 6.0 to 9.0 for a high level of protection of aquatic life and wildlife. The State and NAS also recommend a pH range of 4.5 to 9.0 for the protection of agricultural

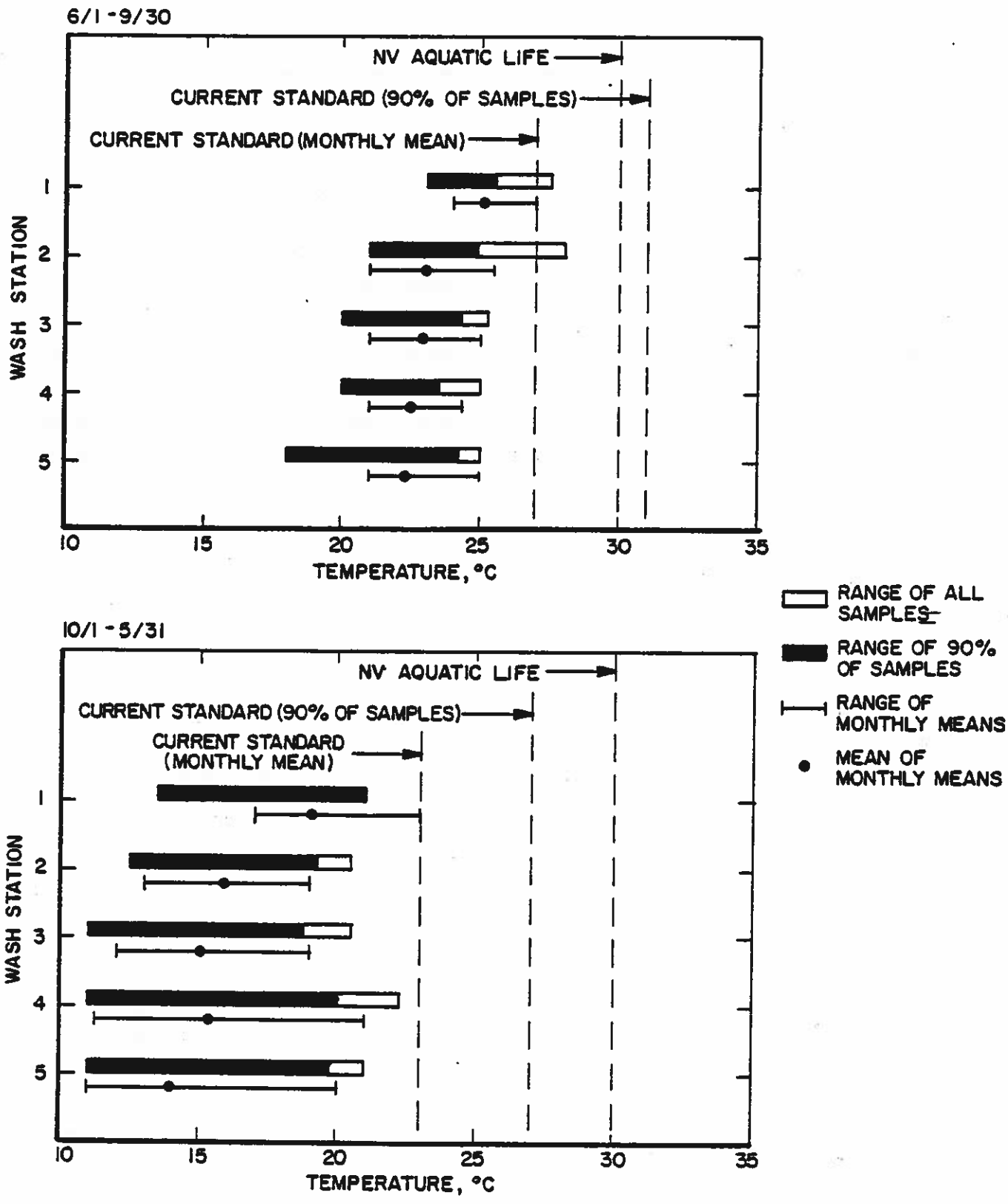


Figure 6-40 Comparison of Temperature Data With Standards and Criteria

water supplies. The pH data at each of the five wash stations are compared to these standards and criteria on Figure 6-41. The existing standards were consistently met at all of the wash stations. The State criterion of a range of 7.0 to 9.2 for the protection of wildlife was not met all of the time at all of the wash stations. At Stations 1 to 4, 90 percent of the pH measurements were in the 7.0 to 9.0 range. Less than 90 percent of the values were in this range at Station 1. The State and EPA criteria for the protection of aquatic life (6.5 to 9.0) and the NAS range of 6.0 to 9.0 for the protection of aquatic life and wildlife were consistently met at Stations 1, 2, and 3, and were met more than 90 percent of the time at Stations 4 and 5. The State and NAS criteria for the protection of agricultural water supplies (4.5 to 9.0) were consistently met at all stations. For the protection of wildlife most of the criteria documents suggest 9.0 as an upper pH limit and between 6.0 and 7.0 as a lower pH limit. The following modification to the current standard is recommended:

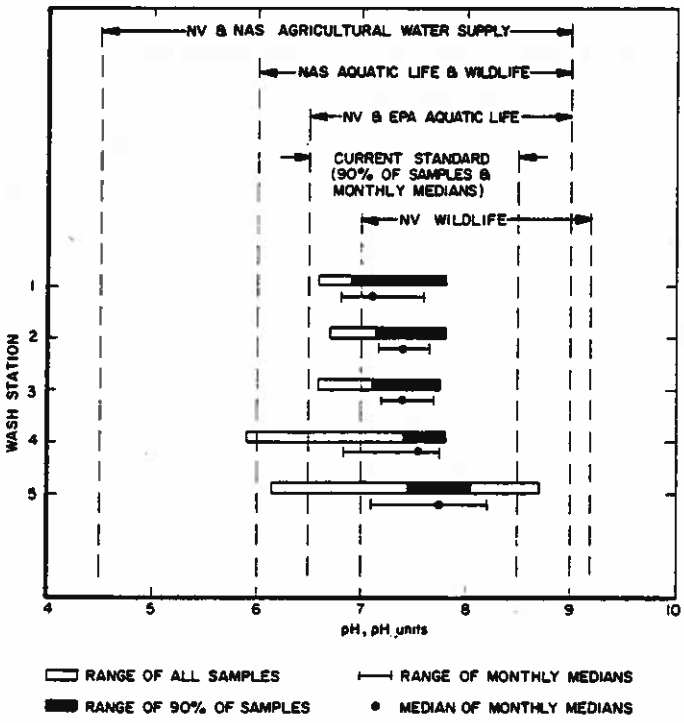


Figure 6-41 Comparison of pH Data With Standards and Criteria

Monthly median—6.5 to 8.5
Single value in 90 percent of samples—6.0 to 9.0

At Stations 4 and 5, the pH may drop below 6.0 occasionally due to factors unrelated to the treatment plant discharges.

Dissolved Oxygen. The dissolved oxygen concentrations in the Las Vegas Wash water affect the beneficial uses of fish, wildlife, agricultural water supplies, and recreation. The water must remain aerobic to avoid the "rotten egg" odor due to the formation of hydrogen sulfide in anaerobic waters. This odor interferes with the aesthetic enjoyment of recreational users. The DO requirements of fish differ between species, between the various life stages and between the different life processes (feeding, growth, and reproduction). The current DO standards for Las Vegas Wash at Northshore Road are:

Monthly mean—Not less than 5.0 mg/l
Single value in 90 percent of samples—Not less than 4.0 mg/l

The State of Nevada and EPA recommend at least 5 mg/l for the protection of aquatic life and the maintenance of a diverse fishery, and aerobic conditions for the protection of nonbody contact recreation. The State also recommends aerobic conditions for the protection of agricultural water supplies and wildlife. The NAS recommends a minimum DO value of 4 mg/l for aquatic life except in situations where the naturally occurring DO level is less than 4 mg/l. In those cases, no further depression of the DO concentration should occur. The DO data at each of the five wash stations are compared to these

standards and criteria on Figure 6-42. The DO concentrations at Stations 1, 2, and 3 were lower than the existing standards and the State, EPA, and NAS criteria for the protection of aquatic life. The existing standard was always met at Station 5 and met most of the time at Station 4. The minimum concentrations were 3.6 mg/l at Station 4 and 4.6 mg/l at Station 5. Both of these values are lower than the 5 mg/l criterion proposed by the State and EPA. Aerobic conditions were consistently maintained in areas of the wash except the marsh. There were several periods of very low or zero DO in the marsh at Stations 2 and 3.

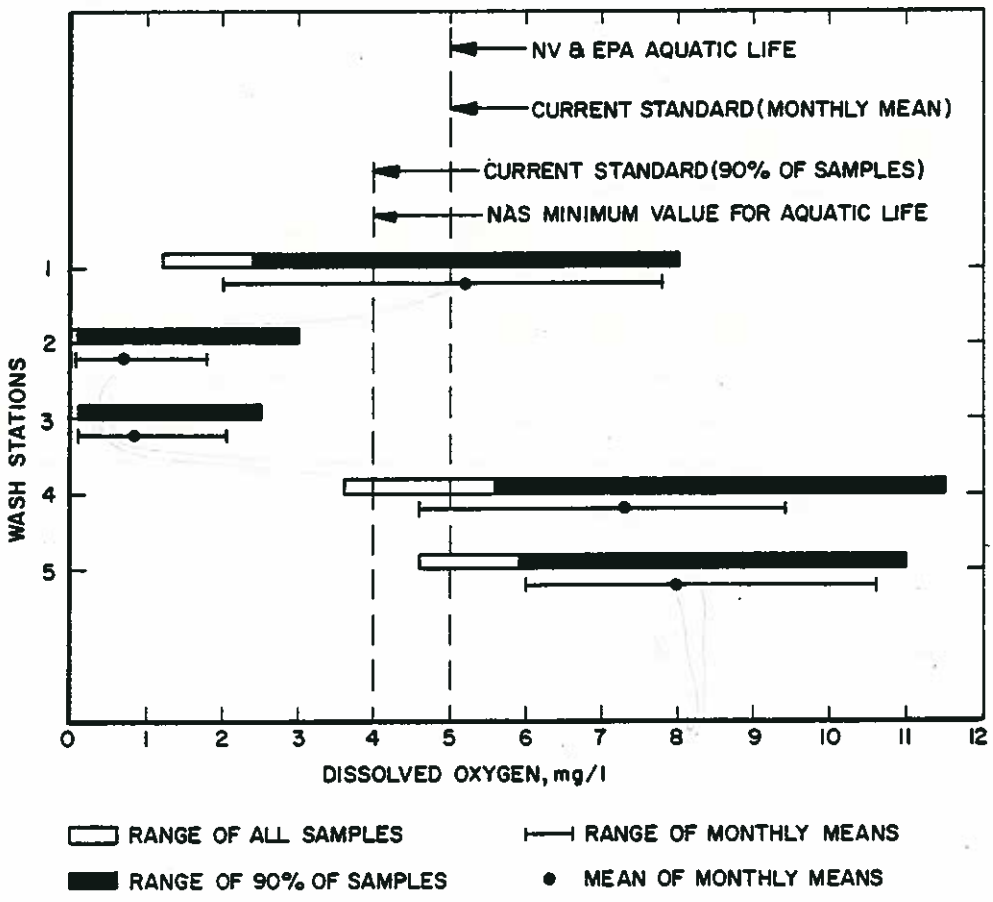


Figure 6-42 Comparison of Dissolved Oxygen Data With Standards and Criteria

The reduction in DO in the marsh portion of the wash is due to three key factors: oxidation of carbonaceous BOD discharged from the treatment plants, sediment oxygen demand, and decay of marsh vegetation. There were a few DO measurements made in areas of the wash not directly affected by the main wash flow. During the longitudinal study, low DO concentrations (0.9 to 2.2 mg/l) were found throughout the northern portion of the marsh between Stations 2 and 3, where the main flow of the wash occurs. However, on the southern side of the marsh, away from the waste discharges, the DO concentration was 3.3 mg/l. The Pabco South station also drains the southern portion of the marsh. The DO concentrations at Pabco South ranged from 1.1 to 5.0 mg/l with a mean concentration of 2.7 mg/l. Since only one measurement was made at Station 2c and only four measurements were made at Pabco South, there is insufficient basis for comparison between the waste discharge-impacted area and the relatively unimpacted area. Thus, the work authorized to date in this program does not provide sufficient data to accurately determine the individual effect of each of the three primary factors on DO levels. The analysis of dissolved oxygen in the preceeding section indicated that two other potential factors, BOD from other surface water sources and exertion of nitrogenous BOD from the treatment plant effluents, are relatively minor influences on DO depletion in the marsh.

Anaerobic conditions in the marsh, particularly in the bottom waters near the sediment-water interface, may actually aid in nitrogen removal since denitrification only occurs under anaerobic conditions. It is likely that aerobic conditions will continue to be maintained in the area of the wash downstream of Station 3 due to the high degree of reaeration that occurs. The area where aerobic conditions will

occur in the future and the level of DO may be influenced by wash management alternatives. For example, impoundments created to help control erosion would alter existing DO levels.

The current DO standard is related to supporting a fishery. Since it is recommended that fish be deleted as a use, the current standard should be modified. It is recommended that aerobic conditions be maintained to support the recommended beneficial uses of the wash.

Biochemical Oxygen Demand. The BOD concentration in Las Vegas Wash does not directly affect the beneficial uses of the wash. The current BOD standards for Las Vegas Wash at Northshore Road are:

> Monthly mean—Not more than 10 mg/l
> Single value in 90 percent of samples—Not more than 15 mg/l

The State, EPA, and NAS do not have BOD criteria. The BOD data at each of the five wash stations are compared to these standards on Figure 6-43. The BOD standards were not met at Stations 1, 2, and 5. The monthly mean standard was met during most months of the study at Station 3 and about half of the time at Station 4. The 90 percent standard of 15 mg/l was met at Stations 3 and 4.

A BOD criterion is not needed since BOD in itself does not impact beneficial uses. BOD is a measure of loadings which in turn affect DO levels. Oxygen requirements are better reflected in the dissolved oxygen criterion. Thus, it is recommended that the existing BOD standard be eliminated for protection of the beneficial uses of the wash. However, a BOD load limitation may be needed at Northshore Road to protect the beneficial uses of Las Vegas Bay.

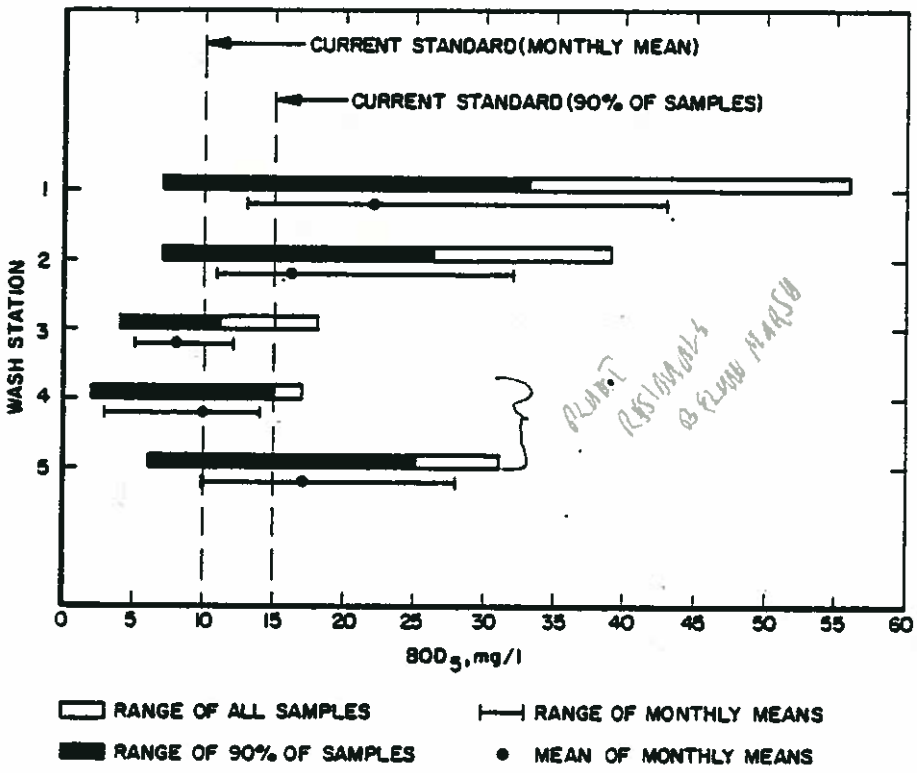


Figure 6-43 Comparison of BOD Data with Standards

Chemical Oxygen Demand. The chemical oxygen demand (COD) concentration in Las Vegas Wash does not directly affect the beneficial uses of the wash. The current COD standards for Las Vegas Wash at Northshore Road are:

Monthly mean—Not more than 40.0 mg/l
Single value in 90 percent of samples—Not more than 50.0 mg/l

The State, EPA, and NAS do not have COD criteria. There were no COD data collected in the wash, since the BOD test was used to measure oxygen demand. It is recommended that the existing COD standard be eliminated, for the same reasons described for BOD.

Total Suspended Solids. The suspended solids concentration of the Las Vegas Wash water affects the beneficial uses of fish and other forms of aquatic life. Suspended solids may kill fish directly by clogging their gills and impairing respiration. Other impacts include burying spawning grounds and benthic organisms. Suspended solids also increase the turbidity in water. The current total suspended solids (TSS) standards for Las Vegas Wash at Northshore Road are:

Monthly mean—Not more than 2 mg/l
Single value in 90 percent of samples—Not more than 5 mg/l

The State of Nevada recommends that the TSS concentration should not exceed 80 mg/l for the protection of aquatic life. The NAS recommends various criteria based on the desired level of protection of aquatic life as illustrated below:

High level of protection	25 mg/l
Moderate protection	80 mg/l
Low level of protection	400 mg/l
Very low level of protection	over 400 mg/l

The TSS data at each of the five wash stations are compared to these standards and criteria on Figure 6-44. The existing standards are not met at any of the wash stations. The Nevada aquatic life criterion is met at Stations 2 and 3 and exceeded at the other wash stations. The NAS criterion of 25 mg/l for a high level of protection of aquatic life was met most of the time at Stations 2 and 3. The low level of protection criterion of 400 mg/l was met at Station 1 and was met most of the time at Stations 4 and 5. The high suspended

solids concentrations in the lower wash are due to the active erosion that is occurring in that area. Until the erosion is controlled, it may not be possible to meet the State aquatic life criterion of 80 mg/l. The high suspended solids concentrations at Station 1 may also be due in part to erosion in the channel. The TSS concentrations are significantly decreased in the marsh, due to the sedimentation that occurs at slower stream velocities.

A standard for suspended solids is not needed since suspended solids has no significant relationship to the recommended beneficial uses of the wash. Thus, it is recommended that the suspended solids standard be eliminated. If erosion control is provided in the future and there are any changes in beneficial uses in the wash, the need for a suspended solids standard could be reconsidered.

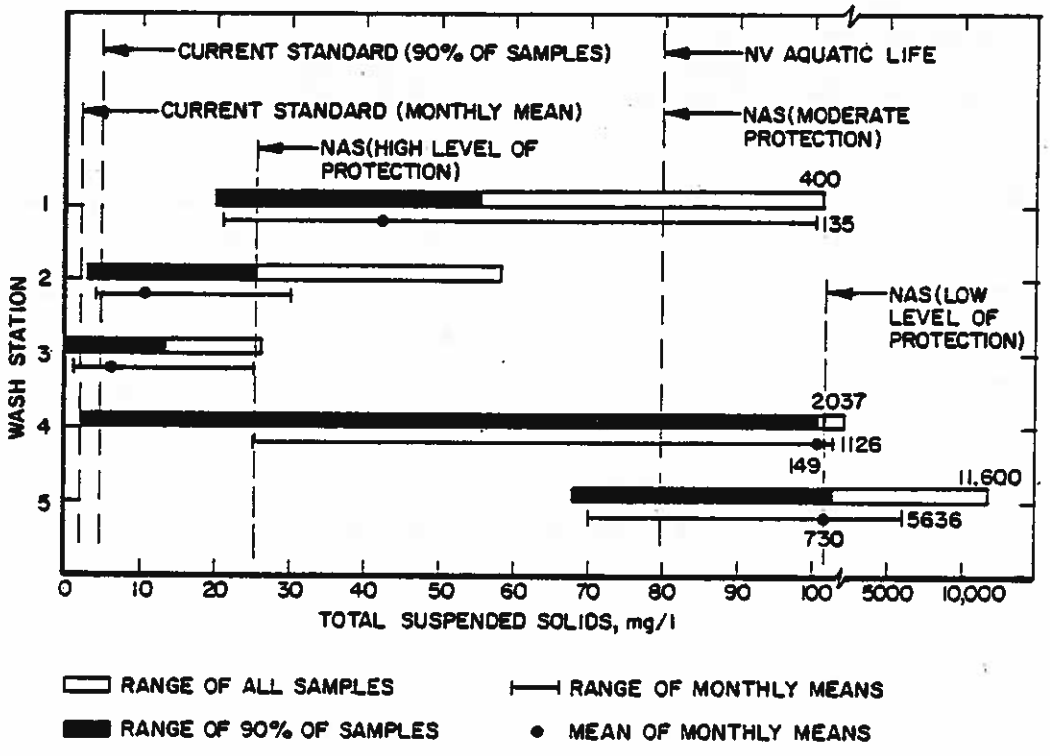


Figure 6-44 Comparison of Total Suspended Solids Data With Standards and Criteria

Methylene-Blue-Active-Substances. The concentration of Methylene-Blue-Active-Substances (MBAS) in Las Vegas Wash affects the beneficial uses of aesthetics and wildlife. MBAS are surfactants contained in synthetic detergents which can result in foaming and frothing of the water. Frothing, foaming water is aesthetically unpleasing and may adversely affect the bird and wildlife population. The current MBAS standards for Las Vegas Wash at Northshore Road are:

Monthly mean—Not more than 0.8 mg/l
Single value in 90 percent of samples—Not more than 1.0 mg/l

The State, EPA, and NAS have no recommendations for MBAS criteria. Only one sample was collected and analyzed for MBAS at each of the five Las Vegas Wash stations. The concentration at Station 1 was 1.3 mg/l which exceeds the standards listed above. The concentrations at the other four stations ranged from 0.17 to 0.22 mg/l. Clark County Sanitation District records indicate that MBAS in the treatment plant effluent averaged about 1.7 mg/l in 1978 and 1979. MBAS was not reported after February 1980. It appears that surfactants used in new detergents (linear alkylate sulfonate) quickly degrade in the wash, with MBAS levels diminishing rapidly as the water flows down the wash.

The current standards of 0.8 mg/l and 1.0 mg/l are adequate to prevent aesthetic problems and protect wildlife. Although only a small amount of MBAS data in the wash are available, it is likely that the current standard is met except in a localized area just downstream of the treatment plant discharges.

Phosphorus. The concentration of phosphorus in Las Vegas Wash does not affect the beneficial uses of the wash. The current phosphorus standards for Las Vegas Wash at Northshore Road are:

Monthly mean—not more than 0.5 mg/l
Single value in 90 percent of samples—Not more than 1.0 mg/l
Load (April to October)—Not to exceed 400 lbs/day

The State criteria include phosphorus as a parameter to be controlled for aesthetics with the value to be determined by bioassay. Phosphorus is of concern to aesthetics when it stimulates algal growth in water bodies where boating and swimming are desired uses. The phosphorus data at each of the five wash stations are compared to these standards on Figure 6-45. The concentration standards are not met at any of the wash stations. The load standard is not met at Stations 1, 3, or 5. Loading data are not available at Stations 2 and 4.

A phosphorus standard is not needed to protect the beneficial uses of the wash since boating and swimming are not current uses. Thus, the phosphorus standards for the wash should be eliminated. However, a phosphorus load limitation may be needed at Northshore Road to protect the beneficial uses of Las Vegas Bay.

Turbidity. The turbidity of the Las Vegas Wash water affects the beneficial uses of fish and other forms of aquatic life as discussed in the suspended solids section. The current turbidity standards for Las Vegas Wash at Northshore Road are:

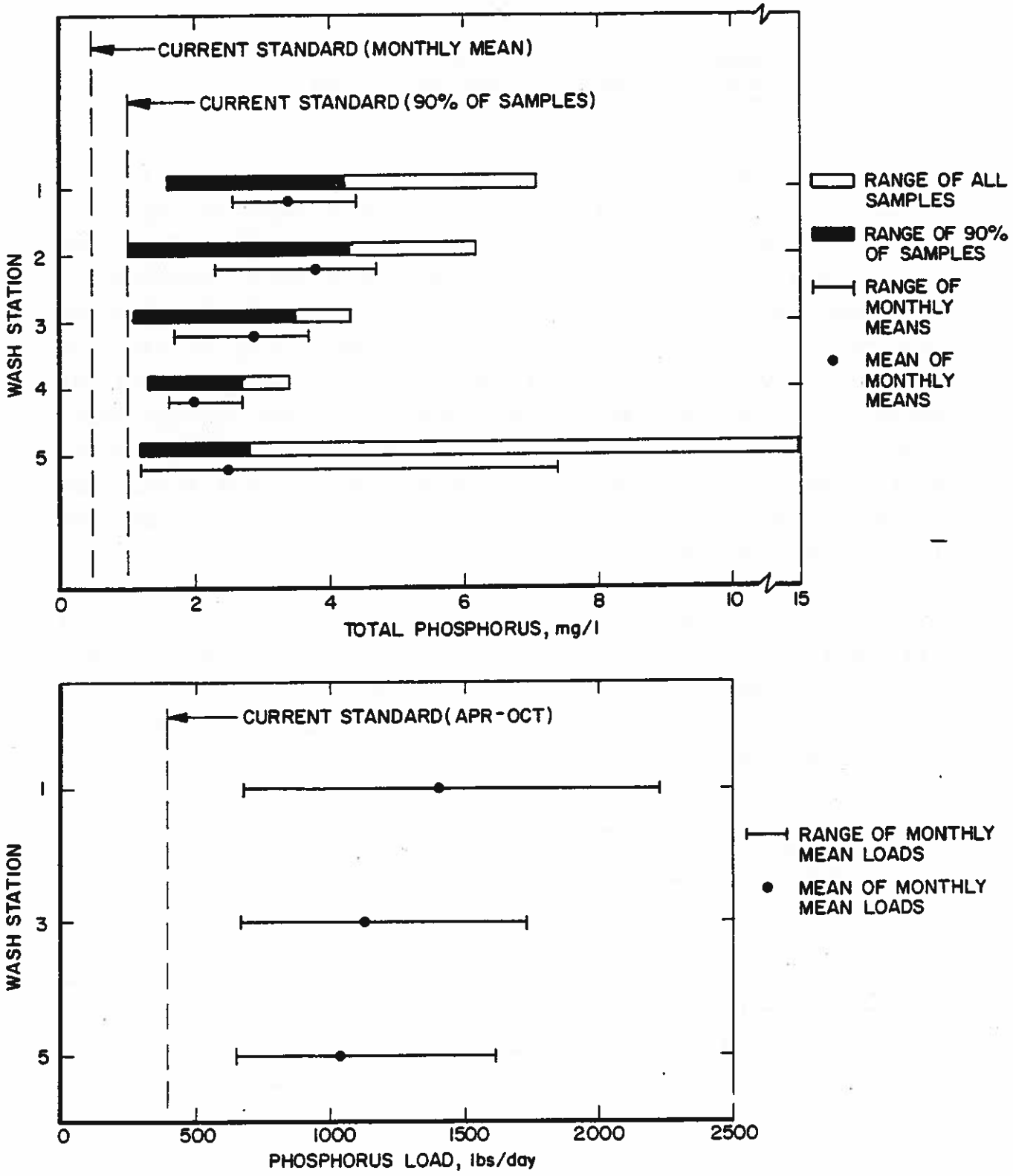


Figure 6-45 Comparison of Phosphorus Data With Standards and Criteria

Monthly mean—Not more than 5.0 JTU
Single value in 90 percent of samples—Not more than 10.0 JTU

The State criteria specify a maximum turbidity of 50 NTU for the protection of a warm-water fishery. There were no turbidity data collected in the wash during the WQSS. Based on suspended solids data, it is clear that the severe erosion occurring in the lower wash would prevent the existing turbidity standards from being met. As in the case of suspended solids, a criterion for turbidity is not needed since turbidity has no significant relationship to the recommended beneficial uses of the wash. Thus, it is recommended that the turbidity standard be eliminated. If erosion control is provided in the future and there are any changes in beneficial uses in the wash, the need for a turbidity standard could be reconsidered.

Fecal Coliforms. The fecal coliform concentrations of Las Vegas Wash affect the beneficial uses of body contact recreation, agricultural water supplies, and wildlife. The current fecal coliform standards for Las Vegas Wash at Northshore Road are:

30-day geometric mean—not more than 200/100 ml
(based on a minimum of 5 samples)
10 percent of samples—not more than 400/100 ml

The State of Nevada recommends that the fecal coliform concentration should not exceed 1,000/100 ml for the protection of agricultural water supplies and wildlife. The fecal coliform data at each of the five wash stations are compared to these standards and criteria on Figure 6-46. The geometric mean of

all samples collected during the WQSS was calculated since there were never five samples collected during a 30-day period. The geometric mean values at Stations 1, 3, 4, and 5 were less than the standard of 200/100 ml. The geometric mean at Station 2 was 800/100 ml. The fecal coliform concentrations at all five stations exceeded the 400/100 ml standard and the 1,000/100 ml criterion proposed by the State.

Although coliforms are harmless to man, they indicate that pathogenic organisms may also be present if the source of the coliforms is human. The ratio of fecal coliforms to fecal streptococci is an indication of whether the pollutant source is human or animal. A ratio greater than 4.4 generally indicates the source is human while a ratio less than 0.6 indicates the source is not human.[10] As discussed previously, the fecal coliform/fecal streptococci ratios in the wash were generally less than 4.4. This indicates that the fecal coliforms found in the wash are primarily from nonhuman sources, such as birds and other warm-blooded animals. Although the nonhuman sources of fecal coliforms do not carry the same risk of human pathogens that may be associated with human sources, it is likely that the nonhuman sources will continue to cause violations of the State fecal coliform standard. There is no assured method of determining if human pathogens are present without analyzing the wash water directly for pathogens. The analytical procedures used to test directly for human pathogens are difficult and costly. Continued use of the wash for a wildlife habitat will result in high fecal coliform values independent of discharges from the wastewater treatment plants. Thus, the fecal coliform standard should be eliminated and an effluent limitation of 200/100 ml should be relied upon to insure that fecal coliforms are not of human origin.

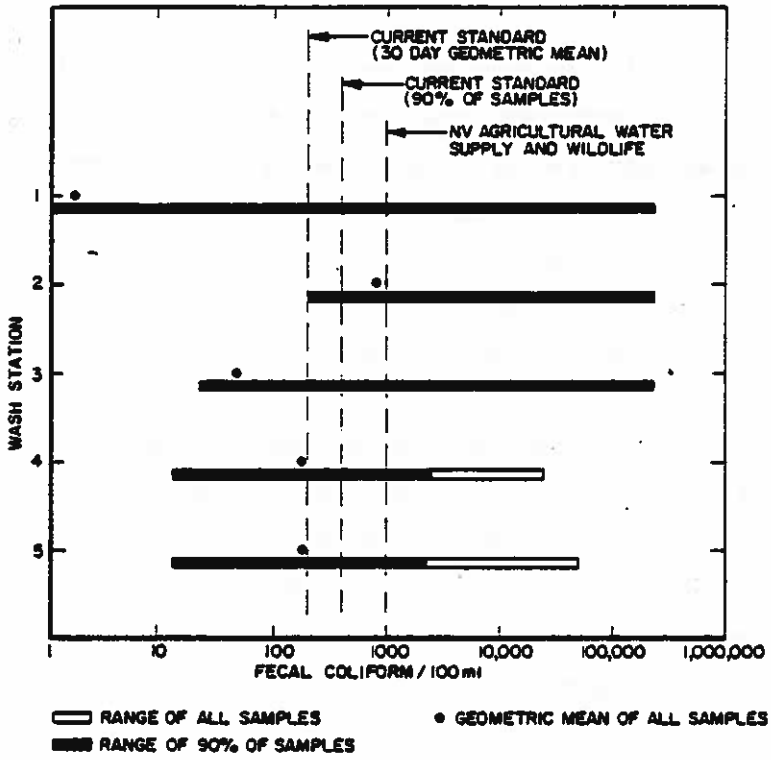


Figure 6-46 Comparison of Fecal Coliform Data with Standards and Criteria

Un-ionized Ammonia. The un-ionized ammonia concentration of Las Vegas Wash affects the beneficial uses of fish and other forms of aquatic life. Un-ionized ammonia is toxic to fish as discussed in Chapter 10 of this report. There is not an existing standard for un-ionized ammonia; however, the State of Nevada recommends that the un-ionized ammonia concentration should not exceed 0.1 mg/l N for the protection of warm water aquatic life and 0.016 mg/l N for the protection of cold water aquatic life. The EPA and NAS recommend a criterion of 0.016 mg/l N for the protection of aquatic life. These criteria are discussed in detail in Chapter 10. The un-ionized ammonia data at each of the five wash stations are compared to these criteria on Figure 6-47. The criterion of 0.016 mg/l N was consistently

exceeded at all five wash stations. The criterion of 0.1 mg/l N was exceeded frequently at all stations, although the mean values were approximately equal to or less than the criterion at all stations except Station 5.

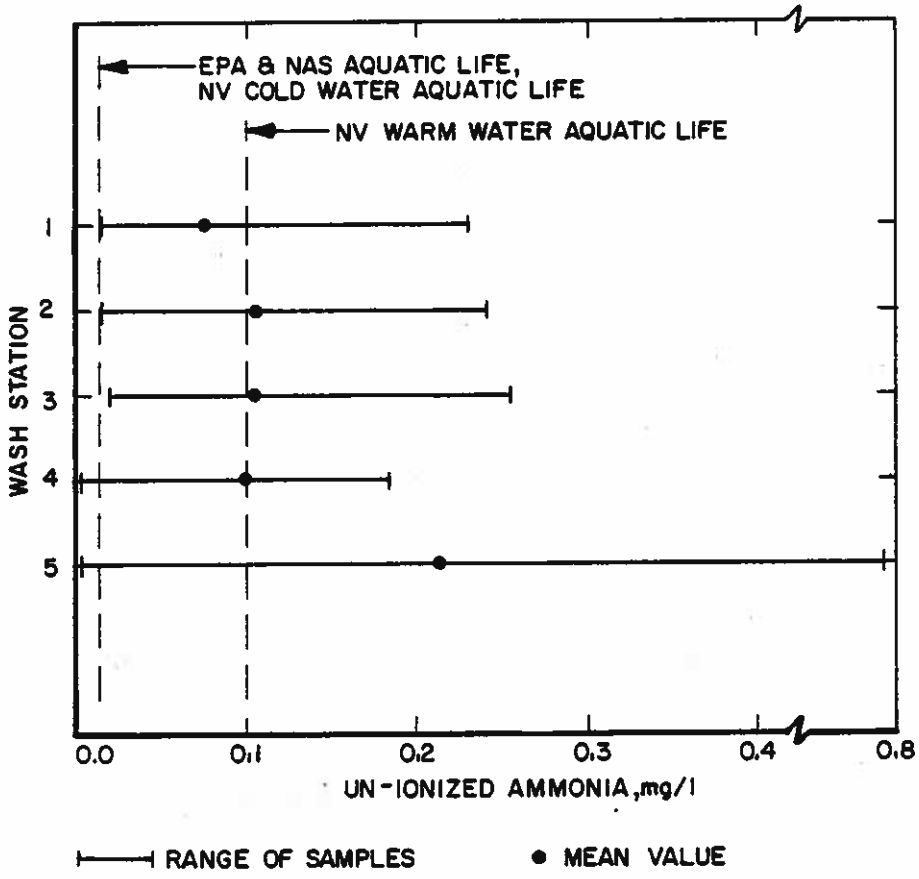


Figure 6-47 Comparison of Un-ionized Ammonia Data with Criteria

These criteria are designed to protect a fishery. Since it is recommended that fish be deleted as a use in the wash, there is no reason to establish an un-ionized ammonia standard.

Nitrate. The nitrate concentration of Las Vegas Wash affects the beneficial uses of aquatic life, wildlife, and agricultural water supplies. There is not an existing standard for nitrate; however, the State of Nevada recommends that the nitrate concentration should not exceed 90 mg/l for the protection of aquatic life, and 100 mg/l for the protection of agricultural water supplies and wildlife. The nitrate data at each of the five wash stations are compared to these criteria on Figure 6-48. The State criteria of 90 and 100 mg/l and the NAS criterion of 100 mg/l of nitrate plus nitrite were always met at all stations. The high concentrations of nitrate at Stations 4 and 5 were due to discharges of nitrate from BMI. The maximum nitrate concentrations in the wash are presented below:

Station 1	2.2 mg/l
Station 2	1.5 mg/l
Station 3	0.7 mg/l
Station 4	4.8 mg/l*
Station 5	5.6 mg/l*

*With exception of discharges from BMI.

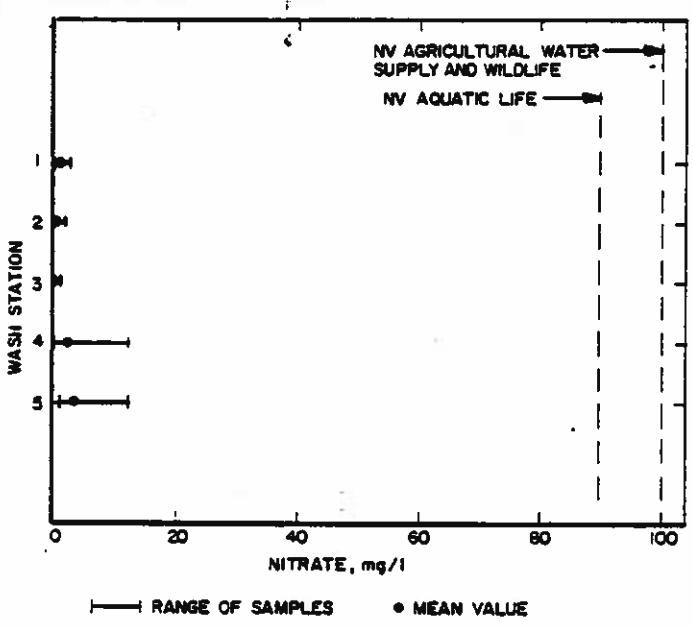


Figure 6-48 Comparison of Nitrate Data with Criteria

It is recommended that a nitrate standard of 25 mg/l be adopted based on non-degradation of existing total nitrogen concentrations. This will allow for beneficial conversion of existing levels of ammonia to nitrate and is still well within the recommended 100 mg/l nitrate criterion for protection of wildlife.

Nitrite. The nitrite concentration of Las Vegas Wash affects the beneficial uses of aquatic life, wildlife, and agricultural water supplies. There is not an existing standard for nitrite; however, the State of Nevada recommends that the nitrite concentration not exceed 0.5 mg/l for the protection of aquatic life. The State recommends a criterion of 10 mg/l for the protection of agricultural water supplies and wildlife. The nitrite data at each of the five wash stations are compared to these criteria on Figure 6-49. The State criterion of 0.5 mg/l was exceeded at all five stations, although the mean nitrite concentrations were much less than 0.5 mg/l at Stations 1, 2, and 3. There was only one violation of the 0.5 mg/l criterion at each of these stations. The State criterion of 10 mg/l was consistently met at all stations. The 0.5 mg/l criterion is for the protection of a warm water fishery. Since it is recommended that the warm water fishery beneficial use be dropped due to problems associated with the lack of suitable fish habitat in the wash, it is not necessary to establish a standard for the protection of a warm water fishery. The State criterion of 10 mg/l for the protection of agricultural water supplies and wildlife was consistently met at all stations. The maximum nitrite concentrations in the wash are presented below:

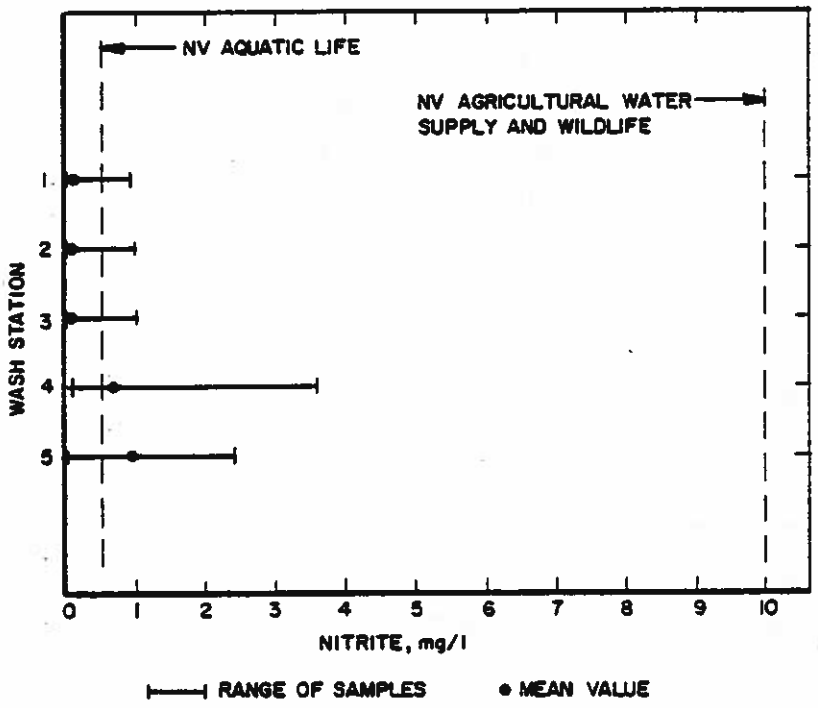


Figure 6-49 Comparison of Nitrite Data with Criteria

Since it is unlikely that nitrite will exceed current concentrations, which are well below the suggested level, it is not necessary to establish a water quality criterion for nitrite.

Total Dissolved Solids. The total dissolved solids concentration of Las Vegas Wash affects the beneficial use of agricultural water supply. TDS affects osmotic pressure, limiting the uptake of water through plant roots. TDS is also toxic to certain sensitive crops. There is not an existing standard for TDS; however, the State of Nevada recommends a TDS concentration of less than or equal to 1,000 mg/l for the protection of agricultural water supplies. The TDS data at each of the five wash stations are compared to this criterion on Figure 6-50. The TDS concentrations at all wash stations

consistently exceeded the criterion. Much of the TDS in the wash water is added from groundwater as the wastewater flows through the wash. Present TDS levels in the wash are not adversely affecting the existing irrigation use because wash water is blended with other lower TDS waters prior to irrigation use.

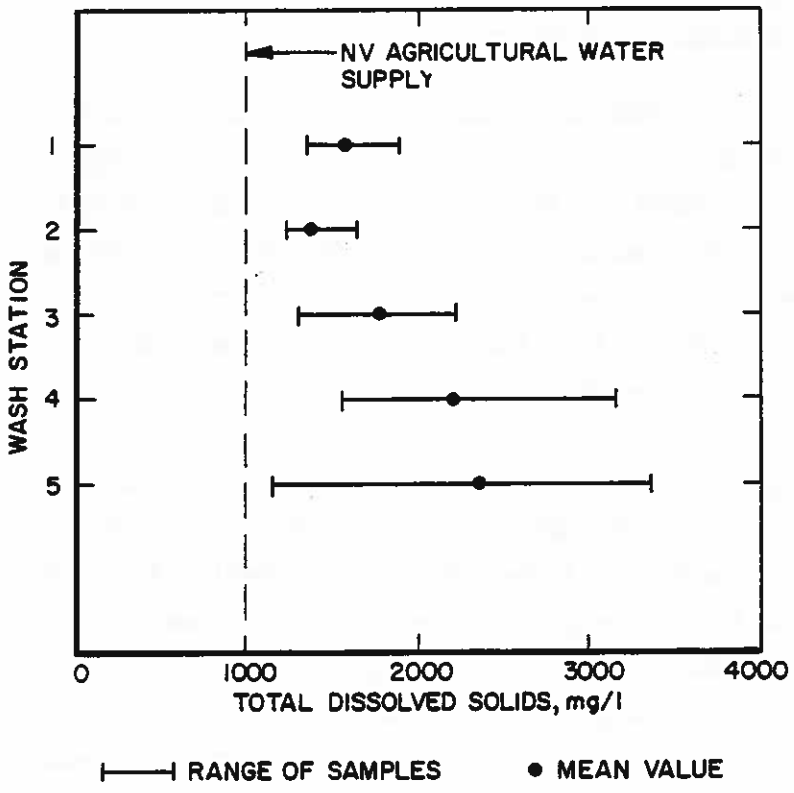


Figure 6-50 Comparison of Total Dissolved Solids Data with Criteria

The marsh vegetation can tolerate 6,000 mg/l TDS.[3] Thus, in order to maintain the marsh vegetation, this level should not be exceeded. Other irrigation uses can continue to be achieved

by blending wash water with lower TDS waters or, as done in several cases, direct diversion of treated wastewaters which are lower in TDS than the wash water. The maximum concentrations in the wash during the WQSS are presented below:

Station 1	1,873 mg/l
Station 2	1,630 mg/l
Station 3	2,210 mg/l
Station 4	3,135 mg/l
Station 5	3,341 mg/l

Appropriate TDS or salinity levels in the Colorado River system and salinity control are broad issues that go beyond the scope of WQSS. Resolution of these issues in the future will likely influence TDS standards for Las Vegas Wash. Thus, it is inappropriate to develop a recommendation for a TDS criterion based on the limited evaluation of the salinity issue made as part of the WQSS.

Alkalinity. The alkalinity of Las Vegas Wash affects the beneficial uses of aquatic life and wildlife. Alkalinity is important to aquatic life because it reduces the magnitude of pH changes that can occur in aquatic systems. There is not an existing standard for alkalinity; however, the State of Nevada recommends a range of 30 to 130 mg/l as $CaCO_3$ for the protection of wildlife. The State and EPA recommend a criterion of greater than or equal to 20 mg/l for the protection of aquatic life. This lower limit is to assure adequate buffering capacity to pH changes. The alkalinity data at each of the five wash stations are compared to these criteria on Figure 6-51. The alkalinity concentrations at all five wash stations consisitently met the 20 mg/l criterion for the protection of aquatic life. The criteria range of 30 to

130 mg/l for the protection of wildlife was never met at any of the wash stations. The alkalinity concentrations in the wash ranged from 134 to 330 mg/l as $CaCO_3$. The basis for the State's recommended upper limit of 130 mg/l as $CaCO_3$ is unknown. The State Guidelines reference NAS; however, NAS does not recommend a range of 30 to 130 mg/l. Their recommendation is that alkalinity not be decreased more than 25 percent below the natural level.

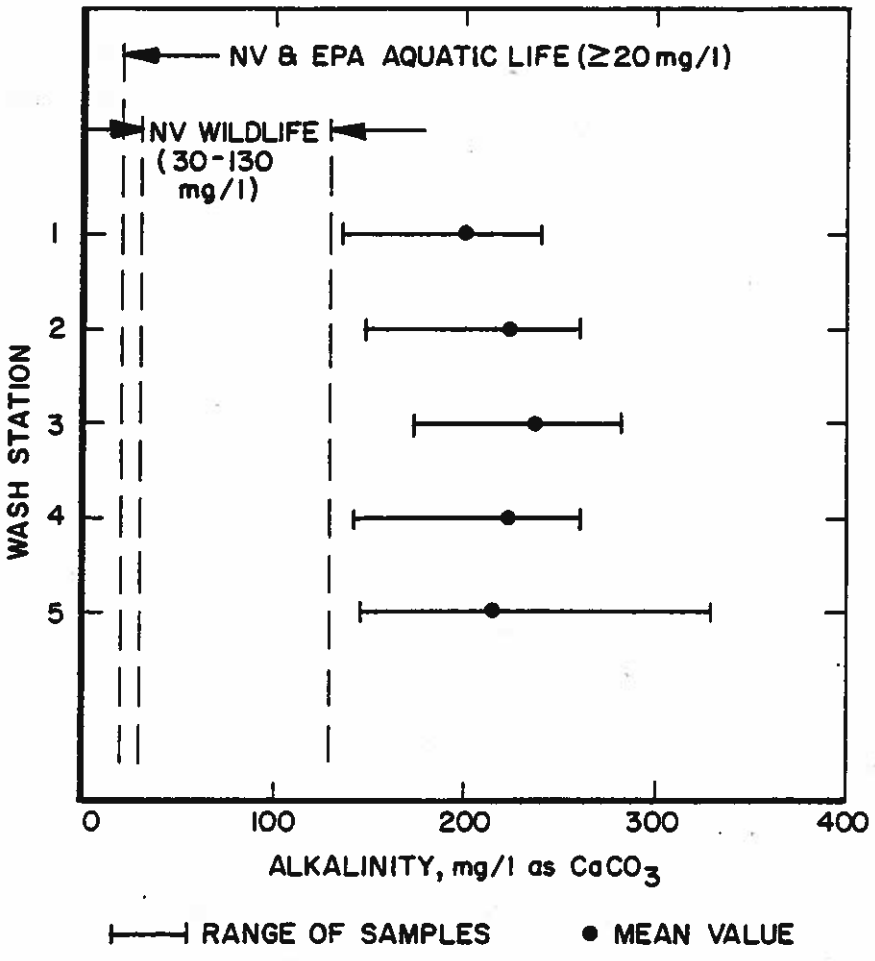


Figure 6-51 Comparison of Alkalinity Data with Criteria

The water supplies in Las Vegas are high alkalinity waters and are probably the major source of the alkalinity concentrations in the upper wash. Since there is no practical approach for controlling alkalinity in this region of highly alkaline waters, no alkalinity standard is recommended.

Toxics. The recommended beneficial uses of the wash, particularly wildlife, should also be protected against toxic substances. No toxics data for Las Vegas Wash were collected as part of the WQSS. Analysis of wash samples for the 65 priority pollutants was proposed in the WQSS, but the work was never authorized. Thus, it is not possible to make any recommendations related to water quality standards for toxics. Some toxics data have been collected by USGS at Northshore Road and the data are described in Chapter 12.

CONCLUSIONS

Conclusions resulting from the analysis of Las Vegas Wash data are as follows:

1. The Clark County Sanitation District and City of Las Vegas treatment plants contribute 98 percent of the total phosphorus load and 86 percent of the total nitrogen load to Las Vegas Wash. The other surface water sources contribute 2 percent of the total phosphorus load and 4 percent of the total nitrogen load. Groundwater contributes the remaining 10 percent of the total nitrogen load.
2. Las Vegas Wash has historically removed 16 to 28 percent of the total phosphorus, 7 to 51 percent of the total nitrogen, and 92 to 96 percent of the ammonia load discharged to the wash from the treatment plants.

3. During the WQSS, approximately 250 kg/day or 30 percent of the total phosphorus was removed in 1979. In 1980, an average of 150 kg/day or 18 percent of the total phosphorus was removed. The decrease in removal occurred after the large storm of February 1980, when the headcut advanced by 4,500 feet and drained a large area of marsh.

4. Most of the total phosphorus removal occurs in the upper wash between Stations 1 and 3. Phosphorus removal in the wash is likely due to adsorption to sediments, settling of particulate phosphorus, and biological uptake.

5. During 1979, approximately 1,300 kg/day or 34 percent of the total nitrogen was removed in the wash. In 1980, an average of 450 kg/day or 12 percent of the total nitrogen was removed. The decrease in removal occurred after the large storm of February 1980 which resulted in a decrease in the marsh acreage.

6. Most of the total nitrogen removal occurs in the upper wash between Stations 1 and 3, however, most of the ammonia removal occurs in the lower wash. Nitrogen removal in the wash is likely due to biological assimilation, denitrification, and adsorption to sediments.

7. The nutrient removal capacity of the wash is remarkable considering that the travel time is only 18 hours and the flow is channelized throughout most of the wash. If the flow was slowed down by spreading the water

throughout the marsh or impounding the water in a series of ponds, greater nutrient removal would be expected to occur. Since the nutrient removal capacity of the wash is decreasing, consideration should be given to mechanisms that will prevent future loss of removal capacity in the wash.

8. Regarding the beneficial uses of Las Vegas Wash, the following is recommended: irrigation, stock watering, and wildlife should be maintained as uses; aesthetics and recreation should be maintained as a use, but it should be qualified to exclude body-contact recreation; and fish should be deleted as a use.

9. The data collected in WQSS provide a basis for comparing existing water quality conditions to water quality criteria. Water quality standards recommendations can be made for most key parameters; the recommendations developed in this chapter are summarized along with the overall WQSS recommendations in Chapter 13.

CHAPTER 7

NUTRIENT BUDGET

Water quality conditions in Las Vegas Bay are affected by nutrient loads from Las Vegas Wash and other sources. Preparation of a nutrient budget is an important element of the Water Quality Standards Study (WQSS) because the budget provides a basis for comparison of the magnitude of the nutrient sources.

INTRODUCTION

The need to develop a nutrient budget for WQSS was identified in the Consent Decree and the work plans for WQSS. This section describes the background of nutrient budget work performed in Segment I of the WQSS and identifies the specific objectives of this chapter.

Background

A preliminary nutrient budget was completed in June 1980 as part of the Segment I WQSS work. The preliminary nutrient budget relied upon literature and data available at that time and indicated potential major sources of nutrients to the bay. The preliminary nutrient budget thus enabled identification of areas where additional effort was needed. As a result, data collection including a study of sediments was completed. Other new sources of data include stormwater analyses performed by the Clark County Department of Comprehensive Planning as part of its 208 work, groundwater analyses performed as part of the WQSS, and continuing exchange of information with the U.S. Bureau of Reclamation (USBR). All

of these sources of information have been utilized in refining the nutrient budget.

Objectives

The main objectives of this chapter are:

1. Define the sources of nutrients to Las Vegas Bay and estimate their relative magnitude.

2. Determine which nutrient source(s) is(are) most significant to provide a sound basis for any nutrient control plans that may be considered.

METHODOLOGY

Nutrient budgets were prepared for Las Vegas Bay since it is the portion of Lake Mead that is most affected by nutrient discharges. During WQSS planning, consideration was given to expanding the nutrient budget to cover all of Boulder Basin. However, key program participants agreed to focus the nutrient budget work on just Las Vegas Bay.

Nutrient budgets were prepared for Las Vegas Bay to correspond to the period of routine WQSS lake limnological monitoring, i.e., July 1979 through November 1980. Total phosphorus, orthophosphorus, total nitrogen, and dissolved inorganic nitrogen are each addressed. Nutrient budget estimates were made using the best available data. Data sources have included literature values, previous studies of Lake Mead, and data collection efforts conducted as a part of the WQSS.

COMPONENTS OF THE NUTRIENT BUDGET

The primary components of the nutrient budget include Las Vegas Wash, stormwater runoff, groundwater, sediment nutrient exchange, atmospheric fallout, nitrogen fixation, fish harvesting, Boulder Basin exchange, and biological uptake. A conceptual diagram of the nutrient budget components is shown on Figure 7-1. Each component is discussed below.

Las Vegas Wash

Treated wastewater effluent, industrial cooling water, surfacing groundwater, and stormwater runoff from the Las Vegas Valley all discharge to Las Vegas Wash. During the WQSS monitoring program, wash water samples were taken at Northshore Road approximately every other week. Results of the wash sampling program reported in Chapter 6 were averaged on a monthly basis and multiplied by average monthly flow data obtained from the U.S. Geological Survey (USGS) streamflow gaging station at Northshore Road to calculate the monthly wash loads shown in Table 7-1.

Stormwater Runoff

Las Vegas Wash has a drainage area of about 1,600 square miles which contributes directly to surface runoff. Runoff loads from the wash are included in the wash load calculation to the extent that storms occurred on sampling days. The second largest wash discharging to the bay is Gypsum Wash. Gypsum Wash has a drainage area of about 80 square miles. Excluding the Las Vegas Wash, a total of about 150 square miles drain to Las Vegas Bay. Stormwater flows were estimated based upon these

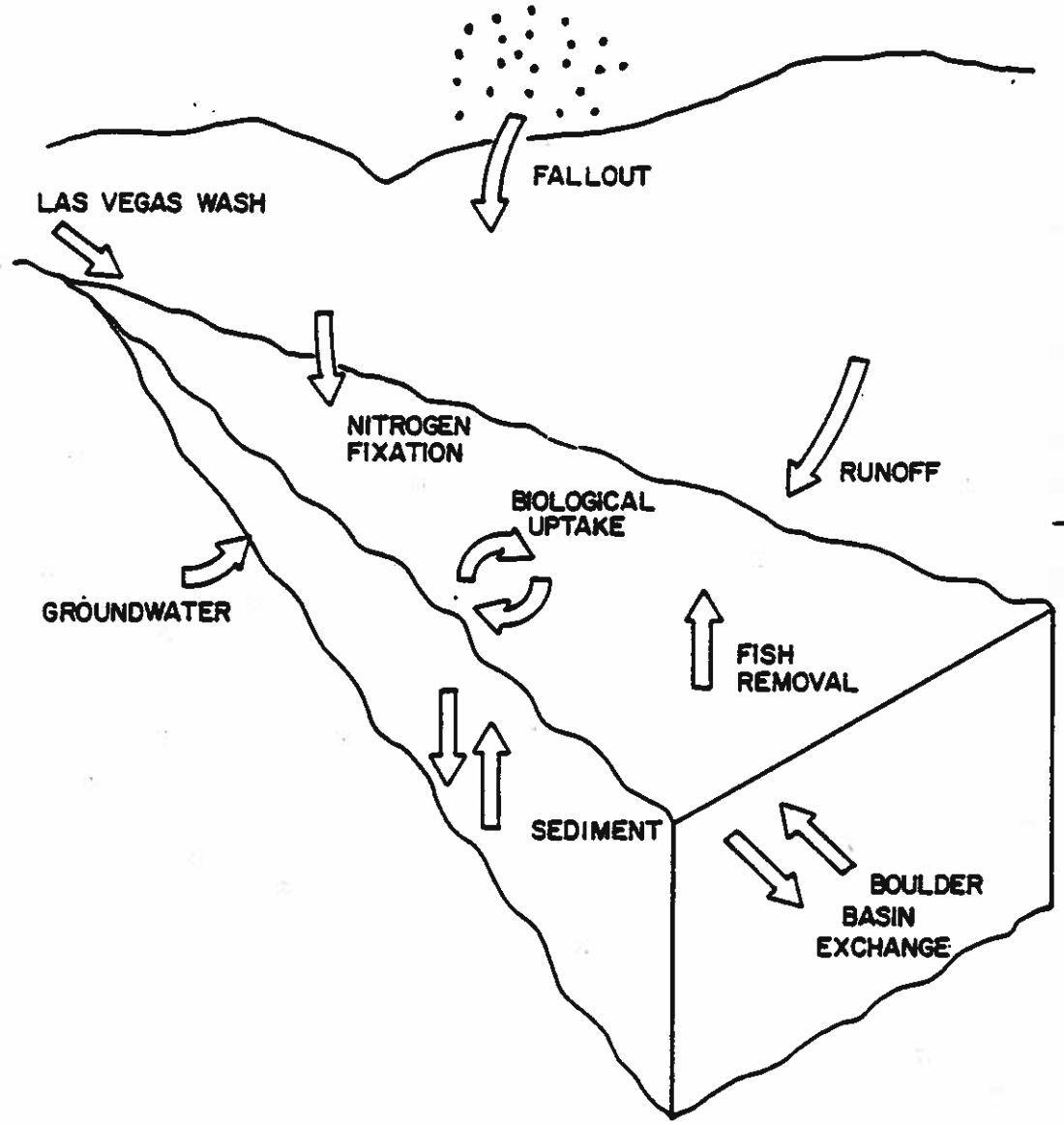


Figure 7-1 Nutrient Budget Components

Table 7-1. Las Vegas Wash Nutrient Loads

Month	Load,[a] 1,000 kg/month			
	Ortho P, as P	Total P, as P	Inorganic N, as N	Total N, as N
07/79	11.0	11.0	57.3	64.0
08/79	9.9	9.2	67.2	70.8
09/79	10.0	12.0	68.9	75.6
10/79	13.2	15.3	82.7	83.4
11/79	12.8	15.5	116.9	126.3
12/79	15.0	17.8	98.3	103.3
01/80	12.0	14.6	95.5	107.4
02/80	8.9	32.2	66.2	95.2
03/80	11.7	45.8	152.5	169.5
04/80	15.3	18.3	93.8	114.4
05/80	9.3	12.1	79.0	96.1
06/80	10.5	11.8	65.0	82.0
07/80	11.8	22.1	71.8	98.6
08/80	12.2	16.5	78.7	93.0
09/80	13.4	17.1	83.5	96.9
10/80	14.5	18.3	104.2	114.1
11/80	9.2	14.4	88.2	94.7
12/80	14.6	16.0	104.2	111.2

[a]Based on samples taken at Northshore Road and U.S. Geological Survey streamflow measurements.

areas using a runoff coefficient of 0.1 inch of runoff/inch of rainfall. This is the same runoff coefficient used by the USGS and Nevada Division of Water Planning in the Water Resources Reconnaissance series of reports.

Nutrient concentrations were determined based upon stormwater samples collected in the Las Vegas Wash at Vegas Valley Drive by the Clark County Department of Comprehensive Planning, and samples collected in Gypsum Wash and Las Vegas Wash as part of the WQSS. Table 7-2 summarizes the stormwater monitoring data.

The relatively high concentrations of total phosphorus in runoff are somewhat surprising. The low concentrations of orthophosphorus indicate that most of the total phosphorus is mineralized and bound to the sediment. Research in Lake Tahoe indicates that nutrients bound to sediment may be released through the action of attached bacteria; however, if the suspended sediment settles to the lake bottom, the nutrients are not released.[1]

Applying the mean nutrient concentrations to the stormwater runoff flows resulting from precipitation which occurred during the study period, as measured at McCarran Airport, yielded estimated stormwater runoff nutrient loads, excluding Las Vegas Wash, summarized in Table 7-3. Precipitation data for the study period are presented on Figure 3-2.

Groundwater

The majority of groundwater flowing into Las Vegas Bay originates in the Las Vegas Valley and flows below the Las Vegas Wash. Estimates of groundwater flows made by USBR have ranged

Table 7-2. Stormwater Monitoring Data

Location	Date	Concentration, mg/l			
		Ortho P, as P	Total P, as P	Inorganic N, as N	Total N, as N
Las Vegas Wash at Vegas Valley Drive	7/20/79	—	—	1.00	1.60
	8/12/79	<0.02	—	0.70	1.64
	8/12/79	<0.02	—	0.94	1.74
	8/12/79	<0.02	—	1.73	2.75
	8/12/79	<0.02	—	1.50	2.02
	8/12/79	<0.02	—	1.23	2.03
	8/12/79	<0.02	—	1.21	1.77
	8/12/79	<0.02	—	0.98	1.38
	8/13/79	0.24	—	3.62	3.73
	8/13/79	0.11	—	1.08	1.25
	1/29/80	—	—	0.29	0.75
	1/29/80	—	—	0.24	0.25
	1/29/80	—	—	0.81	1.69
	7/01/80	—	—	3.05	3.67
	7/01/80	—	—	3.08	4.26
	7/01/80	—	—	3.11	3.84
Gypsum Wash	8/12/79	0.020	35.95	1.42	5.78
	8/12/79	0.021	5.92	1.54	2.71
	7/09/81	<0.01	11.75	—	—
Small unnamed wash	8/12/79	0.025	5.28	0.84	1.90
	8/12/79	0.026	2.20	0.76	0.89
Las Vegas Wash at Northshore Road	2/18/80	—	12.86[a]	—	—
	2/19/80	—	3.06[a]	—	—
Average		0.04	11.00	1.46	2.28

[a]Determined by subtracting average dry weather concentrations.

Table 7-3. Stormwater Runoff Nutrient Loads to Las Vegas Bay

Month	Load,[a] 1,000 kg/month			
	Ortho P, as P	Total P, as P	Inorganic N, as N	Total N, as N
7/79	0.034	18	2.5	3.9
8/79	0.095	50	6.7	11
9/79	0	0	0	0
10/79	0	0	0	0
11/79	0.001	0.71	0.095	0.15
12/79	0.010	5.7	0.76	1.2
1/80	0.064	34	4.6	7.2
2/80	0.10	53	7.1	11
3/80	0.042	22	3.0	4.7
4/80	0.008	4.3	0.57	0.89
5/80	0.007	3.6	0.48	0.75
6/80	0	0	0	0
7/80	0.019	10	1.4	2.1
8/80	0	0	0	0
9/80	0.008	4.3	0.57	0.89
10/80	0.002	0.95	0.13	0.02
11/80	0	0	0	0

[a]Excludes runoff tributary to Las Vegas Wash.

from 1,000 to 2,000 acre-feet per year. An estimated flow of 1,500 acre-feet per year has been used in USBR's most recent groundwater modeling effort.[2] This excludes groundwater that surfaces in Las Vegas Wash and is contained in the wash flow at Northshore Road. Other sources of groundwater to the bay are the Black Mountains area and the River Mountains. Groundwater flow from the Black Mountains area, which extend from the wash to the Muddy River along the northwest shore of Lake Mead, and the River Mountains, which extend from the wash along the southwest shore of Lake Mead, and the west side of the Colorado River south to Lake Mohave, has been estimated to total 1,100 acre-feet per year.[3,4] The shoreline of Las Vegas Bay is only a very small part of the area receiving these groundwater flows, and the contribution to the bay is probably less than 100 acre-feet per year.

Groundwater sampling was conducted as part of Phase II of the Treatment Facilities Study (TFS-II) during January 1981, using the wells and well identification codes previously used by Kauffman in his 1978 report.[5] A map and detailed description of the sampling program are contained in Chapter 6. The data collected are shown in Table 7-4. Total phosphorus was not measured, so it is assumed that all phosphorus is in the dissolved form. In calculating loads, values reported as less than the detection limit are assumed to be the detection limit concentration. The WQSS data compare quite well with data collected by Kauffman. Applying the mean concentrations obtained in the WQSS program to the estimated annual groundwater flow of 1,600 acre-feet results in annual nutrient loads of 20 kg/year of orthophosphorus as P, 20 kg/year of total phosphorus as P, and 11,000 kg/year of nitrate plus nitrite as N.

Table 7-4. Groundwater Monitoring

Date	Well identification	Concentration data, mg/l			
		Ortho P, as P	Total P, as P	Nitrate N, as N	Nitrite N, as N
1/14/81	LG 005	<0.01	<0.01	4.1	<0.01
	LG 010	<0.01	<0.01	14.0	<0.01
	LG 016	<0.01	<0.01	0.09	<0.01
	LG 030	<0.01	<0.01	5.0	<0.01
	LG 034	<0.01	<0.01	2.3	0.05
	LG 151	<0.01	<0.01	8.3	<0.01
1/19/81	LG 005	<0.01	<0.01	3.1	0.35
	LG 010	<0.01	<0.01	14.0	<0.01
	LG 016	<0.01	<0.01	0.12	<0.01
	LG 030	<0.01	<0.01	4.8	<0.10
	LG 034	<0.02	<0.01	2.3	0.04
	LG 151	<0.01	<0.01	8.3	0.25
1/26/81	LG 005	<0.01	<0.01	3.4	0.09
	LG 010	<0.01	<0.01	14.0	<0.01
	LG 016	<0.01	<0.01	0.02	<0.01
	LG 030	<0.01	<0.01	4.8	0.04
	LG 034	<0.01	<0.01	2.2	0.05
	LG 151	<0.01	<0.01	8.3	0.02
Average		<0.01	<0.01	5.5	0.06

Sediment Nutrient Exchange

As part of the WQSS, a study of sediment nutrient exchange was performed by Dr. James Murray and is included in Appendix D. The following paragraphs summarize the WQSS sediment study.

Three forms of nutrient exchange are related to the sediment. The first is the removal of nutrients from the bay water through the accumulation of sediments at the lake bottom. The second is release of orthophosphorus as organic matter oxidizes in the sediment. The third form of nutrient exchange results from dentrification as organic matter is oxidized in the

sediment. Although release of ammonia from sediment often occurs concurrently with the dentrification process, ammonia release was not indicated in the sediment study.

The rate of accumulation of sediment was determined through analyses of the activity of radioactive isotopes buried in the sediment. To determine the average rate of sediment accumulation in the bay, the results reported by Dr. Murray were plotted according to the relative position of the sampling points. In this manner, an average sediment accumulation rate in the bay of about 5 kg/m^2-year was estimated. Analyses of core samples collected indicate that the sediment is composed of 0.11 percent total phosphorus and 0.15 percent total nitrogen dry weight. By applying the sediment accumulation rate and sediment analyses to the area of the bay, annual total phosphorus removal through sedimentation was estimated to be about 150,000 kg/year. The estimated total nitrogen removal rate through sediment accumulation is 200,000 kg/year.

As organic matter decomposes in the sediment, it is oxidized. Although during the sediment survey, dissolved oxygen measurements indicated aerobic conditions in the water at the bay bottom, the sediment core samples were anaerobic. Under anaerobic conditions, oxidation of organic matter occurs concurrently with denitrification. As a result of the oxidation process, orthophosphorus and nitrogen gas are generated. By analyzing the concentration of orthophosphorus in the pore water contained in the sediment, a concentration gradient between the pore water and bottom water can be estimated. When the bottom water is aerobic, oxidized iron compounds form a layer on top of the sediments. These iron compounds give the sediment surface a reddish-brown color and reduce the rate of orthophosphorus

migration from the sediment to the bottom water. The iron compounds do not, however, reduce the rate of oxygen and nitrate migration into the sediment. In Dr. Murray's study, rates of flux of nutrients were calculated based upon the pore water concentrations and bottom water quality at the time of sampling using Fick's law of diffusion. To improve the annual estimates of nutrient flux, bottom water quality has been determined throughout the year. Pore water quality for the outer bay stations has been estimated based upon trends evidenced in the analysis of the inner bay stations. The resultant nutrient flux rates are 17,200 kg/year of orthophosphorus released from the sediment and 11,000 kg/year of nitrite and nitrate denitrified in the sediment.

In June 1981, a sediment study was prepared by the Lake Mead Limnological Research Center for the USBR.[6] That report has been reviewed, and, in general, data and findings are comparable to the WQSS sediment study.

Atmospheric Fallout

Because the preliminary nutrient budget indicated that atmospheric fallout is a relatively minor source of nutrients, additional effort has not been made to refine the preliminary estimates. Literature values of atmospheric nutrient loading rates referenced in the preliminary nutrient budget are tabulated in Table 7-5. To provide a conservative estimate of the fallout load, the maximum values reported were used: 39 mg-P/m^2-yr dissolved phosphorus, 74.4 mg-P/m^2-yr total phosphorus, 1,010 mg-N/m^2-yr dissolved inorganic nitrogen, and 1,600 mg-N/m^2-yr total nitrogen. These rates include both loading from precipitation and dust fall, and were applied to

the average bay surface area of 30 km^2. The resulting annual atmospheric fallout loads are 1,100 kg dissolved phosphorus as P, 2,200 kg total phosphorus as P, 29,000 kg dissolved inorganic nitrogen as N, and 45,000 kg total nitrogen as N.

Table 7-5. Atmospheric Nutrient Loading Rates

Source	Location	Rate, mg/m^2-yr
Dillon, 1974[7]	Ontario, Canada	77.2 Total phosphorus as P
Gomolka, 1975[8]	Ontario, Canada	37.0 Total phosphorus as P
Murphy, et al, 1975[9]	Lake Michigan	2.74 Total phosphorus as P[a] 1.63 Total dissolved phosphorus as P[a]
Nichols and Cox, 1978[10]	Harp Lake, Canada	74.4 Total phosphorus as P 39.0 Total dissolved phosphorus as P 1,600.0 Total nitrogen as N 1,010.0 Dissolved inorganic nitrogen as N
Uttormark, 1975[11]	Ontario Great Lakes	1,000.0 Total nitrogen as N[b] 250.0 Total nitrogen as N[b]

[a]Precipitation only
[b]Estimated

Nitrogen Fixation

Under certain conditions, some species of blue-green algae form heterocysts which are capable of utilizing nitrogen gas directly from the atmosphere to form proteins. During the summer months, blue-green algae represented a significant portion of the phytoplankton populations (expressed as number of organisms) analyzed as part of the WQSS. The proportion of the total algae population represented by blue-green algae was much

less when expressed as biomass. (The significance and diversity of the phytoplankton population is detailed in Chapter 8.) However, over the course of the WQSS, nearly 200 analyses of nitrogen fixation were made and nitrogen fixation was never detected. Therefore, as a source of nitrogen, nitrogen fixation is assumed insignificant.

Fish Harvesting

An average of about 800,000 fish were caught each year in Lake Mead from 1977 to 1979.[12] Assuming an average weight of 0.7 kg per fish, about 550,000 kg of fish were removed each year. A 1976 study of the nutrient content of fish indicates that fish contain about 0.4 percent phosphorus and 2.6 percent nitrogen by wet weight.[13] Applying these percentages, about 2,200 kg of phosphorus and 14,000 kg of nitrogen are removed from Lake Mead annually through removal of fish. Although the Las Vegas Bay represents only a small portion of the surface area of Lake Mead, it is one of the more heavily fished areas. Assuming that one-third of the fish removed from Lake Mead are taken from the bay, about 730 kg of phosphorus and 4,700 kg of nitrogen are removed by fish harvesting annually.

Boulder Basin Exchange

Although direct measurement of Boulder Basin exchange through studies aimed at determining circulation patterns was considered during formulation of the WQSS, such studies were not included in the final WQSS work plan and direct measurements were not made.

As part of the nutrient budget task, an attempt was made to determine the rate of nutrient exchange to Boulder Basin. The

procedure used consisted of solving a water balance on Boulder Basin, including Las Vegas Bay, to determine the flow from Virgin Basin to Boulder Basin. Using nutrient measurements and the calculated flow from Virgin Basin, nutrient inputs were balanced against outputs via withdrawals, solving for the input from Las Vegas Bay via the Boulder Basin exchange. The approach, however, relied upon a number of assumptions regarding runoff, nutrient storage, and sedimentation rates in Boulder Basin. In addition, the calculations were extremely sensitive to small changes in nutrient concentrations. For example, in some cases, a change in orthophosphorus concentrations of 1 ug/l equated up to a 100 percent change in nutrient storage. For these reasons, calculation of Boulder Basin exchange using the existing WQSS data base is judged impractical.

However, a qualitative indication of the effect of Boulder Basin exchange can be obtained by comparing nutrient concentrations at various stations. Comparison of nutrient measurements at Stations 5, 8, and 9 indicates that Boulder Basin exchange acts as a nutrient sink. Monthly mean nutrient concentrations for all sample depths at Stations 5, 8, and 9 are compared in Table 7-6. For the phosphorus species, concentrations at Station 5 were greater than at Stations 8 and 9 for all months. Nitrogen concentrations at Station 5 were greater for nearly all months. Because nutrient concentrations in Boulder Basin are lower than in the bay, any circulation from Boulder Basin into the bay dilutes the higher concentration bay water. Therefore, Boulder Basin exchange acts as a nutrient sink rather than source.

Biological Uptake

Biological uptake consists of the conversion of inorganic nutrients to organic nutrients by metabolic uptake. Biological

Table 7-6. Comparison of Nutrient Concentrations at Stations 5, 8, and 9

	Concentration,[a] mg/l											
	Ortho P, as P			Total P, as P			Inorganic N, as N			Total N, as N		
	Station			Station			Station			Station		
Month	5	8	9	5	8	9	5	8	9	5	8	9
07/79	0.030	0.005	0.001	0.051	0.010	0.004	0.244	0.141	0.195	0.451	0.355	0.353
08/79	0.023	0.004	0.002	0.039	0.009	0.004	0.200	0.135	0.168	0.434	0.406	0.405
09/79	0.028	0.003	0.001	0.037	0.007	0.004	0.191	0.121	0.198	0.313	0.326	0.361
10/79	0.032	0.003	0.001	0.047	0.007	0.004	0.214	0.144	0.199	0.428	0.340	0.392
11/79	0.015	0.006	0.002	0.032	0.012	0.006	0.122	0.163	0.238	0.403	0.319	0.430
12/79	0.006	0.005	0.002	0.014	0.012	0.004	0.134	0.187	0.271	0.348	0.373	0.446
01/80	0.009	0.005	0.002	0.015	0.009	0.003	0.197	0.218	0.242	0.374	0.395	0.426
02/80	0.020	0.005	0.002	0.056	0.013	0.005	0.403	0.258	0.262	0.631	0.468	0.453
03/80	0.013	0.005	0.002	0.025	0.009	0.004	0.320	0.250	0.282	0.577	0.417	0.434
04/80	0.031	0.004	0.002	0.041	0.009	0.006	0.422	0.247	0.267	0.681	0.480	0.435
05/80	0.024	0.004	0.002	0.033	0.009	0.007	0.336	0.211	0.243	0.554	0.375	0.428
06/80	0.017	0.004	0.002	0.030	0.011	0.008	0.277	0.176	0.219	0.564	0.396	0.453
07/80	0.027	0.002	0.001	0.040	0.010	0.011	0.275	0.157	0.230	0.488	0.306	0.370
08/80	0.014	0.002	0.001	0.026	0.010	0.004	0.202	0.147	0.212	0.417	0.332	0.345
09/80	0.017	0.001	0.001	0.030	0.008	0.006	0.178	0.150	0.217	0.413	0.332	0.360
10/80	0.018	0.001	0.002	0.033	0.010	0.007	0.216	0.174	0.221	0.449	0.376	0.398
11/80	0.024	0.002	0.001	0.043	0.011	0.013	0.361	0.235	0.242	0.487	0.370	0.377
Average	0.020	0.004	0.002	0.035	0.010	0.006	0.252	0.183	0.230	0.471	0.375	0.404

[a]Average of all sample depths.

uptake is not a component of the nutrient budgets for total phosphorus or nitrogen. Biological uptake does affect the budgets for orthophosphorus and inorganic nitrogen by conversion to organic nutrients. Biological uptake is cyclical in nature and consists of both synthesis and regeneration. It is generally accepted that algae need a relatively fixed atomic ratio of carbon to nitrogen to phosphorus of 106 to 16 to 1.[14] Primary productivity data collected in the WQSS enable calculation of the total carbon uptake in the bay. Using the primary productivity data at Stations 2 and 5, it is estimated that about 17,000,000 kg of carbon are synthesized annually in

the bay. Based upon the atomic ratio needed by algae, it is estimated that about 3,000,000 kg of inorganic nitrogen and 400,000 kg of orthophosphorus are converted to organic nutrients annually. However, a considerable portion of the nutrients are recycled through excretion and decomposition. Because it is not possible to estimate the recycling of nutrients, net conversion of inorganic nutrients to organic species cannot be calculated.

SUMMARY OF SOURCES AND SINKS

Based upon the estimates of individual components, nutrient budgets for Las Vegas Bay have been developed. The annual budgets for orthophosphorus, total phosphorus, inorganic nitrogen, and total nitrogen for the period October 1979 through September 1980 are shown in Table 7-7.

Table 7-7. Nutrient Budget for Las Vegas Bay

Component	Load,[a] 1,000 kg/year			
	Ortho P, as P	Total P, as P	Inorganic N, as N	Total N, as N
Sources				
Las Vegas Wash	146	239	1,084	1,266
Runoff (excluding Las Vegas Wash)	<1	64	8	13
Fallout	1	2	29	45
Groundwater	<1	<1	11	11
Sediment release	17	17	0	0
Nitrification	—	—	0	0
Sinks				
Sedimentation	0	150	0	200
Dentrification	—	—	11	11
Boulder Basin exchange	NE[b]	NE	NE	NE
Fish harvesting	0	<1	0	5
Biological uptake	NE	0	NE	0

[a]October 1979 to September 1980.
[b]Not estimated.

All appreciable sources of nutrients are included in the tabulation. However, it has not been possible to develop a balance of the sources with the sinks, since there are insufficient data to estimate the magnitude of some of the sinks. One significant nutrient sink that has not been estimated is the net conversion of inorganic nutrients to organic species through biological activity. The resultant organics are lost from the bay through sedimentation and Boulder Basin exchange. Estimation of Boulder Basin exchange relied most heavily upon limited data regarding average concentrations, sedimentation rates, etc., in Boulder Basin. Limited data, however, make refinements difficult.

The relative magnitude of sources of orthophosphorus, total phosphorus, inorganic nitrogen, and total nitrogen to Las Vegas Bay are depicted on Figures 7-2 through 7-5, respectively. In all cases, Las Vegas Wash is several times greater than all other sources combined. Although total phosphorus loads from stormwater are appreciable, stormwater loading is sporadic in nature, and a significant portion of the nutrients bound to sediment may not be released.

Of the sources, estimates of the wash input, stormwater runoff load, and groundwater load are all based upon actual data for this system. The sediment release estimate, although based upon sampling conducted during the study, has a limited data base. The estimate of atmospheric fallout is based upon literature values.

CONCLUSIONS

Conclusions resulting from the nutrient budget work are as follows:

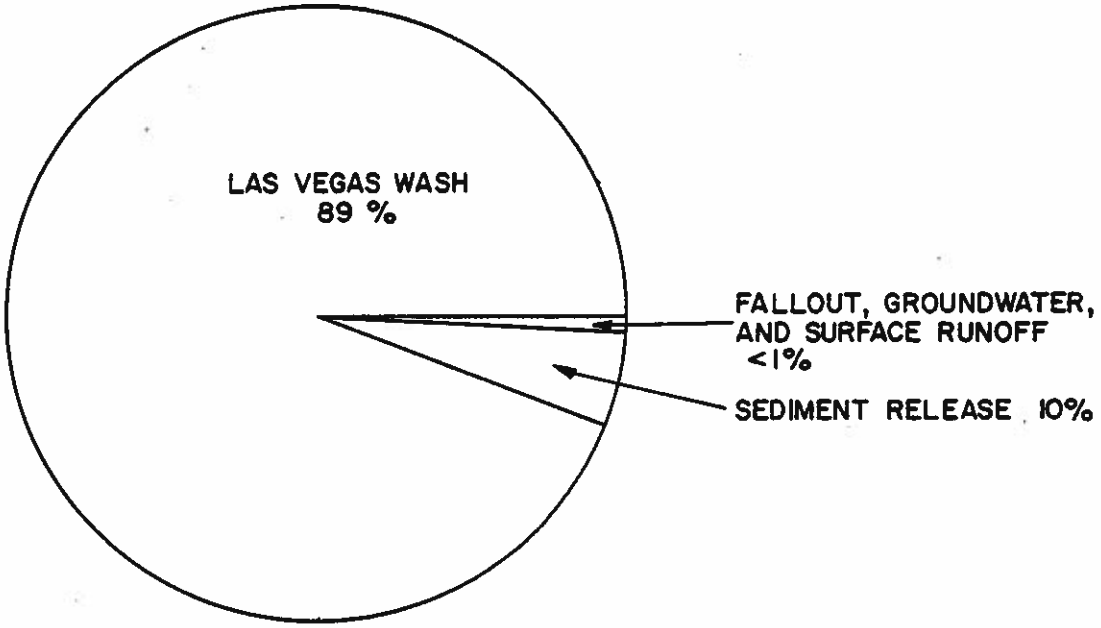


Figure 7-2 Sources of Orthophosphorus to Las Vegas Bay

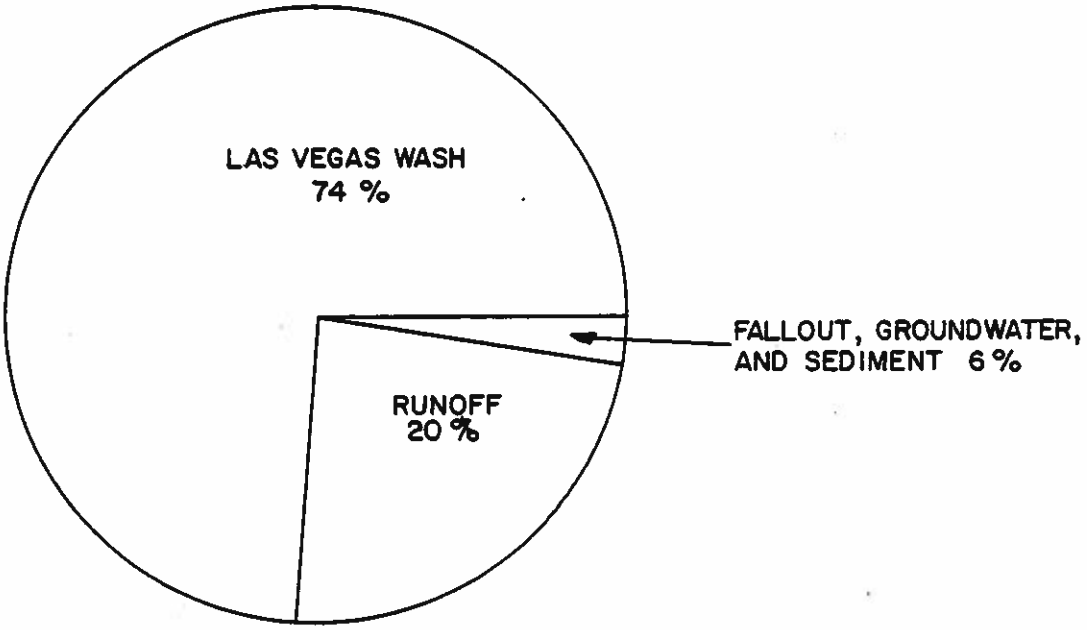


Figure 7-3 Sources of Total Phosphorus to Las Vegas Bay

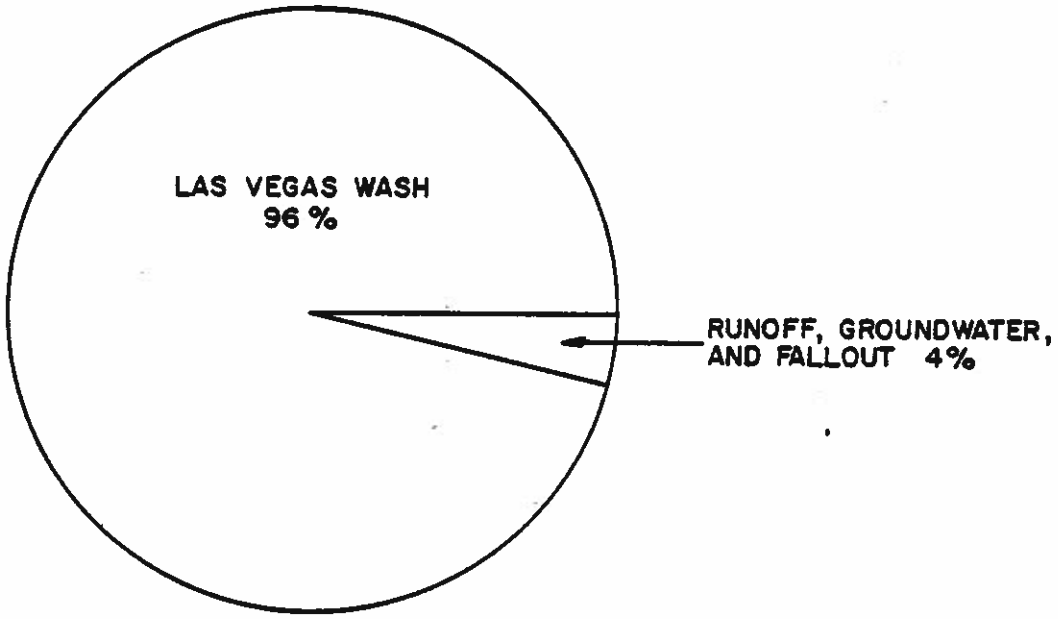


Figure 7-4 Sources of Inorganic Nitrogen to Las Vegas Bay

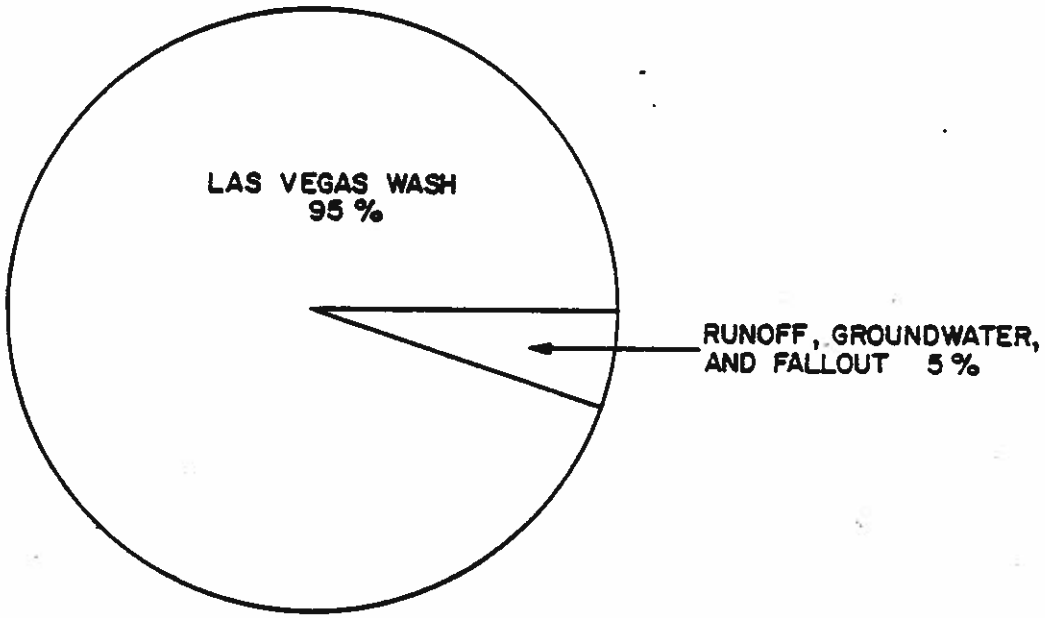


Figure 7-5 Sources of Total Nitrogen to Las Vegas Bay

1. Las Vegas Wash is the primary source of phosphorus to Las Vegas Bay. On an annual basis (October 1979 to September 1980), the wash contributed 74 percent of the total phosphorus and 89 percent of the orthophosphorus.

2. Las Vegas Wash is the primary source of nitrogen to Las Vegas Bay. On an annual basis (October 1979 to September 1980), the Wash contributed 95 percent of the total nitrogen and 96 percent of the inorganic nitrogen.

3. Data to estimate nutrient sinks, particularly Boulder Basin exchange and biological uptake, are inadequate to develop a balance between sources and sinks.

CHAPTER 8

TRANSPARENCY, ALGAE, AND NUTRIENTS

Water transparency is one of the principal issues related to beneficial uses of Las Vegas Bay and Lake Mead. Data and analysis describing how transparency is controlled by the characteristics of water flowing into the lake and by the processes occurring in the lake are described in this chapter.

INTRODUCTION

The background, problem definition and objectives of the transparency analysis, and the organization of the chapter are described in this section.

Background

During initial development of the Water Quality Standards Study (WQSS) work plan, water transparency was identified as one of the key water quality issues to be assessed. Much of the monitoring program design centered around the transparency issue. Both WQSS contracts (Contracts 2 and 6) described the need to analyze the factors affecting transparency.

Several interim products have been prepared which relate to the analysis of transparency, algae, and nutrients.

1. Segment I reports for the Bioassay and Data Analysis tasks were prepared and submitted as required under Contract 2.

2. Compilations of data collected under WQSS up to October 30, 1979, and April 1, 1980, respectively, were prepared and distributed to study participants for the January and June 1980 data review meetings.

3. Conceptual plans for analysis of WQSS data to develop relationships required by the Consent Decree were presented in the Contract 6 work plan.

4. Preparation of the Annual Progress Report provided an exchange of ideas between study participants on methods for estimating total maximum daily loads (TMDL).

Problem Definition

The Consent Decree establishes the general framework for analysis of transparency, algae, and nutrients. When a beneficial use is affected by algal growth, Paragraph 20 of the Consent Decree delineates several specific steps to be followed. These steps are summarized in Table 5-3. The goal of these steps is to establish a quantitative relationship between the transparency of water in the lake and water quality factors that control it. General knowledge of water quality relationships in lakes and means of controlling water quality inputs from wastewater discharges suggest the need to define how this relationship may vary both spatially and seasonally.

The analysis of transparency can be divided into two parts: analysis of the water quality factors that directly affect transparency of water, and analysis of the water quality factors controlling algal or phytoplankton growth. Thus, this

chapter will address three principal questions concerning the factors directly affecting transparency:

1. What factors control transparency of water in Las Vegas Bay and Lake Mead?

2. What is the quantitative relationship between transparency and the controlling factors?

3. How do the quantitative relationships vary seasonally and spatially?

Similarly, three questions will be addressed concerning the factors affecting phytoplankton growth:

1. Assuming that the phytoplankton concentration controls water transparency, what water quality factors control the phytoplankton population (chlorophyll concentration) in Las Vegas Bay and Lake Mead?

2. What is the quantitative relationship between chlorophyll concentration and the controlling factors?

3. How do the quantitative relationships vary seasonally and spatially?

Phytoplankton are the free-floating algae in the lake as distinct from attached algae or periphyton. Hereafter in this chapter, the term algae will be used for simplicity and will refer exclusively to phytoplankton.

Objectives

Objectives of this chapter are as follows:

1. To present WQSS data that pertain to transparency and algae.

2. To analyze the data in accordance with the general framework outlined in the Consent Decree and the WQSS work plans. This will be done to develop quantitative relationships between water transparency and algae levels and between algae levels and controlling water quality factors in the lake.

3. To estimate the degree of control of nutrients entering Las Vegas Bay from Las Vegas Wash needed to control transparency conditions.

4. To identify effects of water transparency on beneficial uses of the lake.

Chapter Organization

The discussion in this chapter is divided into seven sections: (1) Introduction, (2) Methodology, (3) Results, (4) Data Comparisons, (5) Data Analysis, (6) Effects on Beneficial Uses, and (7) Conclusions.

In sections containing data presentation and analysis, the material is divided into subsections dealing with the two major parts of the transparency issue, transparency dependence

on algae, and algae dependence on water quality. Data collected in the WQSS pertaining to the transparency issue are voluminous. To keep the chapter of manageable length, principal elements of the data are presented and summarized within the chapter. Data of secondary and supporting importance are located in appendices. Essential features of methodology concerning sampling, analysis, and data analysis are described in the report. Details of methodology are contained in appendices.

METHODOLOGY

The general approach and methodology used in the WQSS are described in Chapter 5. This section presents additional methodology specific to transparency, algae, and nutrient relationships. The majority of data presented in this chapter was developed in the limnological monitoring program. Additional data important to transparency analysis were developed in the Hydraulic Study and the Bioassay Task. Reference to such information is made as required in this chapter.

As described in Chapter 5, detailed WQSS planning at the outset of the study resulted in a work plan. The plan defined the primary methods to be used for measuring transparency, algae, and nutrient relationships in the lake. Secchi disc depth was specified as the principal measure of water transparency. Chlorophyll was specified as the principal measure of algal concentration. Nitrogen and phosphorus were identified as the algal nutrients of principal interest.

Data collection in the WQSS to define transparency-algae-nutrient relationships can be divided into four major

categories: (1) general water quality, (2) transparency relationships, (3) algal relationships, and (4) nutrient limitation.

General Water Quality

Collection of general water quality data was organized to provide both seasonal and spatial variations. The entire study covered two full algal growing seasons beginning in March 1979 and ending November 1980, as described in Chapter 5, Figure 5-2. The schedule for data collected in this period is specifically related to the transparency issue summarized in Table 8-1. As shown in the table, routine sampling was conducted at weekly, biweekly, or monthly intervals. Additional samples were collected at hourly intervals over two 24-hour periods to establish water quality variations over the diurnal cycle.

Sampling locations were established to define the spatial scale of water quality in Las Vegas Bay and Lake Mead. Eleven routine and index stations were established to show water quality differences from the inner bay to background areas, Figure 5-3. These stations were established along the centerline of Las Vegas Bay and of Bonelli Bay. Approximately 30 synoptic stations were sampled four times to show the degree of lateral and longitudinal variation around the routine stations. The location of these stations is shown on Figure 8-1. The variation of water quality in the vertical direction was established by sampling at intervals from the surface to the bottom at regular sampling stations.

With minor exceptions, the water quality sampling and analysis was conducted by the University of Nevada at

Table 8-1. Data Collection Schedule

Parameter	Sampling Frequency
	3/22/79 — 4/4/79 — 6/27/79 — 7/25/79 — 10/31/79 — 12/19/79 — 2/21/80 — 3/21/80 — 10/31/80 — 11/21/80
Physical	
Secchi disc depth	⊢ Interim sampling period ⊣
Light transmittance	⊢ Weekly → Two weeks → Monthly → Two weeks → Weekly → Two weeks ⊣
Color	
Suspended solids	⊢ Two weeks → Weekly → Two weeks → Monthly → Two weeks → Weekly → Two weeks ⊣
Temperature	
Specific conductance	
Chemical	
Dissolved phosphorus	⊢ Weekly → Two weeks → Monthly → Two weeks → Weekly → Two weeks ⊣
Nitrite	
Ammonia	
Orthophosphorus	⊢ Two weeks → Weekly → Two weeks → Monthly → Two weeks → Weekly → Two weeks ⊣
Total phosphorus	
Nitrate	
Total nitrogen	
Iron	⊢ Two weeks → Monthly → Two weeks ⊣
Silica	
Biological	
Chlorophyll *a*	⊢ Two weeks → Weekly → Two weeks → Monthly → Two weeks → Weekly → Two weeks ⊣
Pheophytin *a*	⊢ Weekly → Two weeks → Monthly → Two weeks → Weekly → Two weeks ⊣
Phytoplankton	
Zooplankton	
Physiological	
Primary productivity	⊢ Two weeks → Monthly → Two weeks ⊣
Nitrogen fixation	
Dark ammonia uptake	
Alkaline phosphatase	
Extractable phosphorus	
Bioassays	
Regular	⊢ Two weeks → Monthly → Two weeks ⊣
Special	⊢ Monthly ⊣
In situ	First — First
AAP	Second — Second

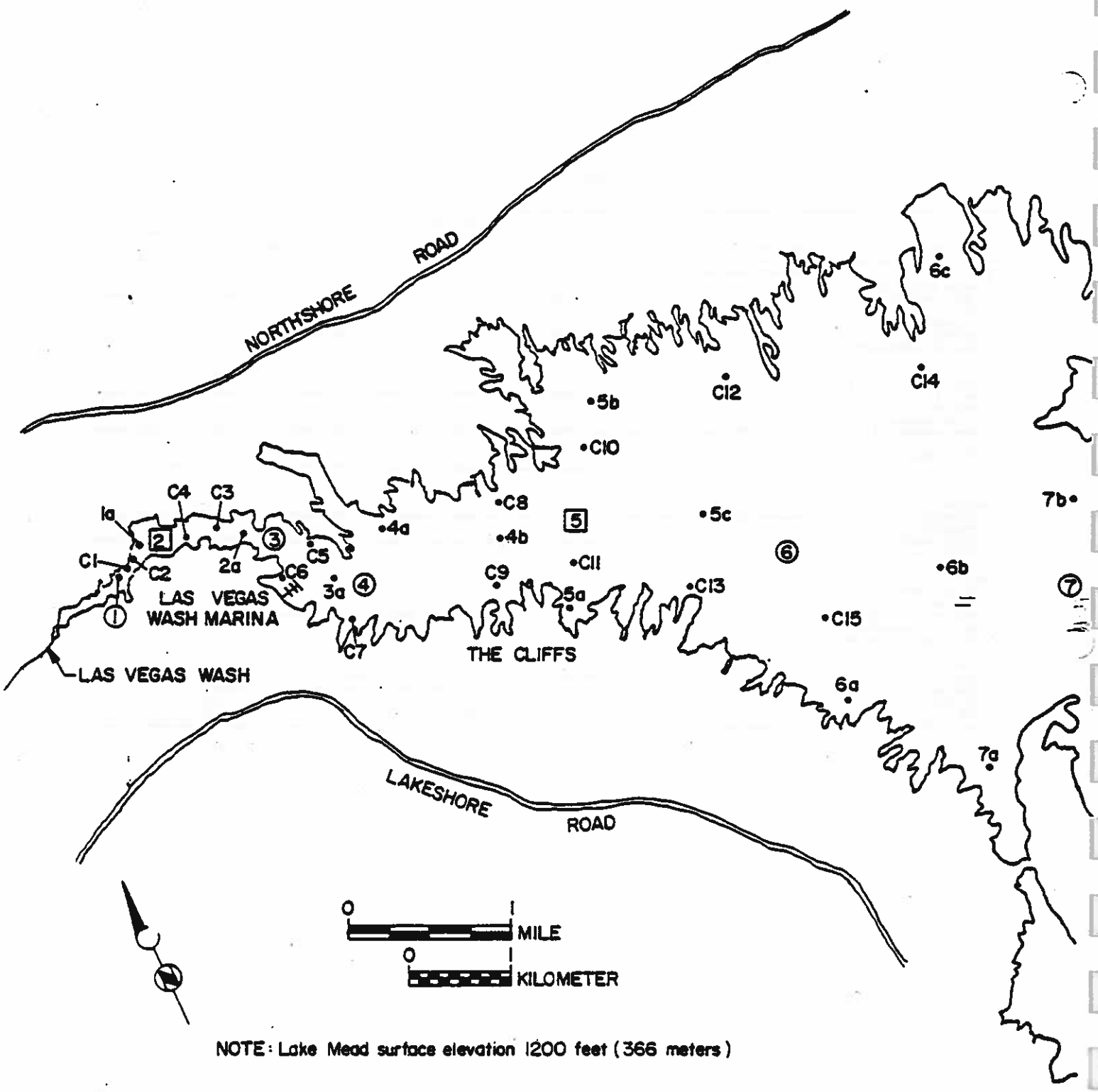


Figure 8-1 Intensive Survey Sampling Station Locations

Las Vegas (UNLV) under the direction of Dr. Larry Paulson. Details of sampling and analysis methodology are included in Appendix A. In summary, water quality samples were collected from the required stations according to the sampling schedule, Table 8-1. Water quality parameters that were measured in the WQSS, related to the transparency, algae, nutrient issue, are listed in Table 8-2 along with the basic purpose of the analysis.

Transparency Relationships

Water transparency was determined by measurement of the Secchi disc depth using an 8-inch-diameter (approximately 20 centimeters) Secchi disc and by measurement of light transmittance using a transmissometer. Light transmittance measurements were made at regular intervals from the surface to the bottom. Although Secchi depth measurements have been shown to be reproducible to approximately 1/10 meter under a wide variety of surface and lighting conditions, the light transmittance measurements which are made by an impartial electronic instrument are not subject to variability among human observers. Analysis of light transmittance measurements, therefore, can be made to identify errors or variability in Secchi disc measurements that might result from its use.

To define the factors controlling water transparency as measured by Secchi depth, measurements of the algae population, turbidity, and water color were made. The principal measure used for quantifying the algal population was chlorophyll. The influence of turbidity was measured by volatile suspended solids (VSS) and total suspended solids (TSS). The possibility of water transparency interference by color other than that

Table 8-2. Transparency Dependence Parameter List

Parameter	Purpose of analysis
Secchi disc depth	Water transparency measure.
Light transmittance	Water transparency measure.
Color	Component of transparency interference.
Suspended solids	Component of transparency interference.
Phytoplankton	Component of transparency interference.
Numbers	Measure of population level.
Biomass	Measure of population level.
Species	Determinant of clarity interference.
Temperature	Influences nutrient distribution and biological growth rates.
Specific conductance	Conservative tracer, indicator of lake structure.
Phosphorus	Principal phytoplankton nutrient.
Orthophosphorus	Principal available nutrient form.
Total dissolved	Measure of less available pool.
Total	Measure of total P resource.
Nitrogen	Principal phytoplankton nutrient.
Ammonia	Readily available form, sewage originated.
Nitrite	Readily available form, intermediate product.
Nitrate	Readily available form, terminal product.
Total	Measure of total N resource.
Iron	Essential micronutrient, influences nitrogen fixation.
Silica	Essential nutrient for diatom species.
Chlorophyll	Phytoplankton population measure, closely related to transparency interference.
Chlorophyll *a*	Pigment component produced in active growth.
Pheophytin *a*	Product of pigment decay—measure of population viability.
Total	Total population indicator.
Primary productivity	Measure of phytoplankton population activity.
Alkaline phosphatase activity	Indicator of phosphorus limitation.
Extractable phosphorus	Indicator of surplus phosphorus in algae.
Ammonia uptake, dark	Indicator of nitrogen limitation.
Nitrogen fixation	Indicator of nitrogen limitation.
Zooplankton	Principal predator of phytoplankton.

imparted by algal chlorophyll was provided for by measurement of water color.

Algal Relationships

Algal concentrations were established by three methods: measurement of the algal pigment, chlorophyll; counting algal numbers; and calculating the volume from algal numbers and cell volumes characteristic of individual species. The species composition of the algal population was determined during the enumeration process. Chlorophyll measurements were the principal population measure used for correlation with water transparency. Information collected on species composition, numbers, and volumes were used to assist in interpretation of water quality differences between locations in Las Vegas Bay and Lake Mead.

Physical, chemical, and biological parameters were measured to define the principal factors controlling the algal population. Principal chemical parameters included major nutrients, nitrogen, phosphorus, iron, and silica. Metals that might inhibit algal growth were periodically measured. Light and temperature measurements were the principal physical measurements related to algal growth. Biological measurements included primary productivity and measurements of the zooplankton and fish populations.

Nutrient Limitation

Several approaches were taken to identify nutrient limiting conditions in the algal population. Water quality data on nitrogen and phosphorus concentrations, alkaline phosphatase

activity, extractable phosphorus, nitrogen fixation, and dark ammonia uptake, all give some indication of either nitrogen or phosphorus limitation. An extensive program of bioassays was conducted to determine which nutrients stimulated the indigenous algal population.

Several types of bioassays were conducted. Details of the bioassay program are provided in Appendix C. In summary, the bioassay program consisted of four segments: regular bioassays, special bioassays, in situ bioassays, and standard Algal Assay Procedure (AAP) bioassays.

Regular Bioassays. A series of 23 "regular" bioassays was performed at weekly to monthly intervals, Table 8-1. Each followed the same plan, enriching 1-liter samples of lake water from Stations 2, 4, 5, and 8 with concentrations of nitrogen, phosphorus, nitrogen and phosphorus combined, and diluted Las Vegas Wash water. Growth response of the indigenous population to the enrichments was compared to growth in unenriched samples. The relative response indicated the sensitivity of the indigenous population to the respective nutrient treatments. Growth stimulation resulting from an individual treatment was interpreted as an indication of the population being limited by that particular enrichment.

Special Bioassays. A series of 19 "special" bioassays was conducted by similar methods to the regular bioassays. They were conducted throughout the WQSS, Table 8-1, and were used to test effects of treated and untreated wastewater, Las Vegas Wash water, and special nutrient combinations on indigenous populations in lake water samples from the standard stations (2,

4, 5, and 8). The special bioassays were also used to investigate the effects of alternative test conditions (sample size, lighting, etc.) on bioassay results.

In Situ Bioassays. Two large volume in-lake or in situ bioassays were conducted to confirm the general validity of the small volume bioassays. They were conducted using lake water from Station 4, placed in 1- and 2-cubic-meter clear flexible plastic containers. They were suspended 1 meter below the lake surface at the breakwater adjacent to Las Vegas Wash Marina near Station 4. These bioassays were conducted in October 1979 and in July 1980. Enrichments of the in situ bioassay containers included a range of nitrogen and phosphorus concentrations similar to the regular bioassays. Additional biological and physiological measurements were made on the in situ bioassay populations for comparison with other indicators of nutrient limitation.

Standard AAP Bioassays. Two standard AAP bioassays were conducted by the U. S. Environmental Protection Agency (EPA), at their Corvallis, Oregon, laboratory. They were conducted at the same time, as their purpose was to provide an additional check of results from the regular, special, and the in situ bioassays against a standardized assay procedure using a test algae not present in the natural population of Lake Mead.

RESULTS

Water quality data pertaining to the transparency-algae-nutrient relationships in Las Vegas Bay and Lake Mead are presented in this section. The data are presented in four sections covering:

1. Physical characteristics of the system
2. Transparency
3. Algae
4. Nutrients

For each of the latter three sections, the data are presented in four ways:

1. A chronological record of the seasonal distribution.
2. A description of spatial variations.
3. Frequency distributions to indicate the variability of the data.
4. Comparison of Las Vegas Bay and Bonelli Bay.

Physical System Description

Several aspects of the physical system described in Chapter 3 are important to understanding water transparency relationships in Las Vegas Bay and Lake Mead. These include the physical setting of the system, water level, meteorological conditions, such as temperature and wind, and the internal lake structure as described by conductivity and temperature profiles.

Physical Setting. Physical characteristics of Las Vegas Bay and the inflow from Las Vegas Wash contribute to water quality conditions through their effects on dispersion of the inflow in the receiving water. Important characteristics include the following:

1. Las Vegas Bay is a wedge-shaped flooded canyon embayment adjoining the main lower basin (Boulder Basin of Lake Mead).

2. Las Vegas Wash discharges into the narrow, shallow, upper end of the bay.

3. The composition of Las Vegas Wash inflow, described in Chapter 6, is significantly different from the composition of water in the main basin of Lake Mead so that Las Vegas Bay is a transition zone between Las Vegas Wash and Boulder Basin.

The narrow inner end of Las Vegas Bay receives relatively heavy use as described in Chapter 4. It is the nearest part of Lake Mead to Las Vegas, and as shown on Figure 4-1, Las Vegas Wash Marina and the National Park Service campground serve as a focal point for recreational and aesthetic beneficial uses of the lake.

Water Level. The water surface elevation in the lake determines its aerial extent. The water depth and surface area of the narrow upper end of the bay are particularly sensitive to changes in water level. At a given location on Las Vegas Bay, the general effect of changing lake level (or water depth) on water quality results from the change in upstream lake volume available for dilution of wash inflow. Except for effects of local bottom characteristics on internal mixing and biological activity, water quality at a given location would be expected to depend almost directly on the bay volume upstream of that point. The water surface elevation in Lake Mead varies with tributary

inflow to the lake and is a function of power-generating needs at Hoover Dam and overall water management strategy along the Colorado River. A description of lake level changes observed in the WQSS and details of Las Vegas Bay geometry and bathymetry are given in Chapter 3.

Meteorology. Meteorological conditions influence water quality through their effects on temperature of the Las Vegas Wash inflow and the temperature of Las Vegas Bay and through the influence of winds on mixing in the lake. Solar radiation and temperature also have significant effects on the seasonal pattern of biological activity in the lake. Rainfall may influence water quality through runoff to the lake.

A description of general Las Vegas area meteorology and a record of air temperature, wind speed, cloud cover, and rainfall measured during WQSS is provided in Chapter 3. The specific effects of rainfall on the nutrient budget are presented in Chapter 7.

The relative temperature of the wash inflow and the lake surface, combined with the difference of total dissolved solids concentration between the wash and background concentrations in the bay, have a significant effect on mixing of the wash inflow with the bay. Temperatures measured in Las Vegas Wash at Northshore Road, and in the water and air at the Las Vegas Wash Marina are shown on Figure 8-2.

Internal Lake Structure. The internal lake structure is described by isopleths of temperature and specific conductance collected over the study period. Isopleths are lines of equal concentration and are presented as a function of depth (vertical

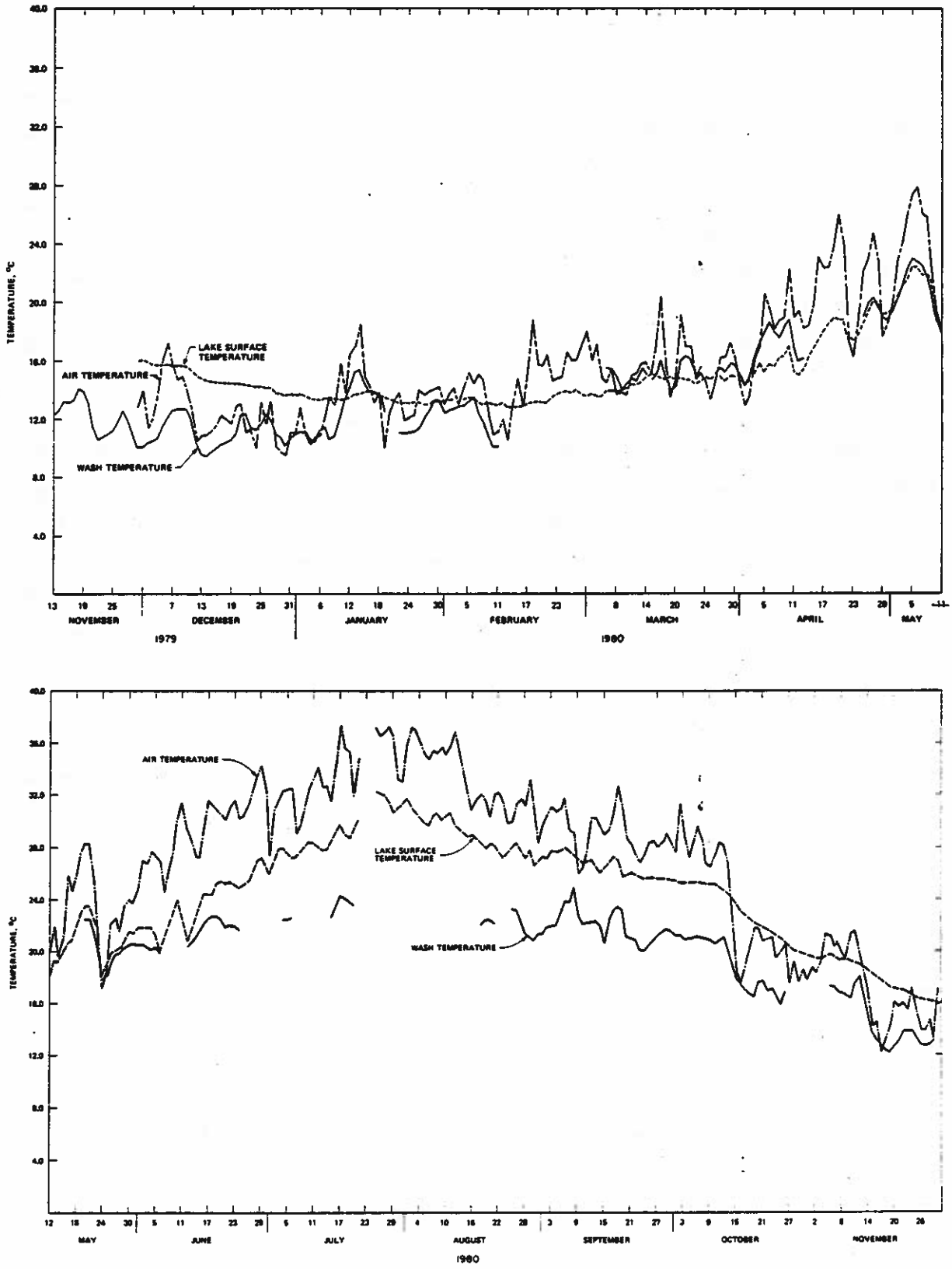


Figure 8-2 Temperature Record for Las Vegas Wash and Las Vegas Bay

axis) and time (horizontal axis). Isopleths for water temperatures are summarized for the index stations (Stations 2, 5, 8, and 9) on Figure 8-3. In general, vertical isotherms indicate uniform mixing and horizontal isotherms indicate stratification. In stratified periods (mid-summer at Stations 5, 8, 9), the thermocline is where the isotherms are most closely spaced. The isotherms indicate uniform mixing in winter to a depth of nearly 100 meters. As surface temperatures warm in spring and summer, the lake begins to stratify, indicated by the increasingly horizontal isotherms. In mid-summer, the lake becomes strongly stratified with surface temperatures as high as 28° to 30°C, mixed uniformly to a depth of between 10 and 15 meters. Below the well-mixed surface layer, or epilimnion, is the thermocline region of rapidly decreasing temperatures separating the warm epilimnion from the relatively cool hypolimnion. Temperatures in the hypolimnion, even in mid-summer, range from 11° to 14°C.

Stratification conditions vary from station to station. The temperature record for Station 2 shows weak stratification at the end of March 1979, with water temperatures gradually warming through mid-April. However, the nearly vertical isotherms in May indicate that stratification was disrupted by increased mixing. This was likely due to a combination of wind and temperature instability between the plume and epilimnion as was observed in 1980 (Figure 8-2). Renewed stratification began in mid-June persisting until late September. At the end of September, mixing again produced uniform temperature profiles with decreasing temperatures through the fall and winter periods. Only brief periods of stratification were observed at Station 2 in May, July, and September of 1980. Isotherm patterns at Stations 5, 8, and 9 are similar, with

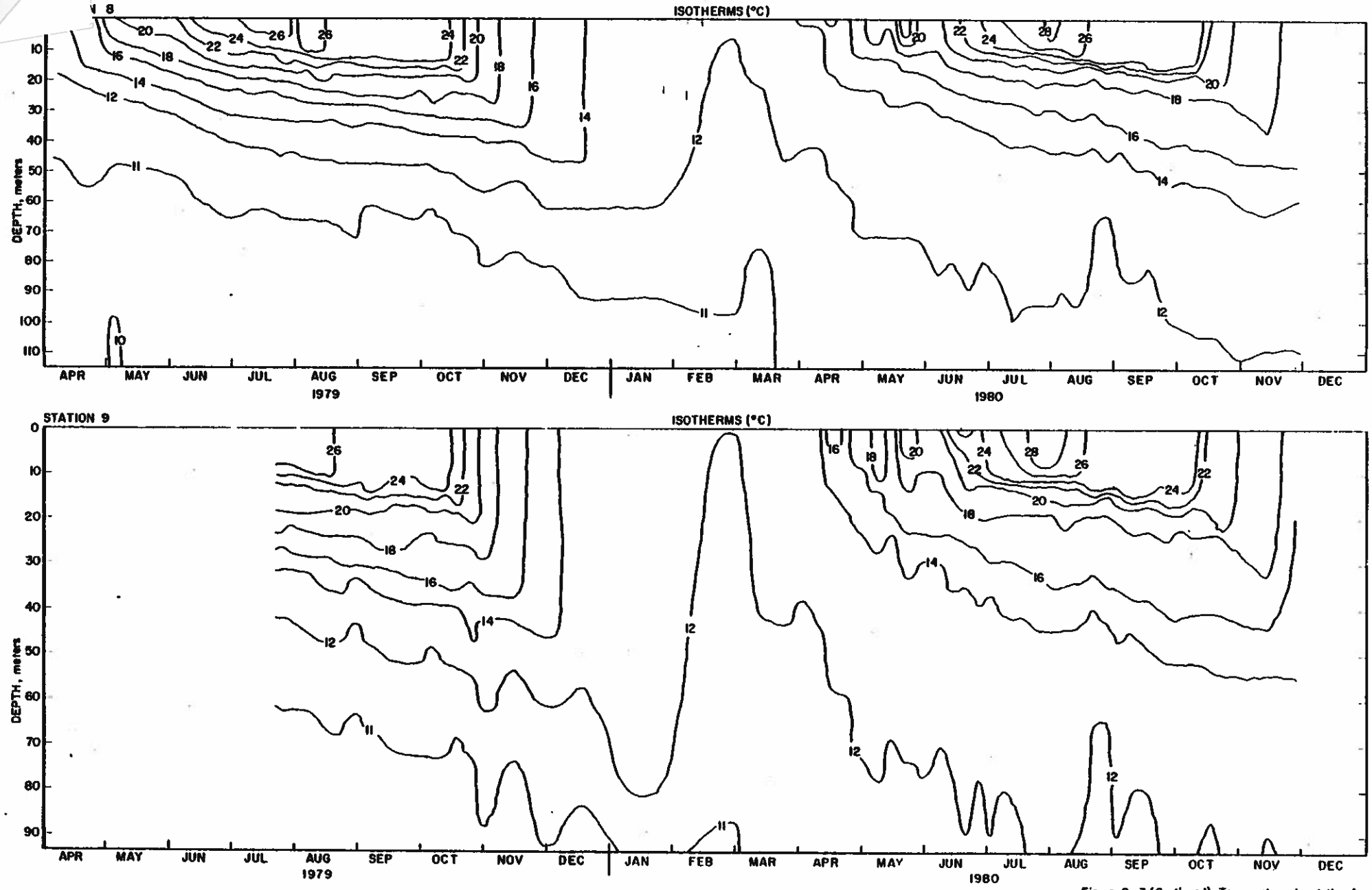


Figure 8-3 (Continued) Temperature Isopleths for Index Stations 2, 5, 8, and 9

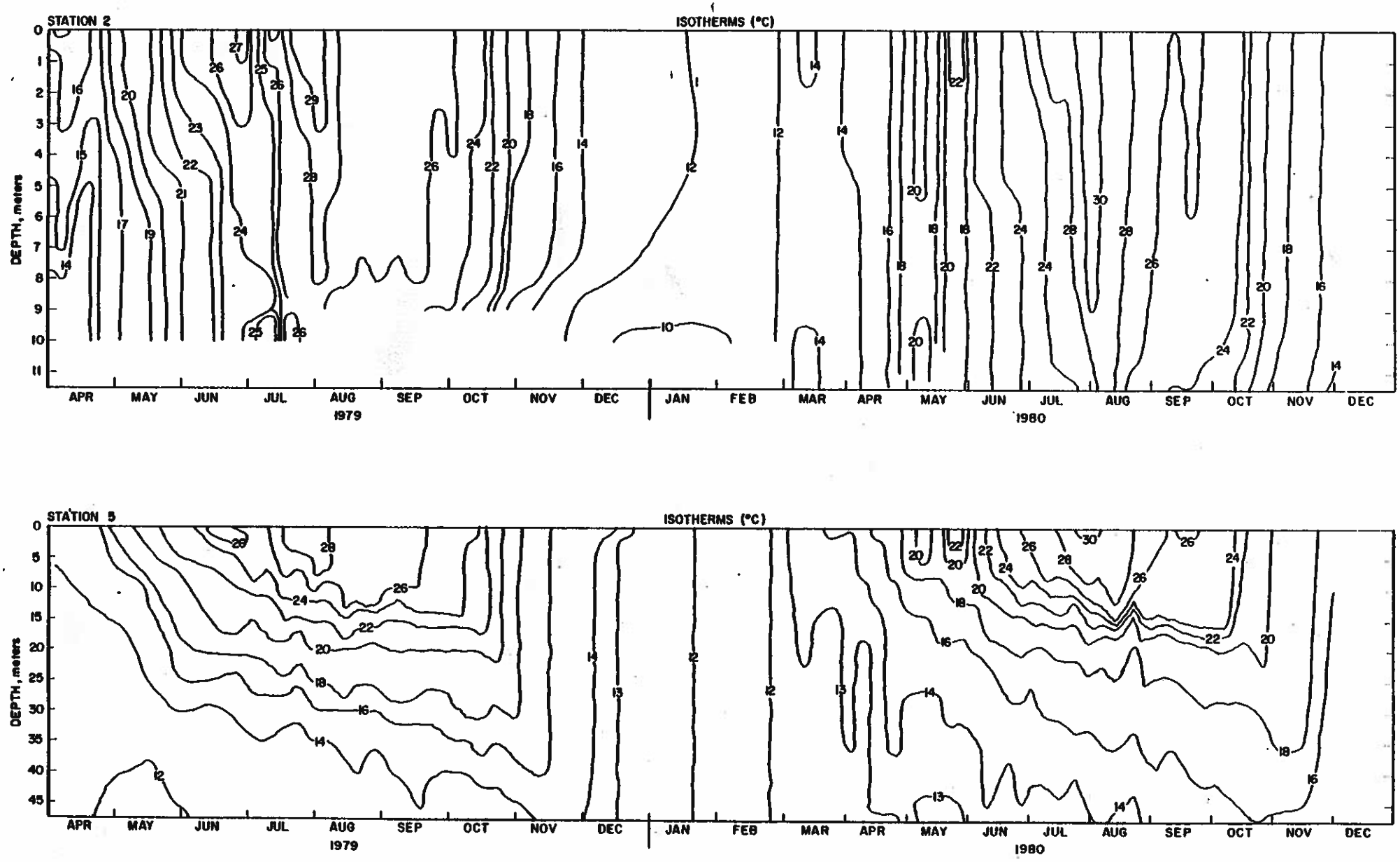


Figure 8-3 Temperature Isopleths for Index Stations 2, 5, 8, and 9

evidence of stratification beginning in early May, and increasing almost continuously until mid-July. This is followed by a period of strong stratification, with uniform temperatures to between 10 and 15 meters depth. This condition persists until lower temperatures and increased mixing in late September return the lake to the cooler, uniform winter temperature profile. Differences in lake temperature conditions at Stations 5, 8, and 9 between 1979 and 1980 are apparent. The onset of stratification in the spring of 1979 was uniform and continuous. In 1980, developing stratification was disrupted in May due to wind and weather conditions. By late summer, August and September, the depth of the mixed layer at 24°C was as much as 20 percent greater in 1980 than in 1979.

Temperature variations among stations can also be demonstrated with longitudinal profiles. Temperature profiles along the axis of Las Vegas Bay from Station 1 through Station 8 for representative samplings from spring through winter are shown on Figure 8-4. The progressive warming and stratification of the bay can clearly be seen. Surface temperatures rise from 14°C in mid-March to greater than 25°C in mid-August, cooling again to approximately 20°C by mid-October and less than 14°C by mid-December. The depth of uniform temperatures at the surface ranges from 7 to 10 meters in spring and summer, to 15°C in early fall, followed by a rapid increase to more than 20 meters in mid-October and greater than 40 meters in mid-December. Stratification in the spring is an important factor contributing to the physical isolation of a biologically active zone in the epilimnion through the spring and summer periods. The uniform mixing in the surface layer and the underlying boundary of the thermocline confine the algal population in the warm surface water. There, the light intensity and available nutrients

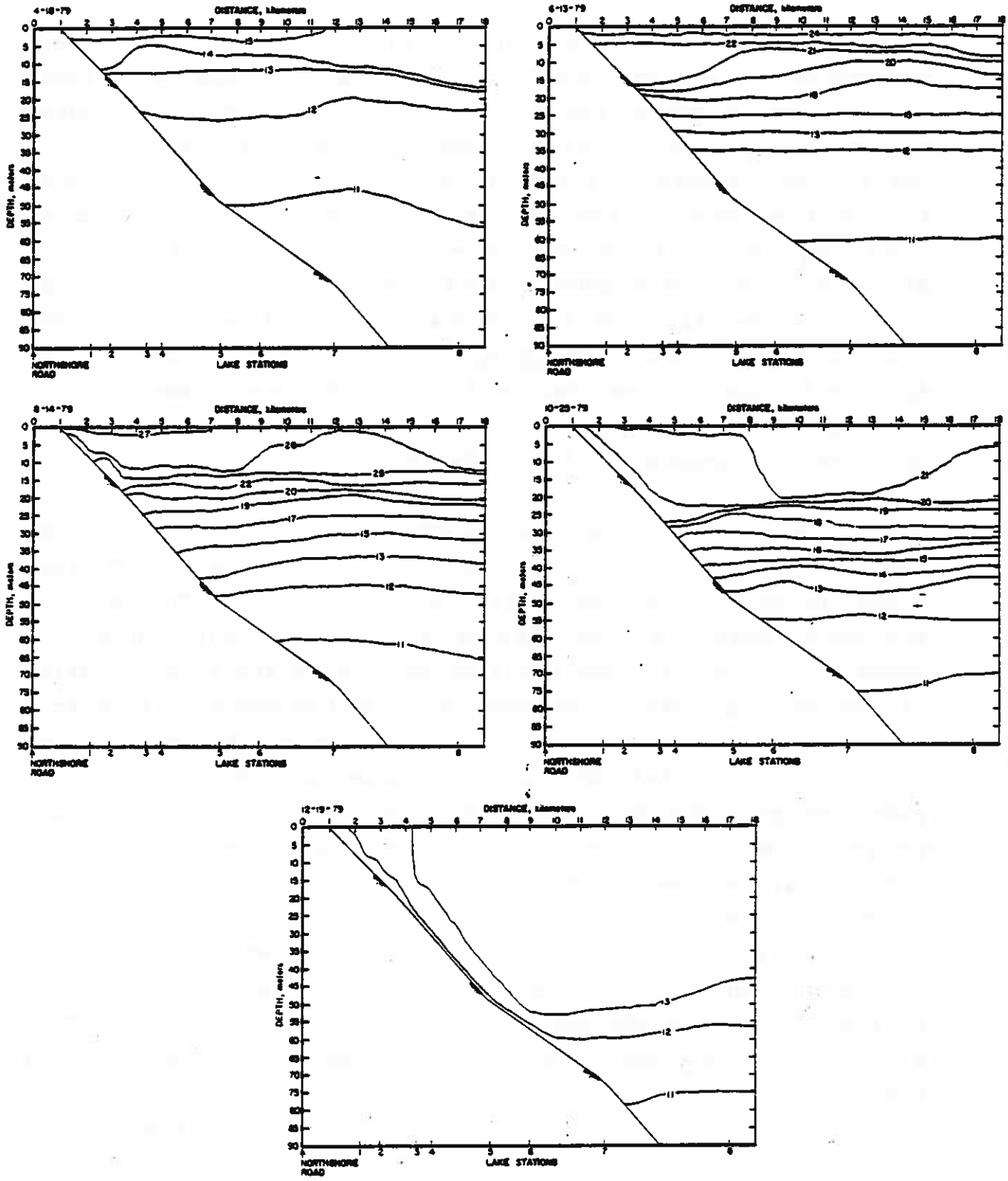


Figure 8-4 Longitudinal Temperature Profiles in Lake Mead

produce suitable conditions for rapid growth. In the fall, as water temperatures drop, and as the mixing depth becomes greater with accompanying lower fall and winter light levels, conditions become increasingly less favorable for photosynthesis, ending the biological season.

The specific conductance of wash flow entering Las Vegas Bay is typically about 3,000 umho/cm (Chapter 6). The specific conductance of water in areas of Lake Mead unaffected by Las Vegas Wash is typically between 1,000 and 1,200 umho/cm. Differences in temperature and specific conductance between the inflowing wash and Las Vegas Bay, together with physical factors such as the geometry of the system and mixing forces, determine how the wash flow is distributed into the bay. The effective dilution increases gradually with increasing distance from the wash/bay confluence. The manner in which the wash flow is distributed in the bay varies seasonally with changes in temperature, specific conductance, and mixing forces as detailed in the Hydraulic Study (Appendix F). The wash flow identified by regions of higher specific conductance remains segregated from the water column for a considerable distance into the bay. The segregation forms a plume-like zone of temperature and specific conductance discontinuity in the otherwise natural physical and chemical structure of the bay.

The vertical location of the plume in the water column varies with seasons. Characteristic patterns of specific conductance along the axis of the bay are shown on Figure 8-5 covering a typical annual cycle. The changes in plume location occur in a sequence of steps:

1. In April, the colder, relatively dense water of the plume flows along the bottom until separating from the

bottom at a depth of approximately 55 meters at a location between Stations 6 and 7 (Figure 8-5a).

2. As Wash and lake water temperatures rise, stratification begins, and the depth of plume separation from the bottom decreases. By mid-May, separation occurs at a depth of less than 30 meters in the region between Stations 4 and 5.

3. Lower temperature differences between the wash and the bay, (Figure 8-2) and mixing forces through the spring period contribute to more rapid dispersion of the plume contents throughout the deeper water of the bay. This is evidenced in lower maximum plume concentrations at stations progressively closer to the wash confluence through the summer months (Figure 8-5c).

4. By mid-July, plume separation from the bottom occurs at a depth of approximately 15 meters at a location between Stations 2 and 3. Under these conditions, the plume specific conductance is dispersed to a degree virtually indistinguishable from background conditions by approximately Station 5 in the middle of Las Vegas Bay (Figure 8-5d).

5. Through mid- and late summer when the bay is firmly stratified, the plume appears separate from the bottom consistently at a depth from 12 to 15 meters, and floats immediately below the well mixed surface layer (Figures 8-5e, f).

6. With cooling temperatures in the fall, the process reverses. As the depth of stratification increases, the

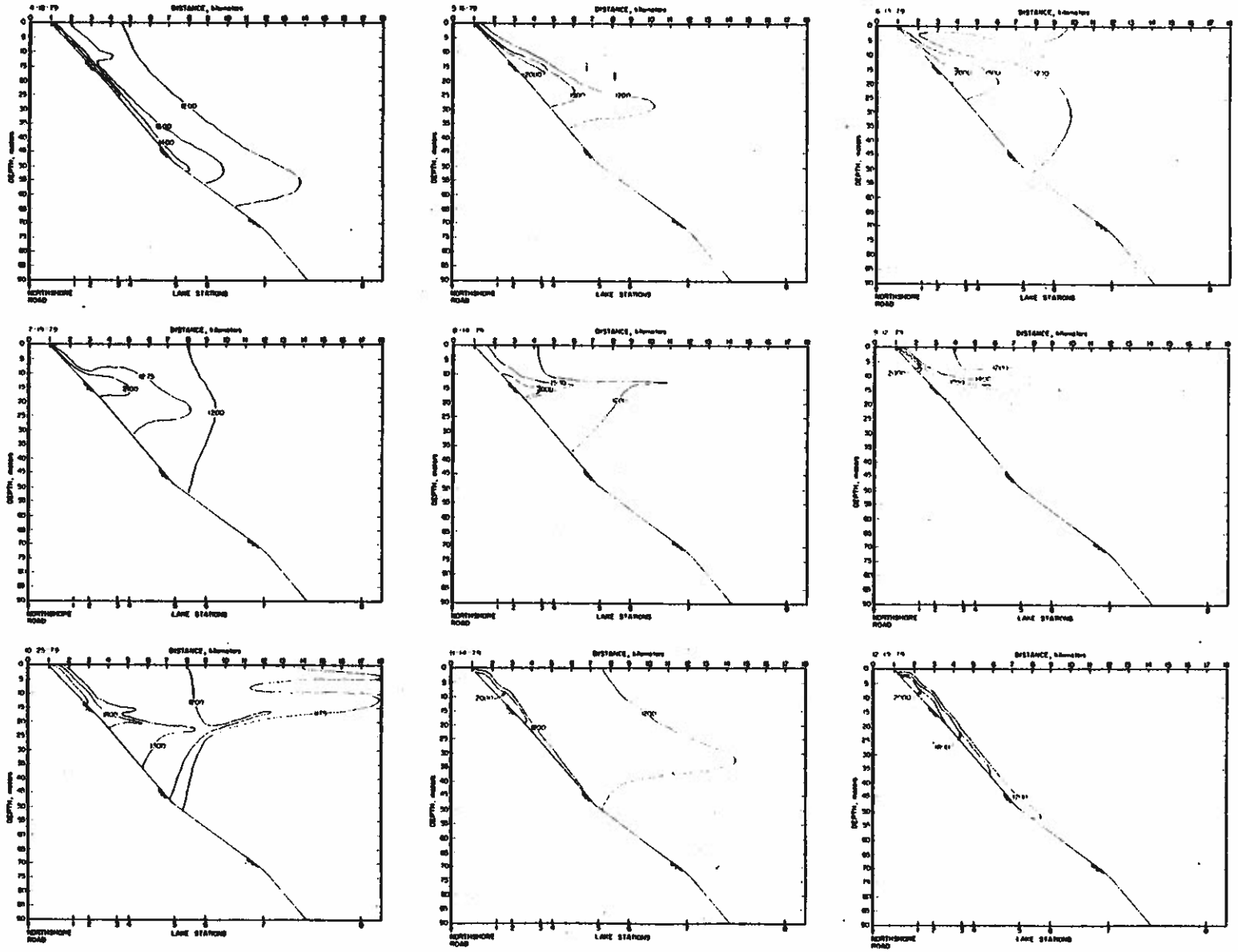


Figure 8-5 Longitudinal Specific Conductance Profiles in Lake Mead

depth of plume separation increases correspondingly. As the temperature difference between the plume and surface water increases, the plume contents are distributed farther and farther out into the bay (Figure 8-5g).

7. By mid-November, the plume separates from the bottom at a depth between 35 and 40 meters with its contents distinguishable from background by specific conductance as far as Station 7 (Figure 8-5h).

8. In mid-winter, the maximum depth of plume separation appears to be approximately 70 meters with the plume detectable by specific conductance measurements between Stations 7 and 8 in Boulder Basin (Figure 8-5i).

Data for plume depth and salinity levels at Station 3 are shown on Figure 8-6, along with the daily average air temperature in Las Vegas for the calendar year of 1980. The seasonal behavior of the plume at this station is clearly described with the wash inflow segregated on the bottom until mid-May when warming temperatures raise it above the bottom and occasionally distributes its contents into the surface layer. For most of the summer period between June and September, the depth of maximum plume concentration ranges from 10 to 15 meters corresponding approximately to the depth of the well-mixed layer in the thermocline region. Plume depths measured at stations farther out in the bay in periods before April and after October indicate its greater depth during late fall, winter, and early spring periods. Plume behavior is described in detail in the Hydraulic Study, which is contained in Appendix F.

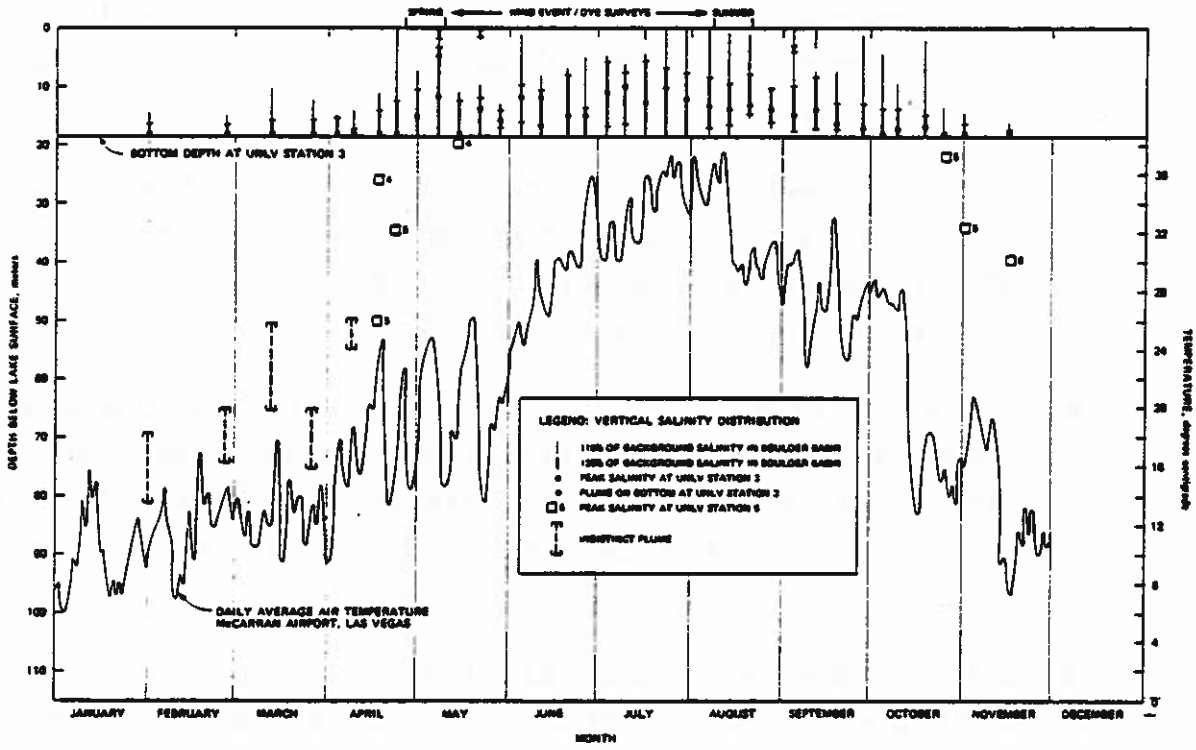


Figure 8-6 Plume Depth at Station 3

Transparency

Transparency observations made in the WQSS consist of Secchi disc depth measurements and light transmittance measurements. Measurements made of factors controlling transparency include chlorophyll, volatile and nonvolatile suspended solids, and color. Secchi depth, suspended solids, and color data are discussed in this section, while chlorophyll measurements are described in the next section.

Seasonal Distribution. The chronological record of Secchi depth measurements at Stations 1 through 11 is shown on Figure 8-7. Secchi depths range from a minimum of about 1 meter

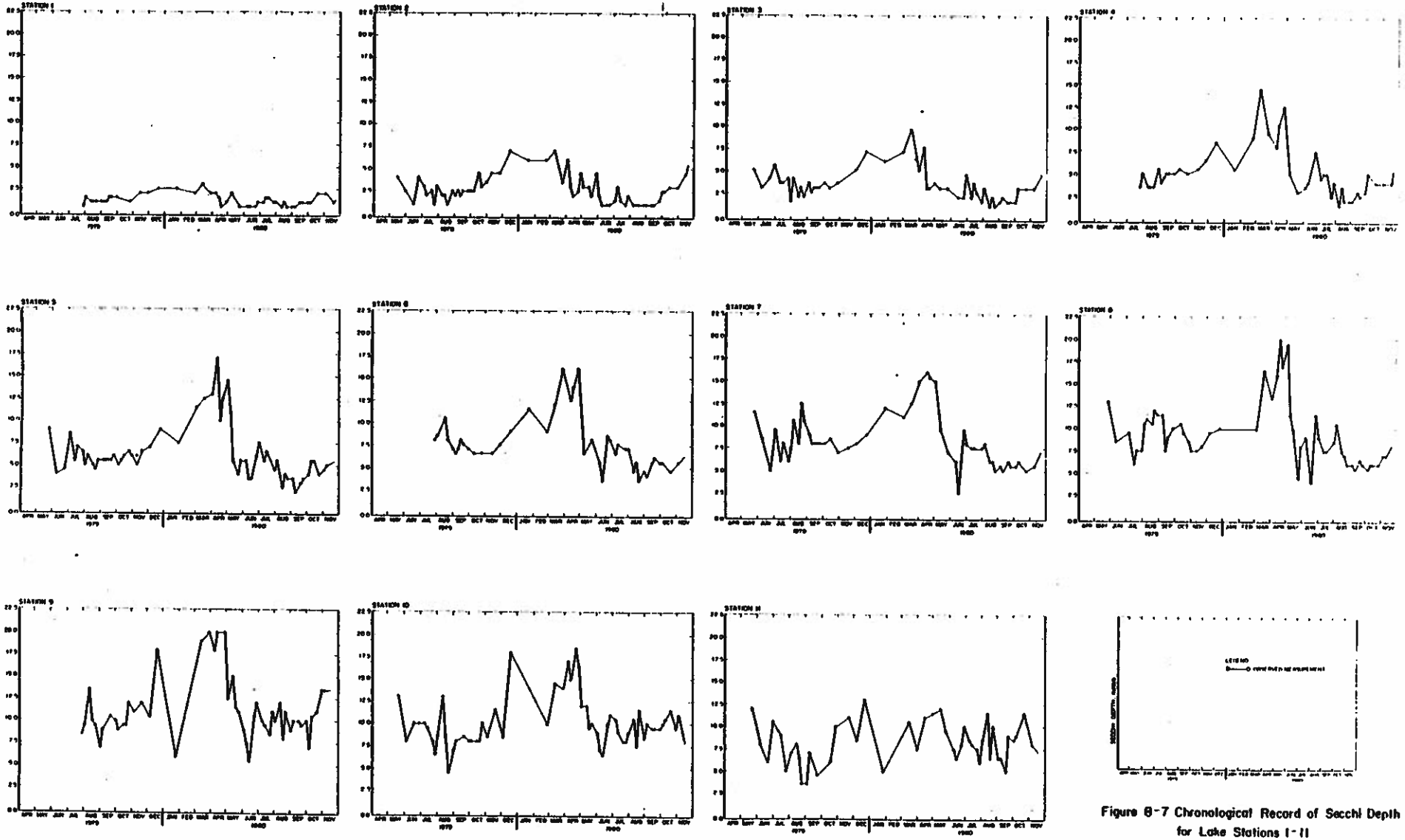


Figure 8-7 Chronological Record of Secchi Depth for Lake Stations I - II

at Station 1 to a maximum of approximately 20 meters at Stations 8 and 9. The chronological record shows a distinct seasonal influence with possible exceptions at Stations 1 and 11. Transparency was greatest in winter and early spring, between the months of December and April. Minimum Secchi depths were observed in mid- to late summer and early fall (months of July through September). This seasonal trend occurred in both 1979 and 1980.

Data for light transmittance, color, and suspended solids have been compiled and are available in the permanent STORET data file. Light transmittance was found to vary in a manner similar to that shown for Secchi disc depth. Color measurements varied little over the course of the year with the exception of occasionally higher values at inner bay stations that appear to be related to isolated storm periods. Suspended solids measurements are most closely related to the algal population and vary approximately inversely with observed Secchi depths. The nonvolatile fraction of total suspended solids was virtually constant from station to station in both Las Vegas Bay and Bonelli Bay. This is consistent with visual observations, particularly in inner Las Vegas Bay, where the inflowing wash was observed to be a consistently opaque light brown color. No visible remnant of the brown color was evident beyond the plunge point located within approximately 100 meters of the confluence of the wash and the bay.

Spatial Distribution. The spatial variation of transparency of Las Vegas Bay and Lake Mead is shown on Figure 8-8. A continuous gradient of increasing Secchi depths was observed between Stations 1 and 8 in Las Vegas Bay and Boulder Basin. A similar gradient was observed between Stations 11 and 9 in

Bonelli Bay and Virgin Basin. The average transparency as measured by Secchi depth increased continuously from an average of 1.2 meters at Station 1 to an average of approximately 9 meters at Station 8. Minimum Secchi depths measured at Stations 1 through 4 ranged from 0.25 meter to 1.5 meters, increasing more rapidly between Stations 5 and 8 from 2 meters to 3.75 meters. Secchi depths at Station 1 were sometimes limited by the water depth. Maximum Secchi depths were 15 to 17 meters between Station 4 and 7, and almost 20 meters at Station 8. Secchi depths measured in Bonelli Bay and Virgin Basin were equal to or greater than those measured throughout Las Vegas Bay except at Station 7, at the interface between Las Vegas Bay and Boulder Basin.

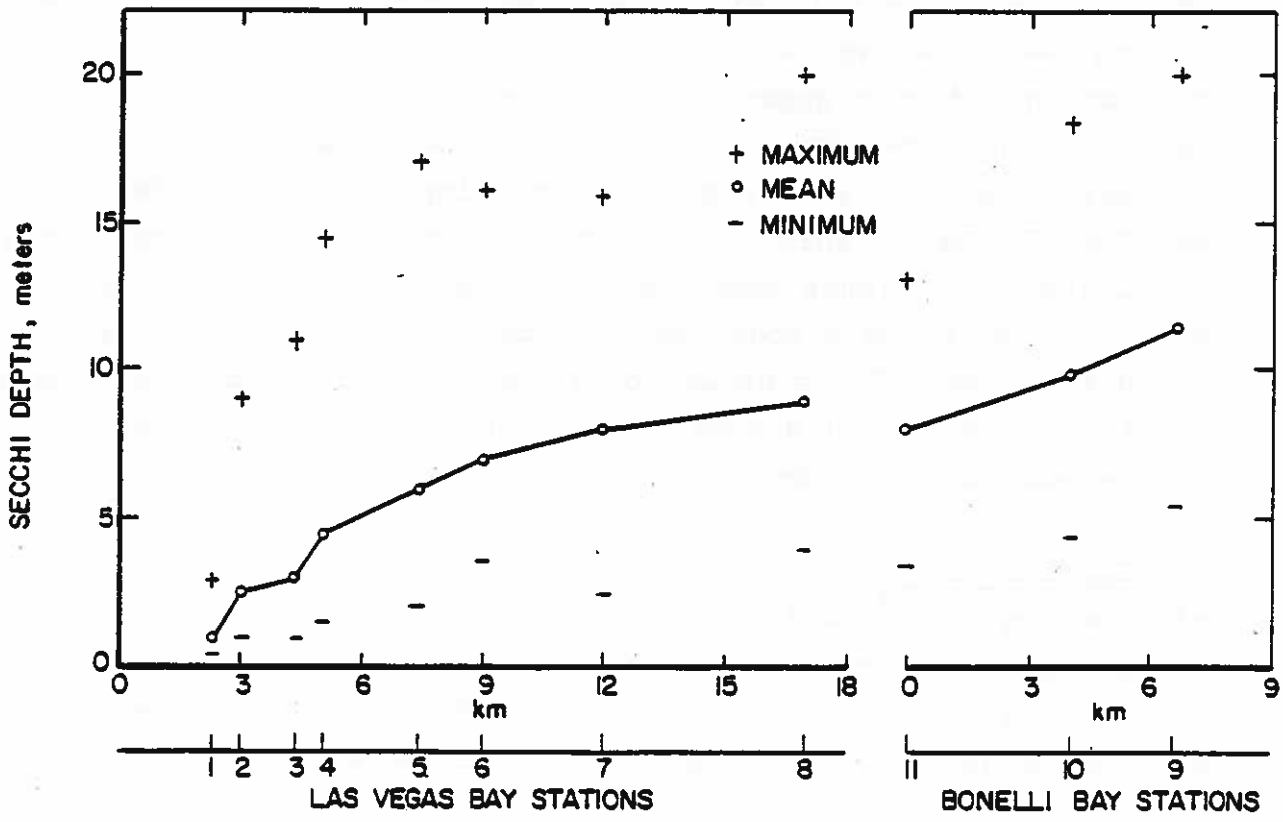
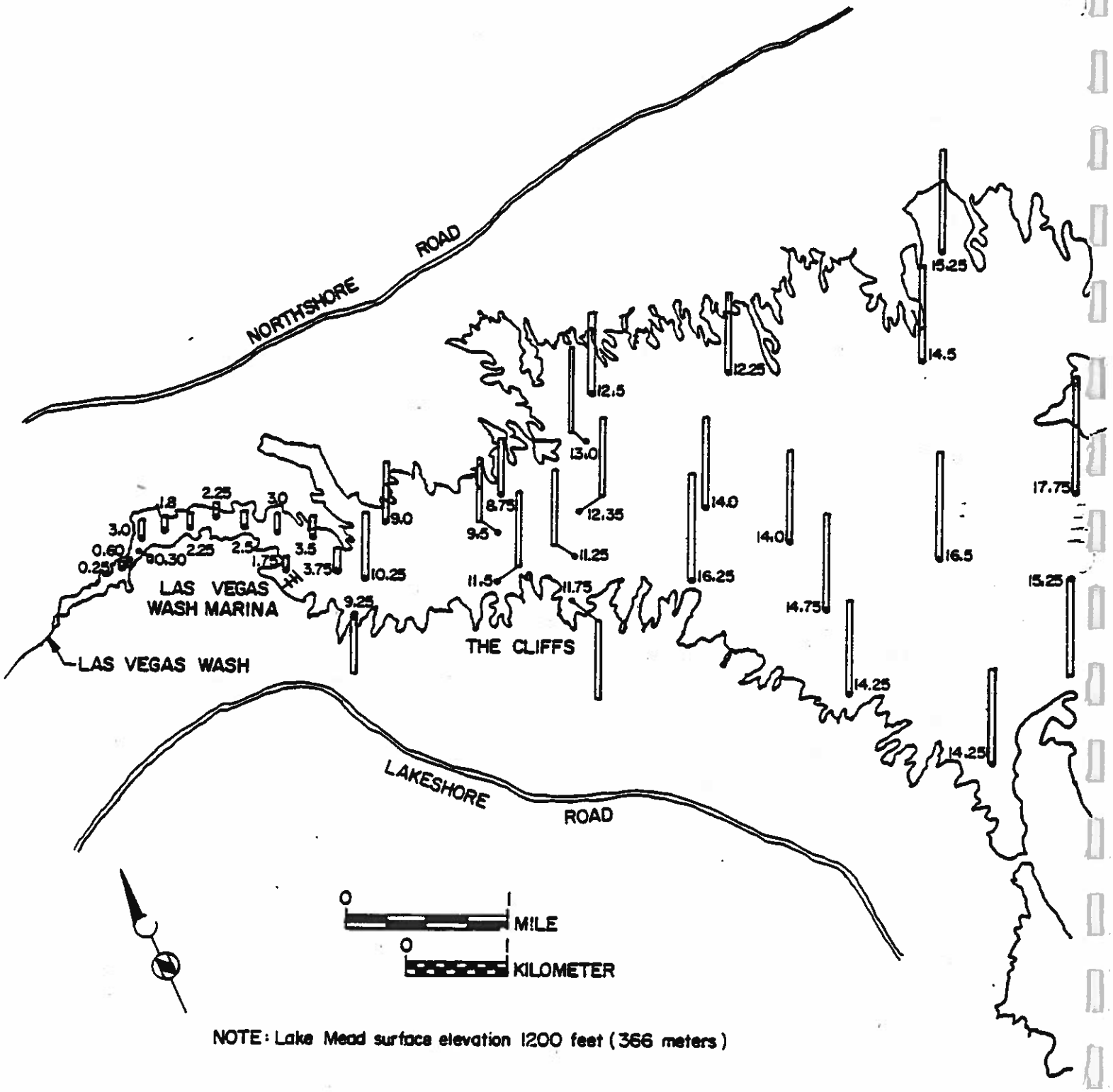


Figure 8-8 Secchi Depth Means and Ranges, WQSS Stations 1-11

Four intensive surveys were conducted to define spatial variations during the different seasons. The surveys showed relatively little variation in Secchi depth laterally at locations along the axis of the bay. Intensive survey stations generally showed the expected gradients in water quality between the regular stations. Secchi depth results from the April 1980 survey are indicated on Figure 8-9. Data for the other three surveys have been compiled and are available in the permanent STORET data file.

Frequency Distribution. Cumulative frequency distributions of Secchi depth data were developed for Stations 1 through 5, 8, and 9, for the 1979 and 1980 recreation seasons (April to October) (Figure 8-10). These indicate differences in the level and the variability of Secchi depths at the respective stations. Median Secchi depths at each station were lower in 1980 than in 1979. The 1980 median Secchi depth at Station 2, for example, was approximately 1.7 meters compared to 2.4 meters for 1979; the 1980 median for Station 4 was approximately 3.5 meters compared to 4.6 meters for 1979. The variability of Secchi depth transparency is indicated by the slope of the lines on the log probability plots. The steeper slopes of the 1980 distributions indicate a wider range of variation in transparency than in 1979. The abscissa of the probability plots is the normal (Gaussian) distribution expressed in terms of percentage of occurrences less than the plotted ordinate value. For uniformly spaced sampling of events randomly distributed in time, the percentage of occurrences is equivalent to the percentage of the time period covered in the sampling program.



NOTE: Lake Mead surface elevation 1200 feet (366 meters)

Figure 8-9 Intensive Survey Secchi Depth Observations, 4/17/80

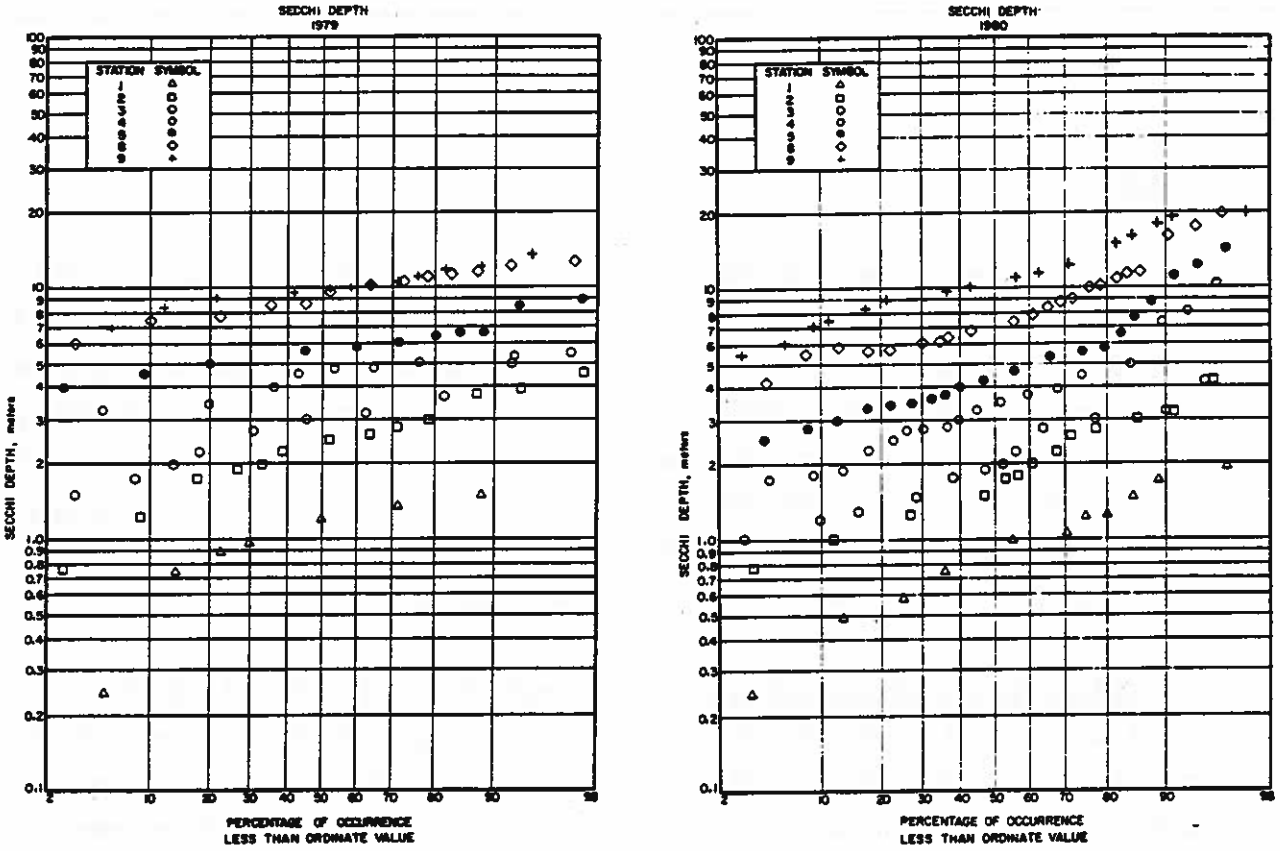


Figure 8-10 Secchi Depth Frequency Distributions, 1979 and 1980

Las Vegas Bay-Bonelli Bay Comparison. Comparison of transparencies in Las Vegas Bay and Bonelli Bay can be made using Figures 8-7, 8-8, and 8-10. Transparencies at Stations 9 and 10 were consistently greater than at all other stations, including Station 8. Station 10, with a water depth comparable to Station 5 in Las Vegas Bay, had a mean Secchi depth of approximately 10 meters which is comparable to that of Station 8 in Boulder Basin. Station 11 in Bonelli Bay, with a water depth comparable to between Stations 3 and 4 of Las Vegas Bay, had a mean Secchi depth comparable to that at Station 7 at the interface between Las Vegas Bay and Boulder Basin. The mean Secchi depth at Station 11 in Bonelli Bay, 8.1 meters, was approximately double that at stations of comparable water depth in Las Vegas Bay; 3.2 meters at Station 3 and 4.7 meters at Station 4.

Algae

Algal measurements made in the WQSS include chlorophyll, primary productivity, identification and enumeration of algal species, and measurements of biomass. Measurements of the zooplankton population are also reported in this section. Data are presented to identify variations through the study period, and the spatial distribution of the algal population. Also, comparison of algal observations is made between Las Vegas Bay and the background areas.

Seasonal Distribution. Seasonal variations occur in virtually all indicators of the algal population, including chlorophyll, primary productivity, algal biomass, algal species distribution, and zooplankton. Chlorophyll levels measured at Stations 1 through 11 during the WQSS are shown on Figure 8-11. In general, levels were relatively high in spring, summer, and fall months, and low in the winter months, December and January. For comparable periods, chlorophyll levels were highest in inner Las Vegas Bay decreasing from Station 1 toward Station 8. Chlorophyll levels at Stations 9, 10, and 11 were uniformly low throughout the study with little influence of seasonal changes. Changes in chlorophyll levels from week to week were large, particularly at the inner bay Stations 1 through 4. During the growing seasons of both 1979 and 1980, week to week changes in chlorophyll concentration ranged from 10 ug/l or less to 35 to 40 ug/l or more. The peak chlorophyll concentrations in the WQSS occurred in the 1979 fall bloom in September, October, and November. This peak is a dominant feature of the chlorophyll record at every station from 1 through 8. It is not as distinct at the inner bay stations due to routinely higher concentrations. Similarly, high chlorophyll levels occurred in

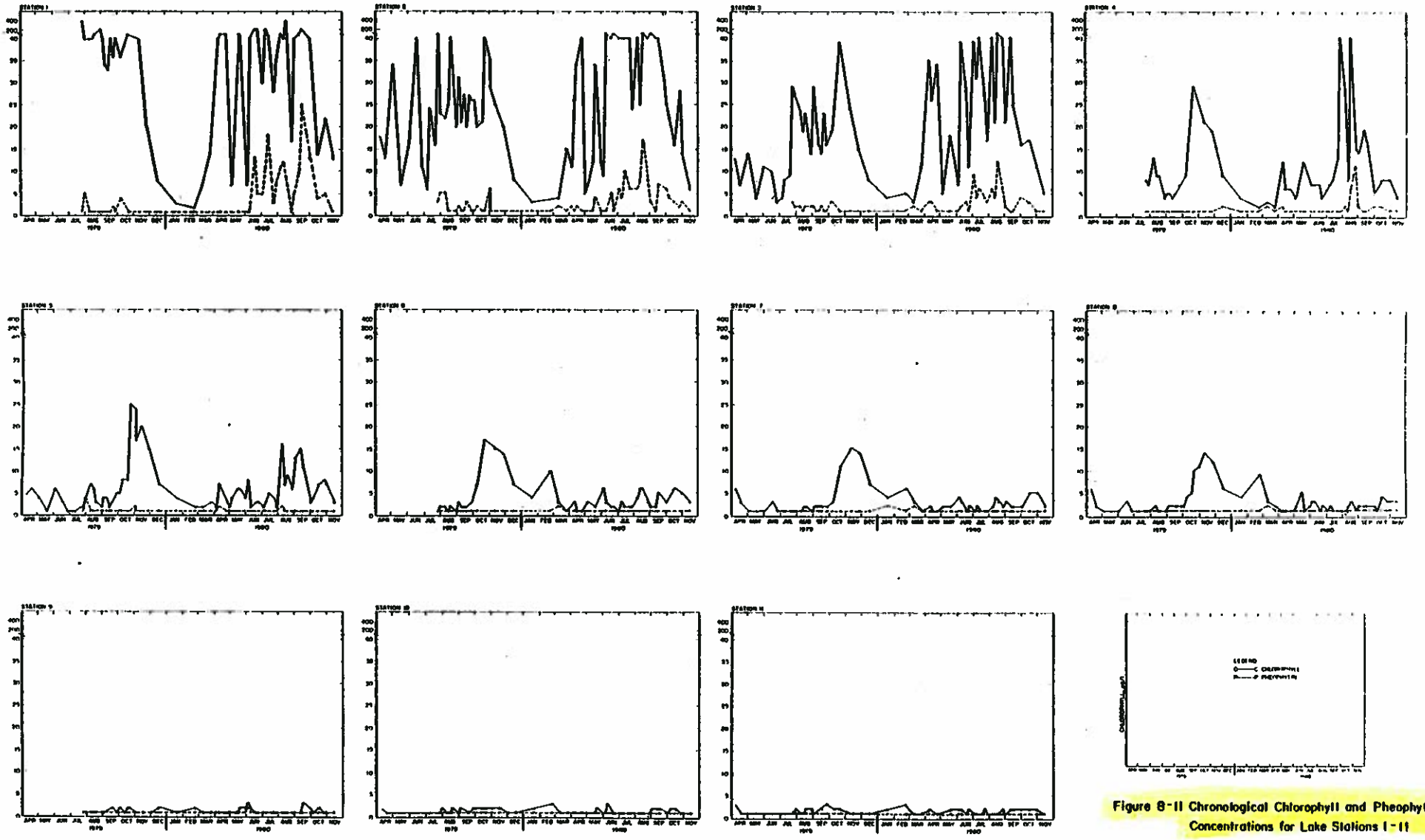


Figure 8-11 Chronological Chlorophyll and Pheophytin Concentrations for Lake Stations 1-11

1979-1980

the fall bloom of 1980, also in September, October, and November. The general seasonal pattern of high chlorophyll levels through spring, summer, and fall months and low chlorophyll levels through winter months corresponds generally to the inverse of the pattern observed for Secchi depth measurements with low Secchi depths corresponding to high chlorophyll concentrations and vice versa.

The Las Vegas Bay and Lake Mead sampling stations can be divided into three groups according to the magnitude and variability of chlorophyll levels. The highest and most widely varying concentrations are observed in the inner bay stations, 1, 2, 3, and 4, with a generally decreasing trend from Station 1 to Station 4. The magnitude and degree of variability in chlorophyll concentrations from middle Las Vegas Bay (Station 5) to Boulder Basin (Station 8) cover a middle range, lower than the inner bay stations, but higher than at the background Stations, 9, 10, and 11.

Primary Productivity--Primary productivity at the index stations (2, 5, 8, 9, and 10) from July 1979 to November 1980 is summarized on Figure 8-12. It follows a pattern similar to that of chlorophyll, decreasing from Station 2 to Station 8 with lowest levels at background Stations 9 and 10. Relatively high values occurred in summer and fall months with minimum levels occurring between mid-December and mid-March. Peak annual levels of primary productivity occurred in the late fall, as in the case of chlorophyll.

Algal Biomass--Algal biomass at Stations 2, 5, and 8 is shown on Figure 8-13. These measurements follow the general pattern of chlorophyll variation. Station 2 showed the

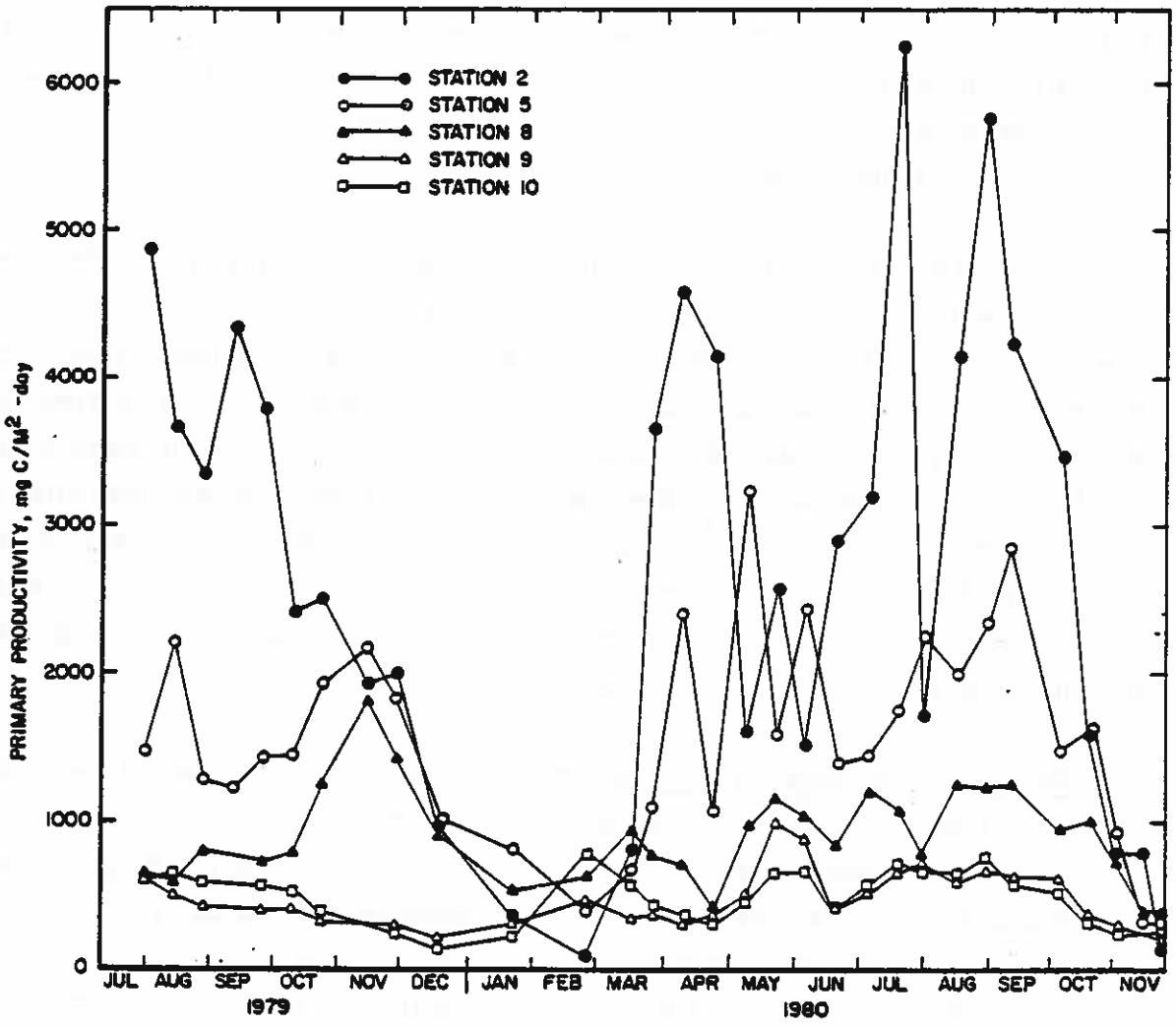


Figure 8-12 Primary Productivity at Index Stations 2, 5, and 8, 1979 and 1980

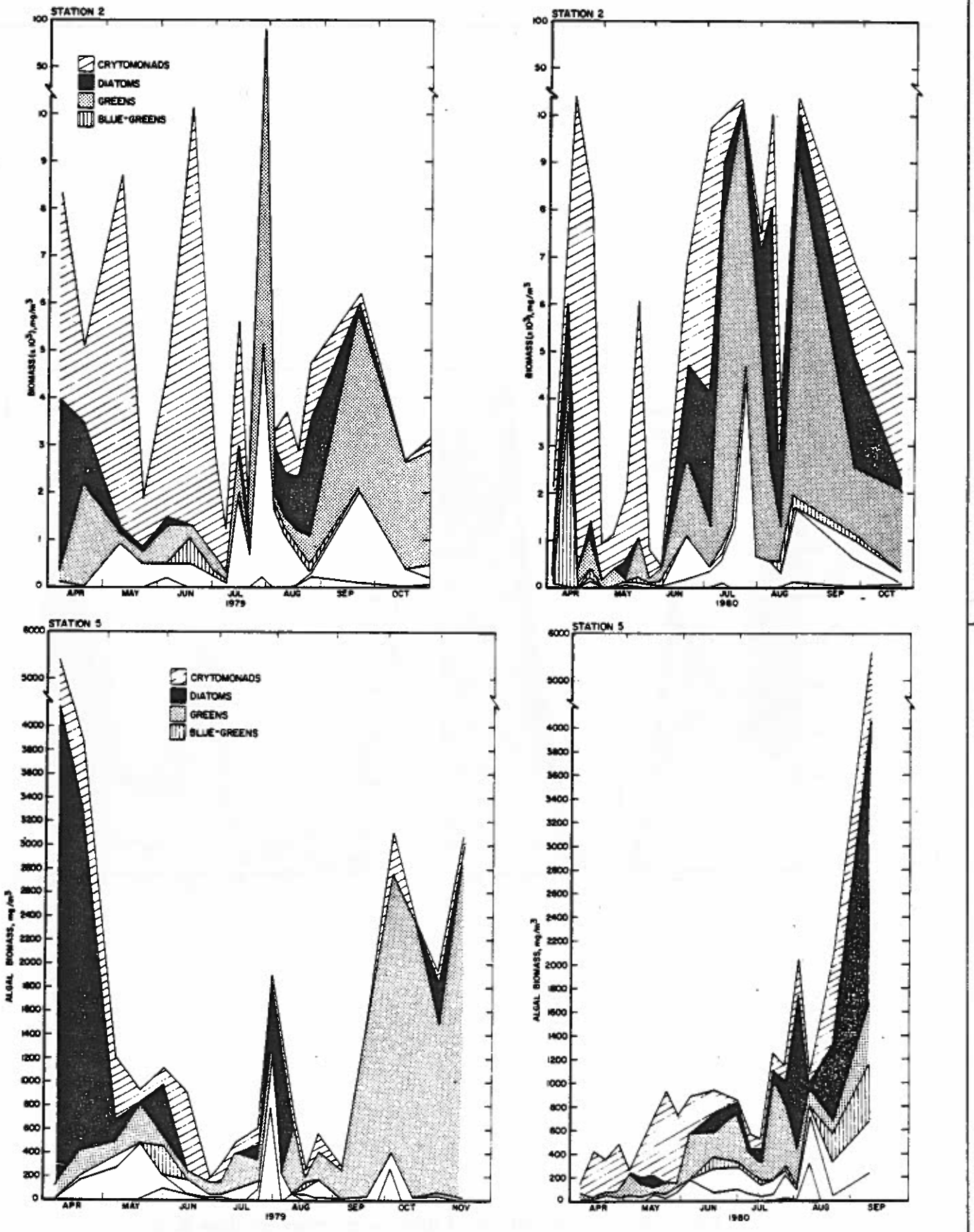


Figure 8-13 Algal Biomass at Index Stations 2, 5, and 8, 1979 and 1980

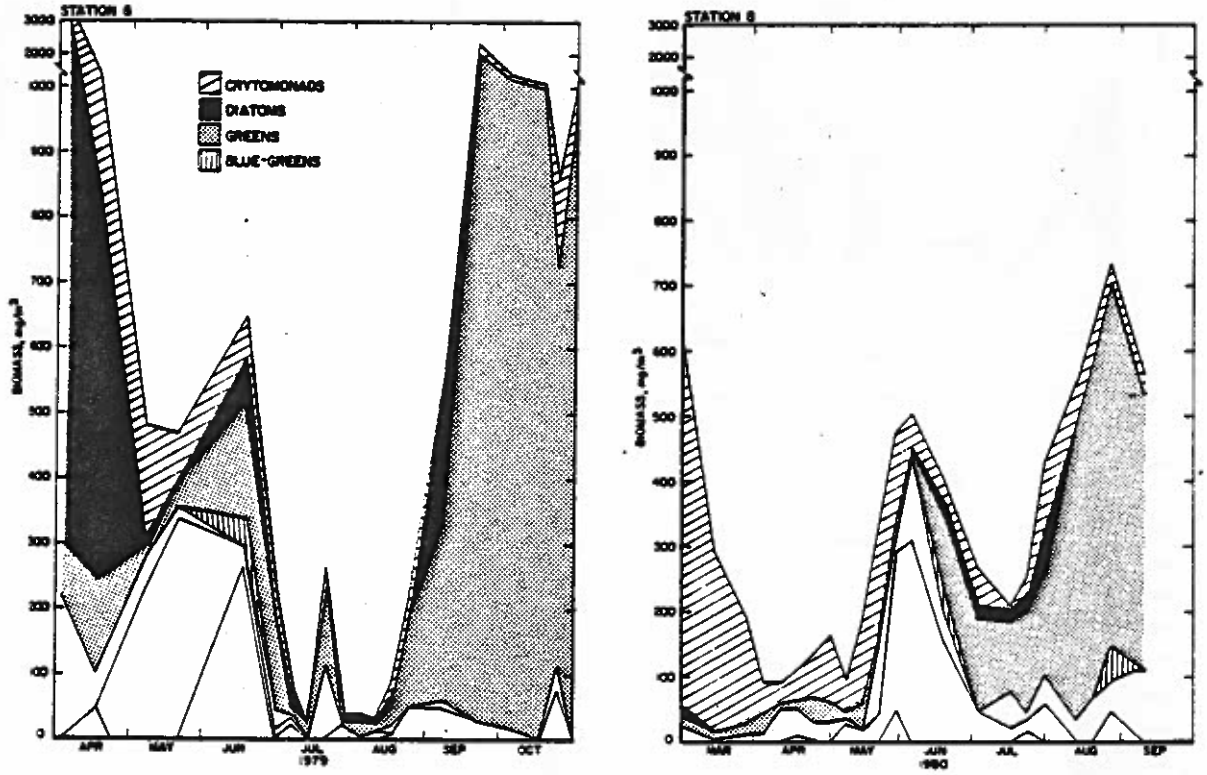


Figure 8-13 (Continued) Algal Biomass at Index Stations 2, 5, and 8, 1979 and 1980

highest levels accompanied by large changes in biomass from week to week. The magnitude of algal biomass at Stations 5 and 8 followed a similar patter to that of chlorophyll, with relatively low levels through the spring and summer of 1979 followed by a large peak in the fall. A large peak in biomass occurred both in spring and in the fall of 1980, with relatively low levels through the mid-summer period.

Algal Species--The distributions of algal species, expressed as percent by numbers and percent by weight, for Stations 2, 5, and 8 are shown on Figure 8-14. The successional pattern of algal species from spring to fall in both 1979 and 1980 was similar at these three stations, despite the fact that physical conditions and nutrient concentrations differ widely between these stations. Although the relative proportions are not the same in terms of numbers and biomass, the general pattern and species present are similar from station to station.

Dominant species early in the year were diatoms and Cryptomonads. Spring blooms of diatoms occur in many lakes. Cryptomonads are small algae adapted to low light and temperature conditions characteristic of the late winter-spring period. Colder conditions in 1980 may have contributed to the increased Cryptomonad dominance. Species dominance varied continuously through the May to August period, alternating between Bacilariophycae (diatoms), Chlorophyta (greens), Chrysophyta (Chrysomonads) and Cyanophyta (blue greens). The large numbers of blue green algae, though small in biomass, were non-nitrogen fixing species. Green algae dominated the population later in the season, August through October. The greater variety of species in the fall of 1980 may have been due to the cooler temperatures compared to 1979.

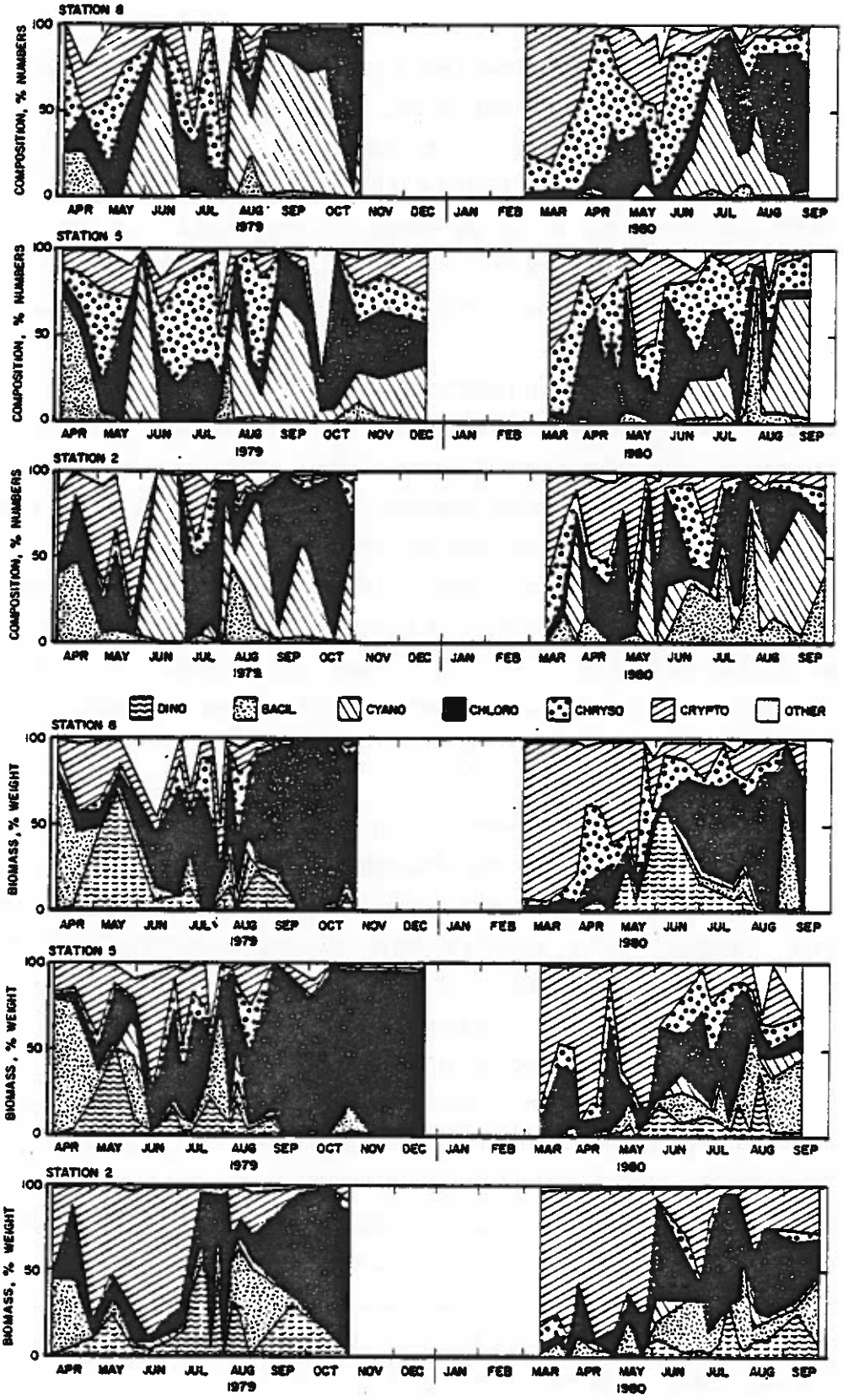


Figure 8-14 Algal Composition by % Numbers and Biomass by % Weight at Index Stations 2, 5, and 8

Zooplankton--Zooplankton levels are of interest principally because of their potential effects on chlorophyll levels. Some zooplankton species are herbivorous, subsisting largely on algae. Grazing by such species may consequently reduce chlorophyll levels. Zooplankton levels observed in the study are shown on Figure 8-15 along with corresponding chlorophyll levels. In some cases, zooplankton and chlorophyll levels varied together, rising and falling at the same time. In such cases, zooplankton levels did not appear to affect the chlorophyll levels. In other cases, such as the zooplankton, peaks of November/ December 1979 and March/April 1980, chlorophyll levels are seen to decrease while zooplankton levels either increase or remain high. In such cases, zooplankton predation may indeed have contributed to the lower chlorophyll levels.

Spatial Distribution. The means and ranges of total chlorophyll values measured in the WQSS are shown on Figure 8-16. Mean values decrease uniformly from Station 1 outward to Station 8. Major differences in chlorophyll levels occur between Stations 1, 2, 3, 4, with the mean level falling from 75 ug/l to 30 ug/l, 21 ug/l, and 11 ug/l, respectively. The mean chlorophyll level at Station 6 in outer Las Vegas Bay is approximately half of the mean chlorophyll level at Station 5, 4 ug/l and 8 ug/l, respectively. Mean levels at Stations 7 and 8 are very little different than observed at Station 6. Mean chlorophyll levels observed at the three background stations were virtually the same, with less than 0.5 ug/l separating them. Background levels were approximately half the mean level observed at Station 8.

Maximum chlorophyll levels show a similar trend. Peak chlorophyll concentrations at Stations 1 through 4 range

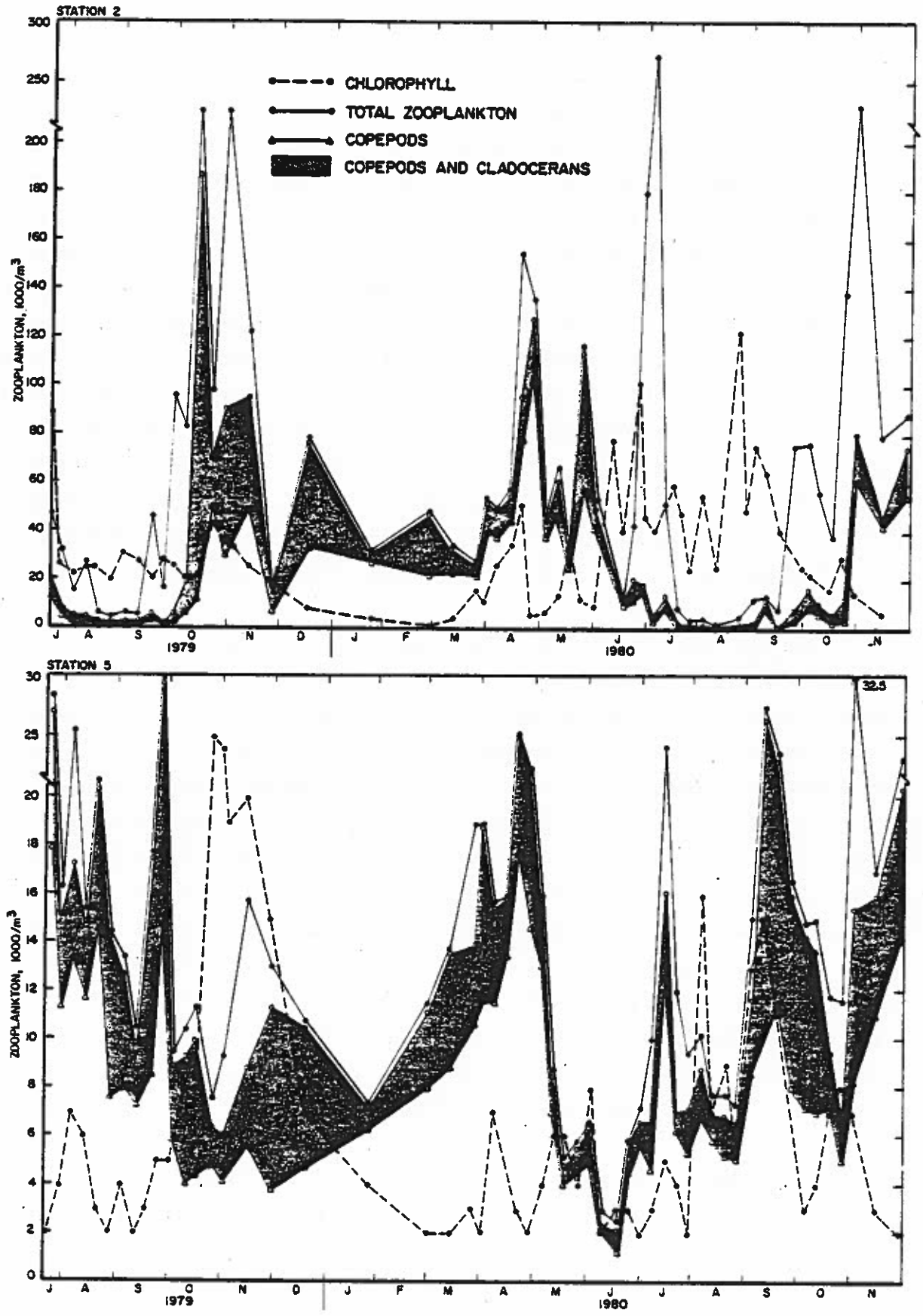


Figure 8-15 Chronological Zooplankton and Chlorophyll Plots for Index Stations 2, 5, 8, 9, and 10

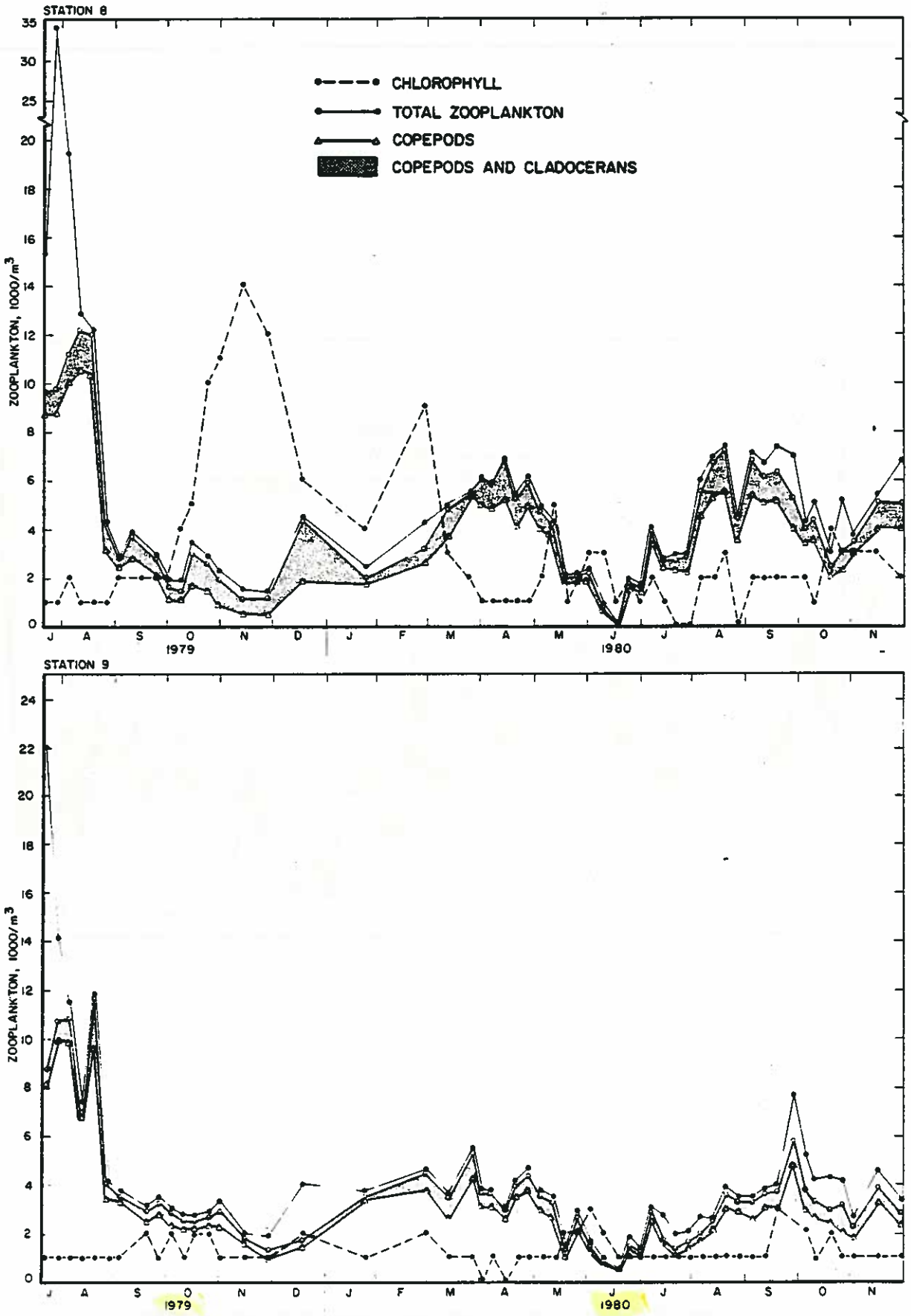


Figure 8-15 (Continued) Chronological Zooplankton and Chlorophyll Plots for Index Stations 2, 5, 8, 9, and 10

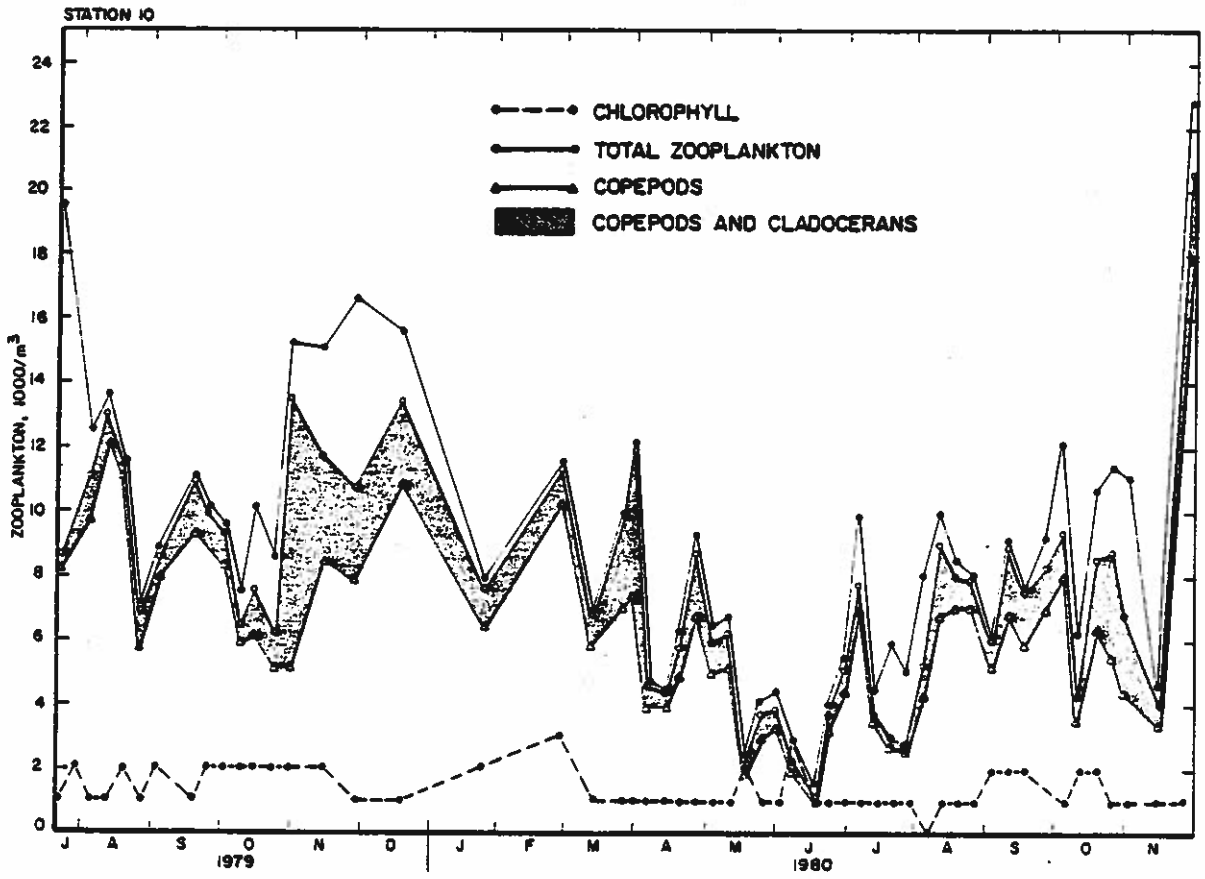


Figure 8-15 (Continued) Chronological Zooplankton and Chlorophyll Plots for Index Stations 2, 5, 8, 9, and 10

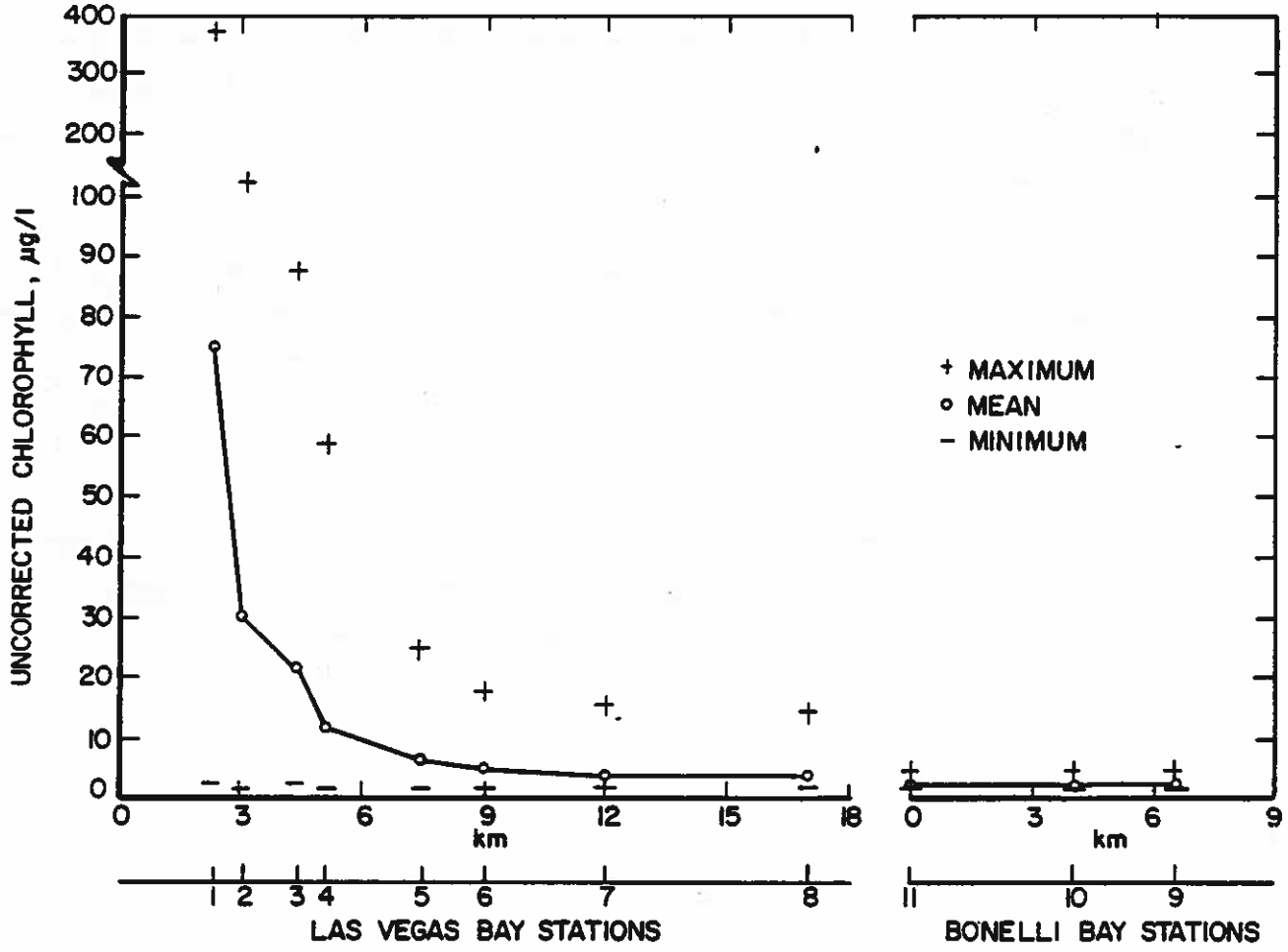
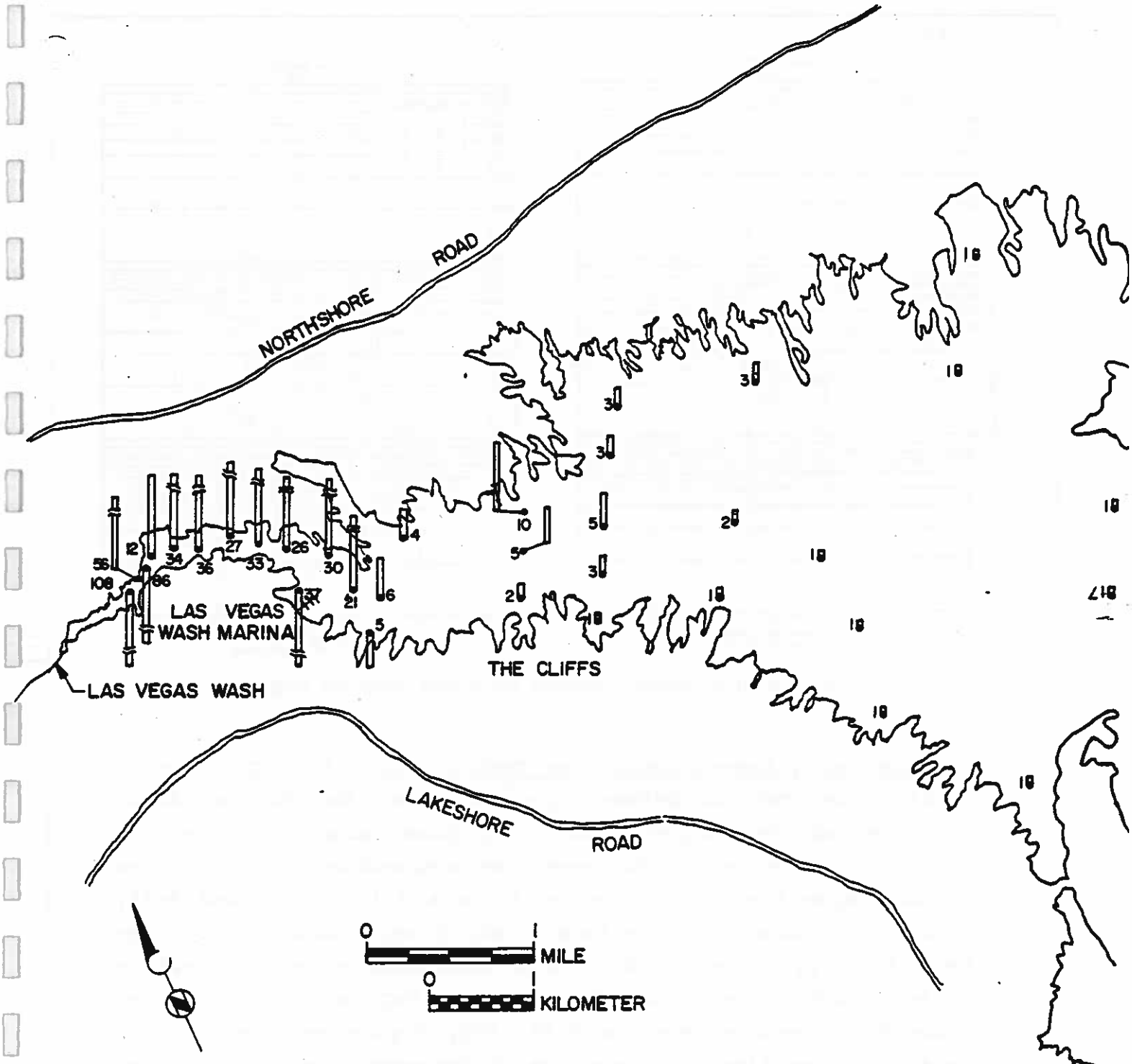


Figure 8-16 Uncorrected Chlorophyll Means and Ranges, WQSS Stations 1-11

from 35 to 300 or 400 ug/l. Peak concentrations at Stations 5 through 8 range from 10 to 25 ug/l. Chlorophyll levels at the background stations were uniformly low throughout the study period. Peak levels were less than 3 ug/l with average levels on the order of 1 to 1.5 ug/l. Average concentrations at Stations 5 through 8 ranged between 5 and 10 ug/l where average concentrations from Station 4 inward to Station 1 ranged from approximately 10 ug/l to 75 ug/l. At each station, the maximum was between four and five times the mean.

Four intensive surveys were conducted to define spatial variations during the different seasons. These surveys showed the same type of chlorophyll gradient between stations that were observed in the regular weekly samplings. Chlorophyll levels decreased continuously from Station 1 outward to Station 7. Chlorophyll showed relatively little variation laterally at locations along the axis of the bay. Chlorophyll results from the April 1980 survey are shown on Figure 8-17. Results of the other three surveys have been compiled and are available in the permanent STORET data file.

Frequency Distribution. Cumulative frequency plots of chlorophyll levels for Stations 2 through 5, 8, and 9, are shown for 1979 and 1980 on Figure 8-18. Average chlorophyll levels and the degree of variability in 1979 were slightly lower than 1980. For example, the median chlorophyll level at Station 2 in 1979 was approximately 23 ug/l compared to 34 ug/l in 1980. At Station 4, the median in 1979 was approximately 7.2 ug/l compared to 8 ug/l in 1980. Steeper slopes, particularly at Stations 1 through 4 indicate greater variability in 1980. This pattern is similar to that of the Secchi depth distributions where greater variability also occurred in 1980. The higher chlorophyll levels in 1980 correspond to lower Secchi depths in the same period.



NOTE: Lake Mead surface elevation 1200 feet (366 meters)

Figure 8-17 Uncorrected Chlorophyll a, Intensive Survey, 4/17/80

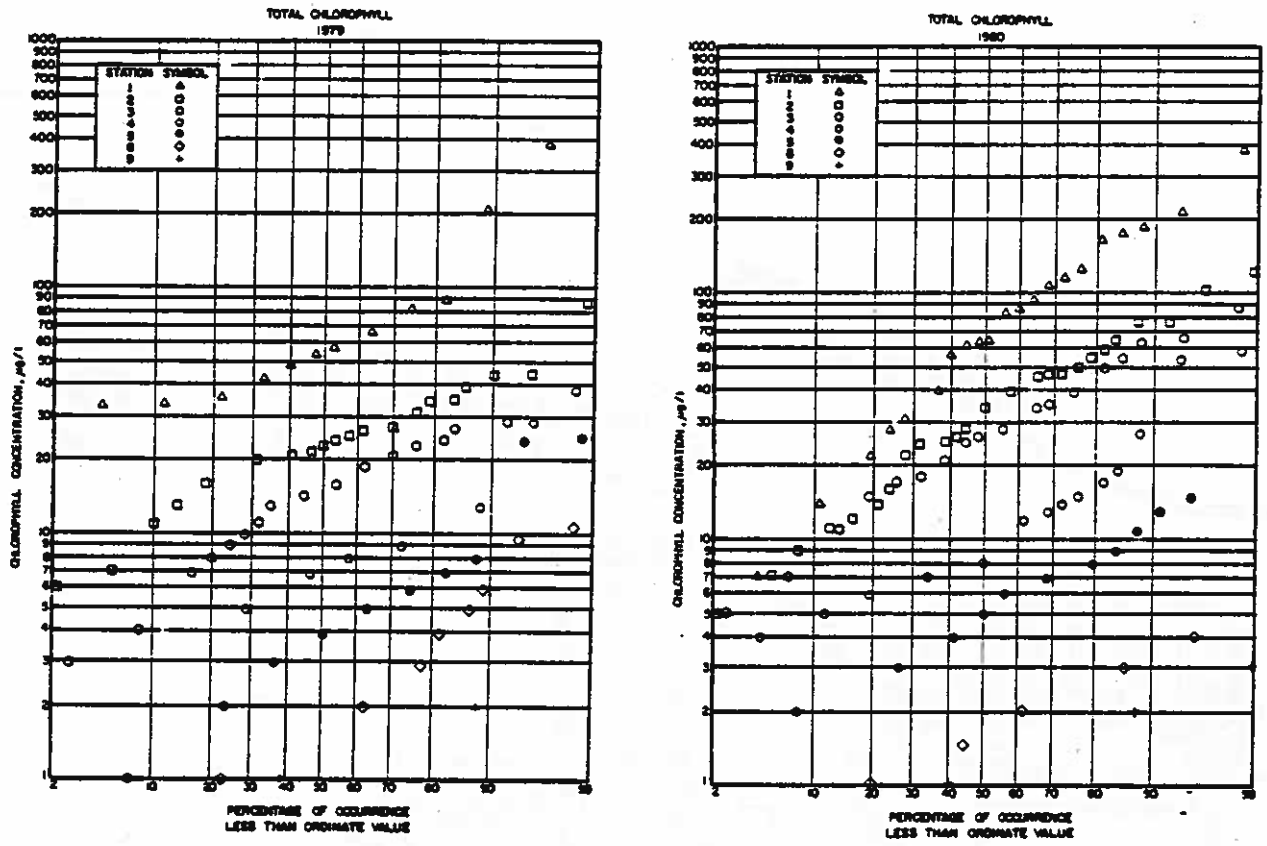


Figure 8-18 Chlorophyll Frequency Distribution, 1979 and 1980

Las Vegas Bay--Bonelli Bay Comparison. A comparison of algal concentrations between Las Vegas Bay and Boulder Basin stations and the background stations shows background levels to be consistently less than levels at comparable depth stations in Las Vegas Bay. As shown on Figures 8-11, 8-16, and 8-18, chlorophyll levels at Stations 8 and 9 were consistently less than 5 mg/l. Station 8 levels were consistently slightly higher than those of Station 9. The September to November chlorophyll peak at Station 8 in 1979, Figure 8-11, appears to be simply a smaller scale version of the same peak that occurred at the Las Vegas Bay stations. This peak, corresponding to the fall bloom on Figure 8-16 did not occur at Station 9 in Virgin Basin. As shown on the mean chlorophyll level at

Station 5 in Las Vegas Bay was more than five times the level at Station 10, of comparable depth in Bonelli Bay. Similarly, average chlorophyll levels at Station 3 in Las Vegas Bay were 17 times average chlorophyll levels at Station 11, of comparable depth in Bonelli Bay.

Nutrients

Nutrient measurements made in the WQSS include the inorganic forms of nitrogen (nitrate, nitrite, and ammonia) and total nitrogen, orthophosphorus, dissolved phosphorus and total phosphorus, iron, and silica. The chronological record of principal components of these nutrient measurements along with their spatial variation and frequency distribution is presented in this section. Also comparison is made between conditions observed in Las Vegas Bay and the background stations of Virgin Basin and Bonelli Bay.

Seasonal Distribution. Inorganic nitrogen (the sum of nitrate + nitrite + ammonia), total nitrogen, orthophosphorus, and total phosphorus measured in integrated surface samples at Stations 1 to 11 in 1979 and 1980 are shown on Figures 8-19 through 8-22. Data on iron and silica concentrations are shown on Figures 8-23 and 8-24, respectively.

Inorganic nitrogen and total nitrogen concentrations in the surface layer exhibit a very strong seasonal trend. The trends are similar at Stations 4 to 8, and slightly different at Stations 9, 10, and 11. The same trend appears to underlie the higher concentrations at Stations 1, 2, and 3. The basic trend is as follows: inorganic nitrogen concentrations in mid-summer

1979 were uniformly low, less than 50 ug/l; in mid-September, coinciding with decreasing water temperatures and the windy fall period, nitrogen concentrations gradually increased, reaching approximately 250 ug/l in late December and January.

The mid-winter concentrations were the highest of the year. Concentrations were approximately the same at Stations 4 to 11, approximately equal to the mid-summer hypolimnetic concentration in the same region. Inorganic nitrogen concentrations at all stations decreased rapidly beginning in about March. The decrease continued until minimum mid-summer levels were again reached. The rate of decrease differed from station to station, highest at inner stations and lowest in the background areas. Unlike mid-winter concentrations that were virtually the same at Bonelli Bay and Las Vegas Bay stations, minimum mid-summer inorganic nitrogen levels in Bonelli Bay were not as low as at Stations 4 to 8.

Total nitrogen concentrations, Figure 8-20, follow a similar pattern to that of inorganic nitrogen. The more irregular pattern appears to be due to the nitrogen component of algal solids superimposed on the inorganic component. The variations correspond generally to the irregular pattern of chlorophyll concentrations. The total nitrogen pattern began with low summer concentrations rising through fall to mid-winter, then rapidly decreasing through the spring to relatively constant mid-summer levels. This pattern was similar for Stations 3, 5, 8, 9, and 10. The significantly higher concentrations at the inner bay Stations 1, 2, and 3 of both inorganic nitrogen and total nitrogen appear to be due to the high concentrations of these substances in the plume underlying the relatively shallow water at those stations.

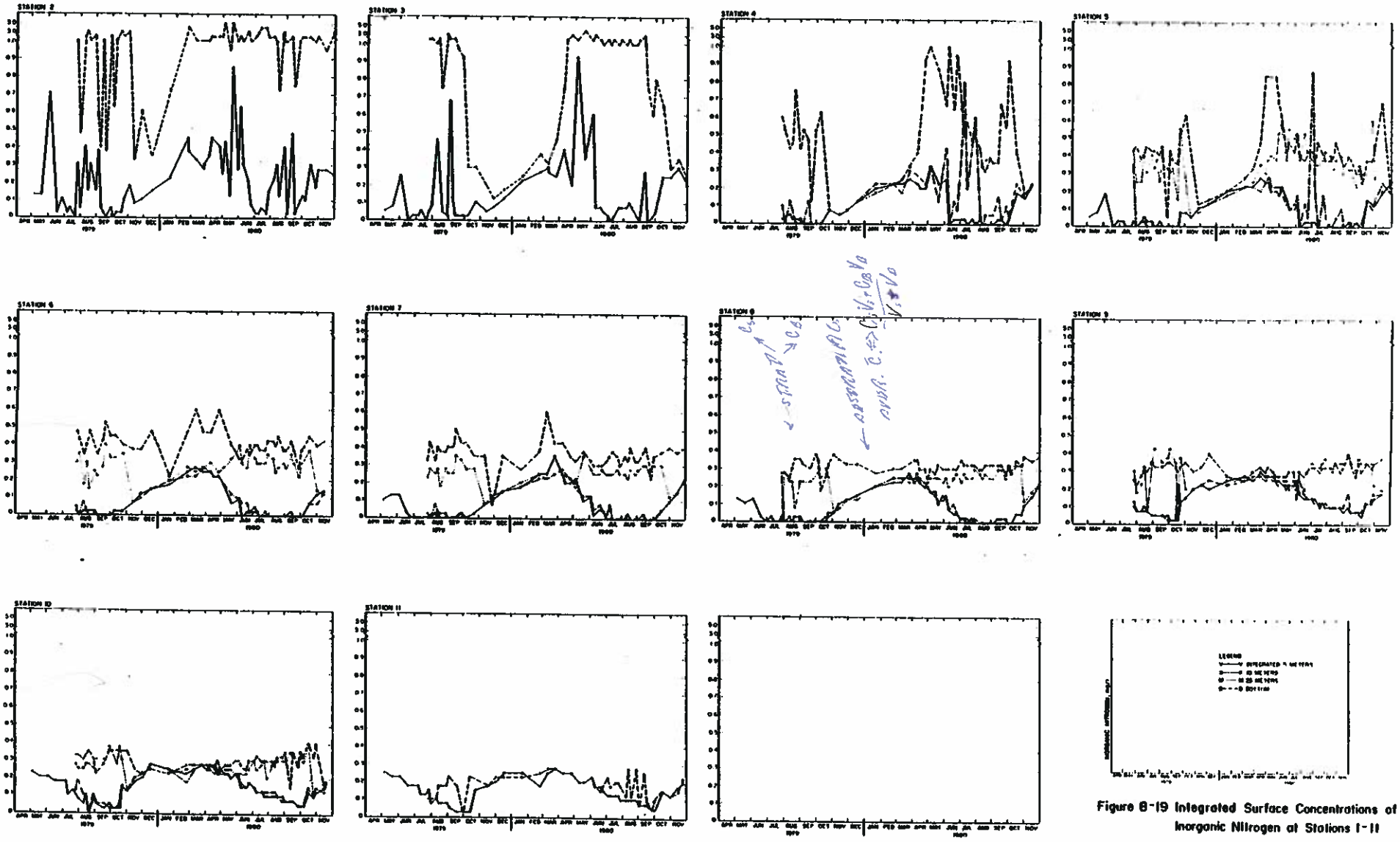


Figure 8-19 Integrated Surface Concentrations of Inorganic Nitrogen at Stations 1-11

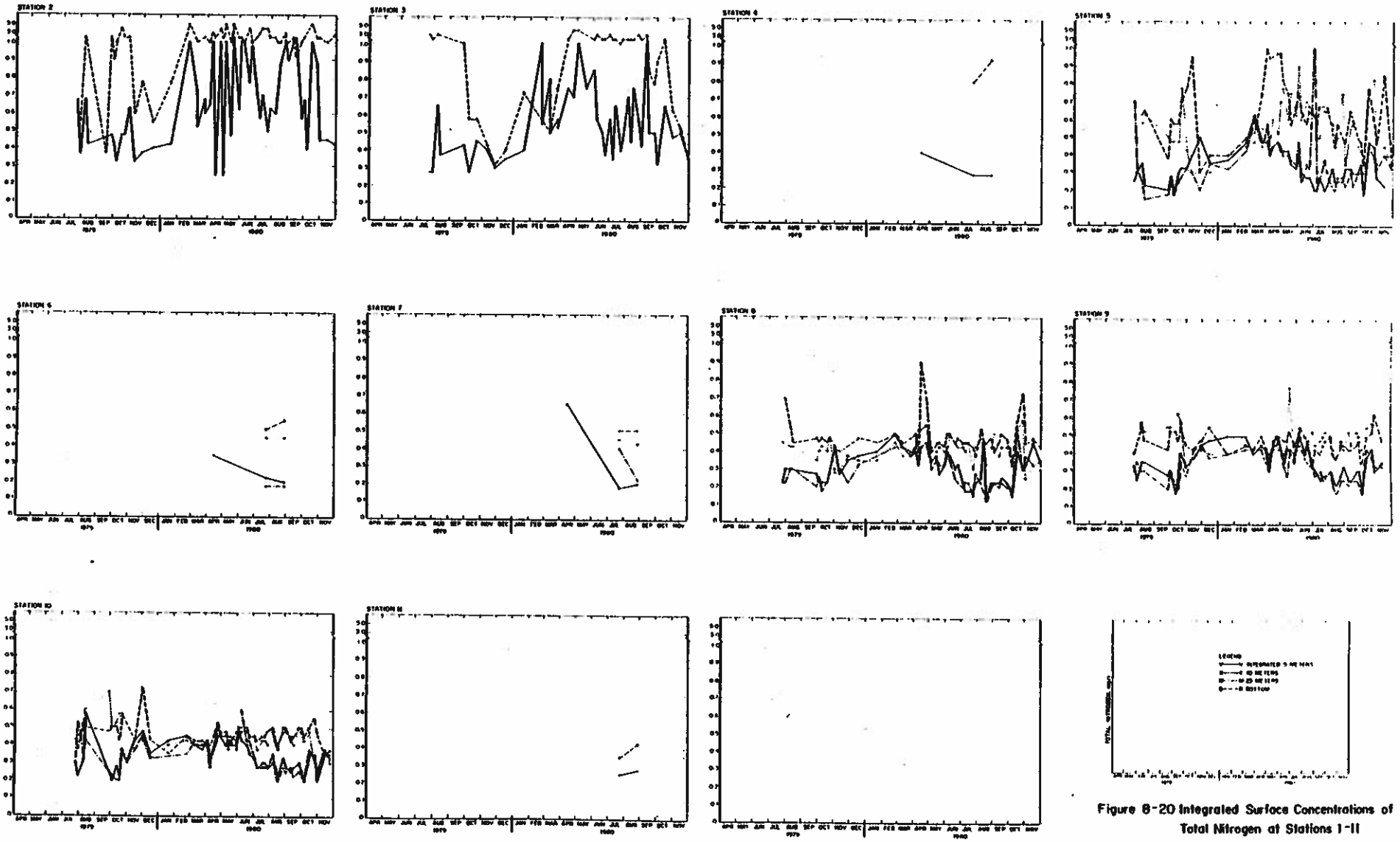


Figure 6-20 Integrated Surface Concentrations of Total Nitrogen at Stations I-II

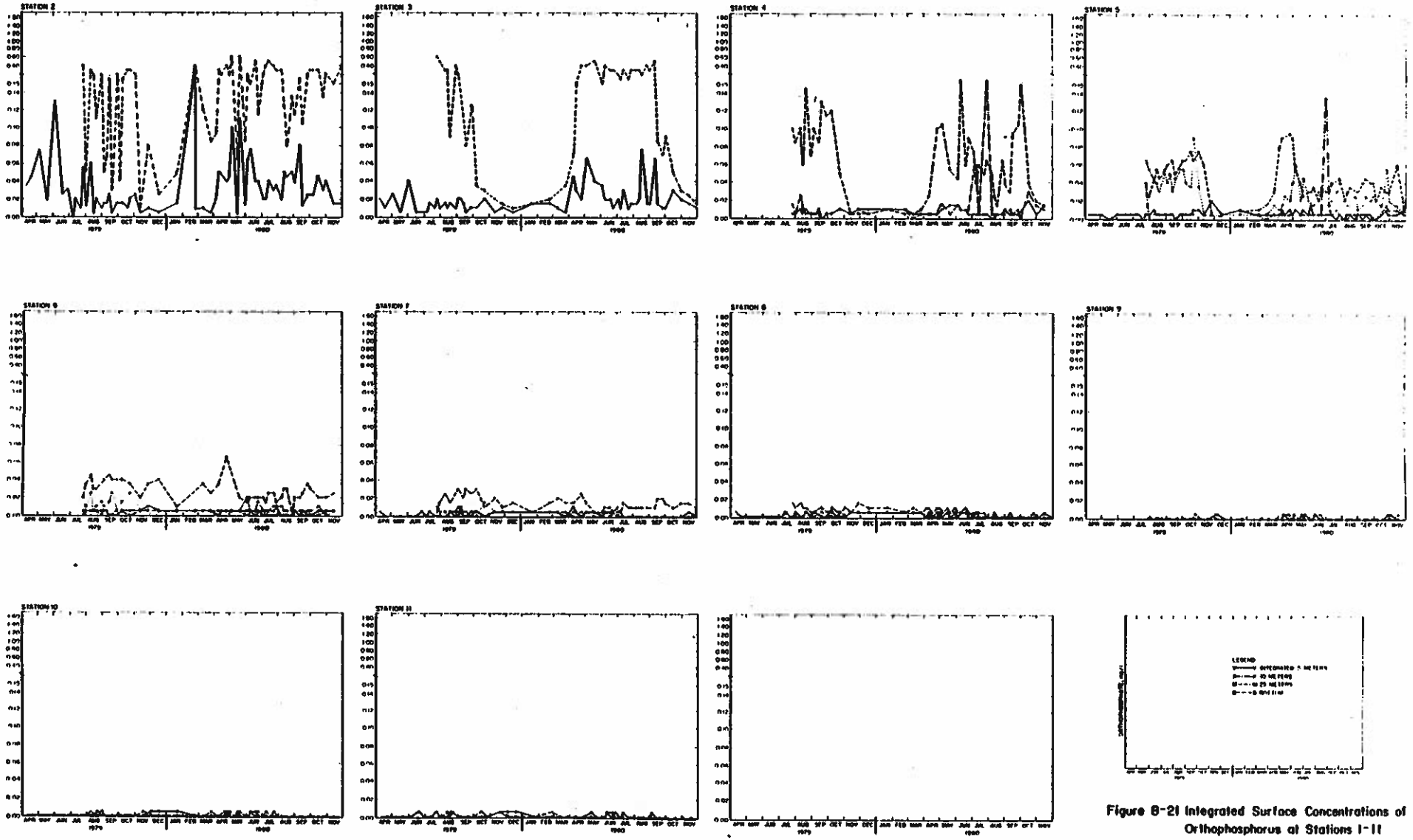


Figure 8-21 Integrated Surface Concentrations of Orthophosphorus at Stations I-11

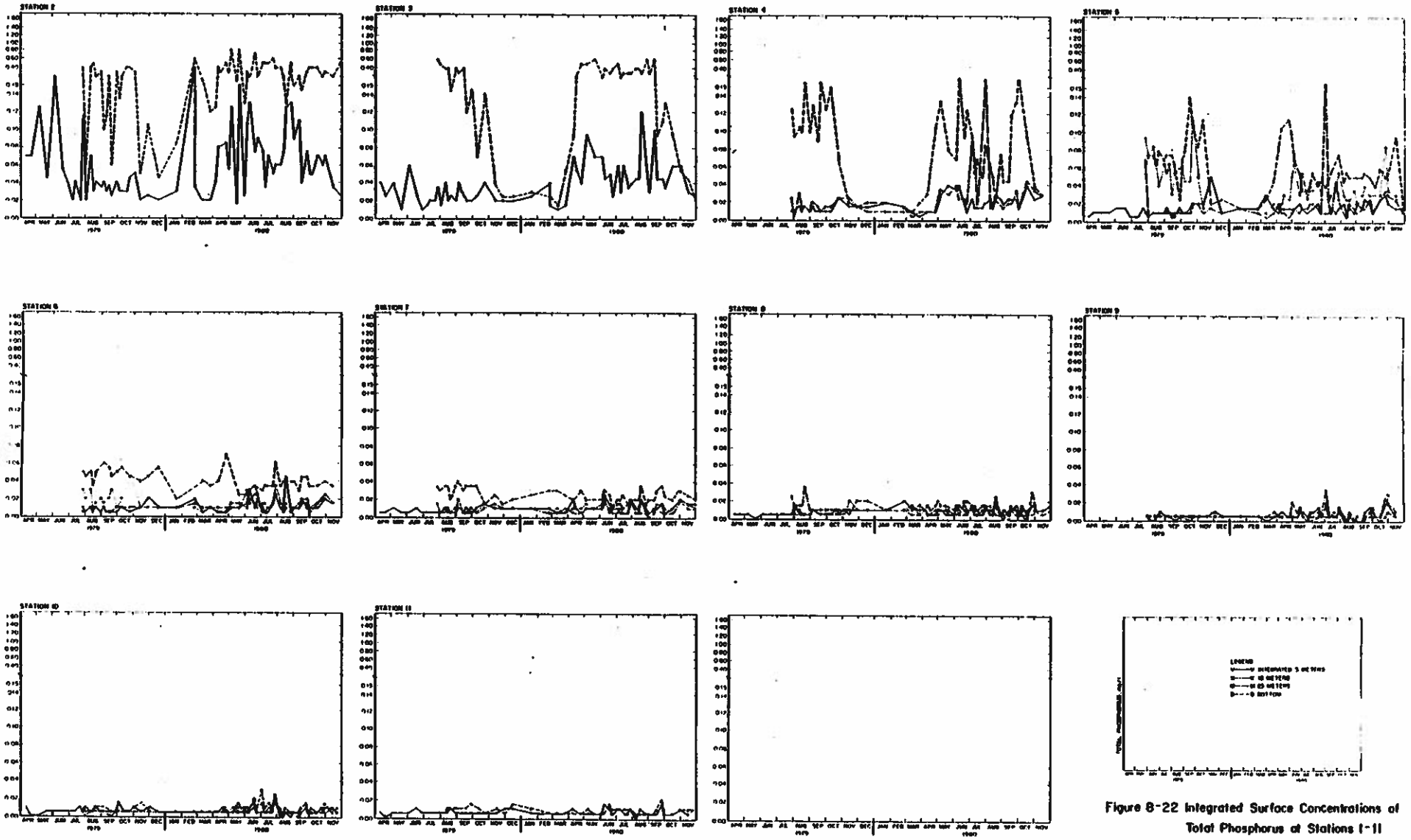


Figure 8-22 Integrated Surface Concentrations of Total Phosphorus at Stations 1-11

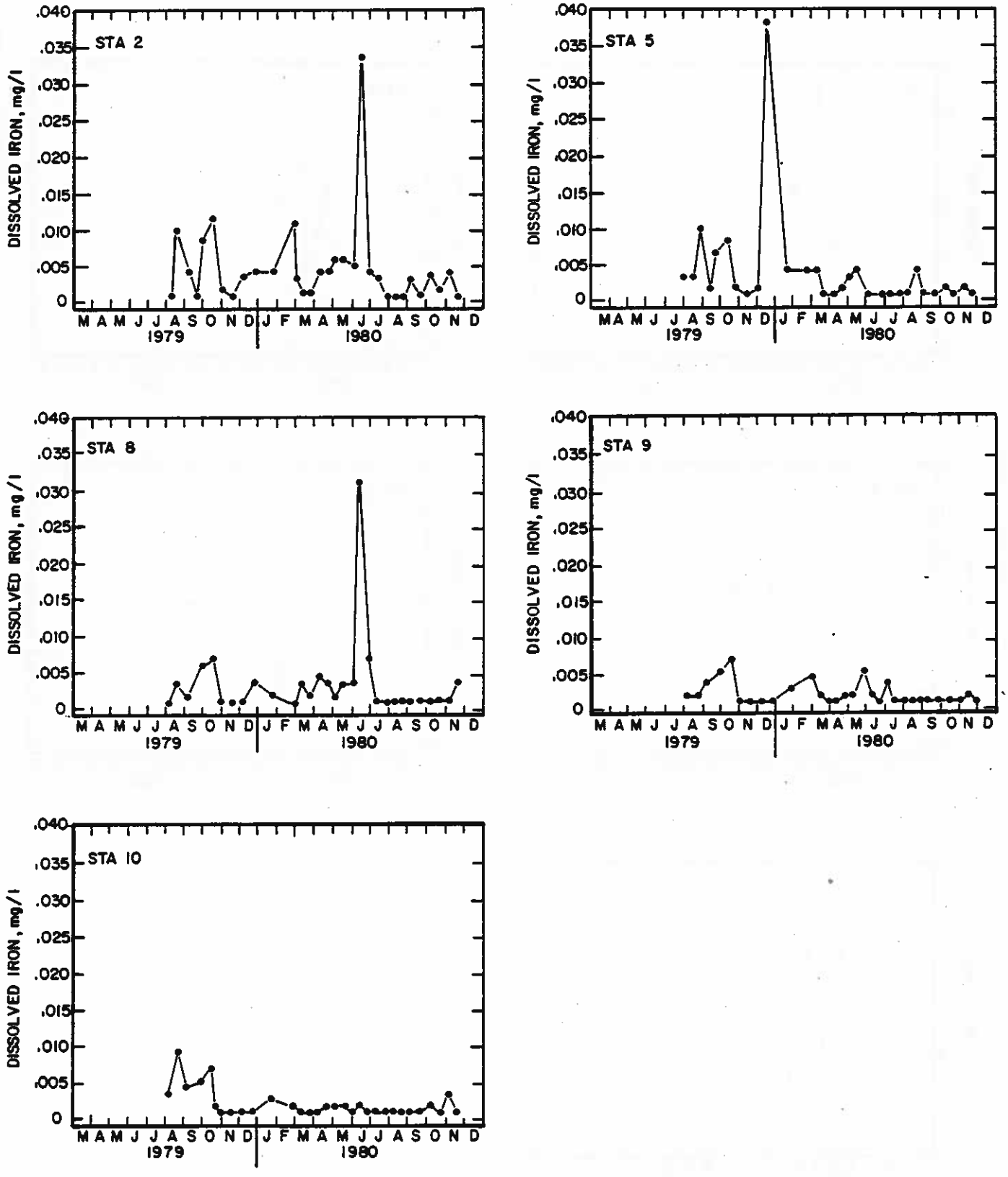


Figure 8-23 Dissolved Iron Concentrations at Lake Stations 2, 5, 8, 9 and 10

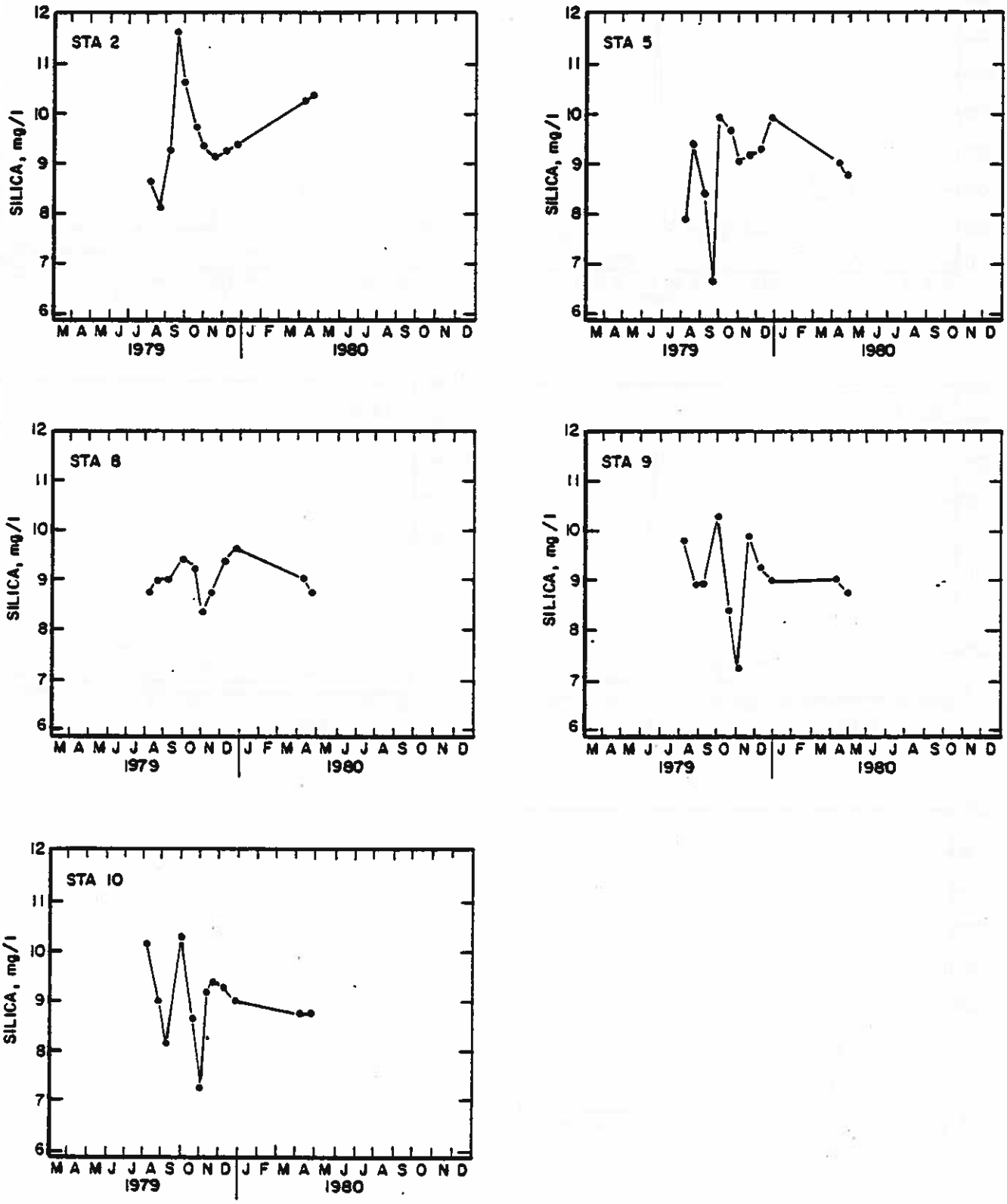


Figure 8-24 Silica Concentrations at Lake Stations 2, 5, 8, 9 and 10

Phosphorus concentrations did not have the same seasonal pattern as nitrogen. Very little seasonal variation occurred beyond Station 3, Figures 8-21 and 8-22. In the inner bay, Stations 1, 2, and 3, phosphorus concentrations in winter months were low with relatively little variations for the rest of the year. From March to November, phosphorus concentrations were relatively high and highly variable. The lack of a strong seasonal pattern at the outer stations is due to the relatively low concentrations of phosphorus in the hypolimnion. The pattern at the inner stations is due to the relatively high phosphorus concentrations in the plume and to biological activity in the non-winter period. The lower levels and variability in winter appears to result from the lower influence of the plume and lack of biological activity (Figures 8-5 and 8-11).

Concentrations of the major nutrients, inorganic nitrogen and total nitrogen, orthophosphorus, and total phosphorus, in samples from depths below the 5 meter integrated surface layer (10 meters, 25 meters, and at the bottom) are summarized on Figures 8-25 through 8-28. Examination of the inorganic nitrogen and total nitrogen data, Figures 8-25 and 8-26, indicates several important features. The heavy influence of the plume on the inner bay Stations 2 and 3 can be seen in the elevated bottom concentrations. Levels at Stations 2 and 3 were as much as five times the average concentration in the middle and outer bay. The difference in concentrations between the integrated surface samples and the bottom samples at Stations 2 and 3 reflect the isolation of the plume near the bottom of the bay and the high relatively undiluted concentrations in the plume. Differences in concentration between surface and bottom

samples at outer stations, Stations 5, 8, 9, and 10, are a reflection of thermal stratification and biological processes occurring during the growing season. Little or no difference existed between integrated surface samples and 10-meter samples at those stations. This is consistent with the depth of the well-mixed surface layer of from 10 to 15 meters, formed by thermal stratification, discussed previously, Figure 8-8. Also, little difference occurred between samples collected at a mid-depth (25 meters) and at the bottoms. Some exceptions occurred occasionally in the deepest stations, Stations 8 and 9. This may be due to an underflow of Colorado River water.

Biological and physical processes combined during the biologically active period (April through October) to deplete nitrogen concentrations in the surface layer. Inorganic nitrogen was virtually exhausted within a span of less than two months from the onset of biological activity at Stations 5 and 8. Inorganic nitrogen was exhausted more slowly at Stations 9 and 10, reflecting the lower levels of biological activity in that area of the lake. Total nitrogen was only partially depleted. Minimum levels were 200 to 250 ug/l at all the outer stations. Concentrations of inorganic and total nitrogen were essentially uniform from surface to bottom during the period of winter destratification from mid-November to mid-February. The surface layer was replenished with both inorganic and total nitrogen during this period to be depleted again by the spring/ summer biological processes. However, the volume of the hypolimnion is so much larger than the volume of the epilimnion, that nitrogen lost from the epilimnion to the hypolimnion during summer months did not cause an appreciable increase in hypolimnetic concentrations.

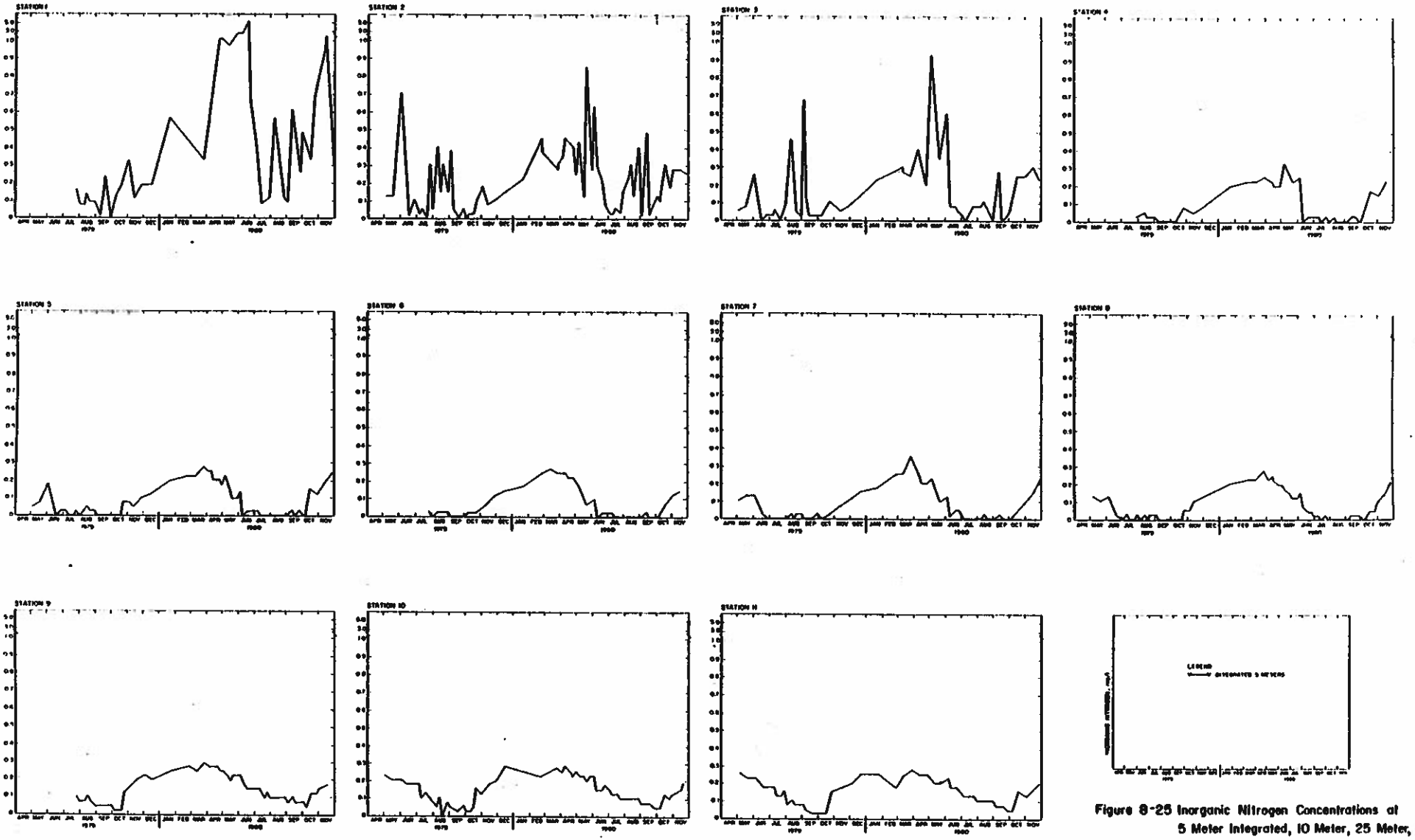


Figure 8-25 Inorganic Nitrogen Concentrations at 5 Meter Integrated, 10 Meter, 25 Meter, and Bottom, Lake Stations 2-11

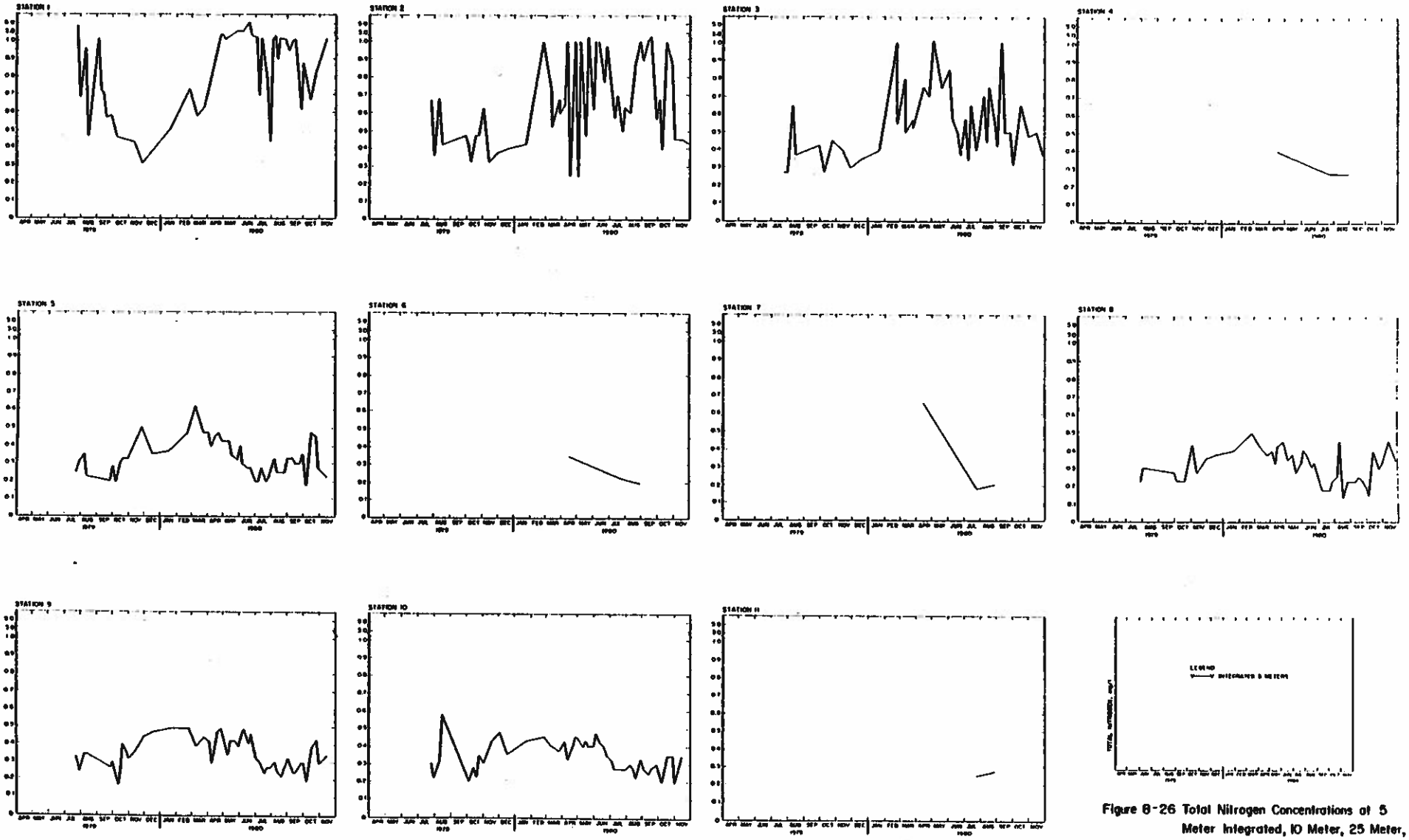


Figure 8-26 Total Nitrogen Concentrations at 5 Meter Integrated, 10 Meter, 25 Meter, and Bottom, Lake Stations 2-11

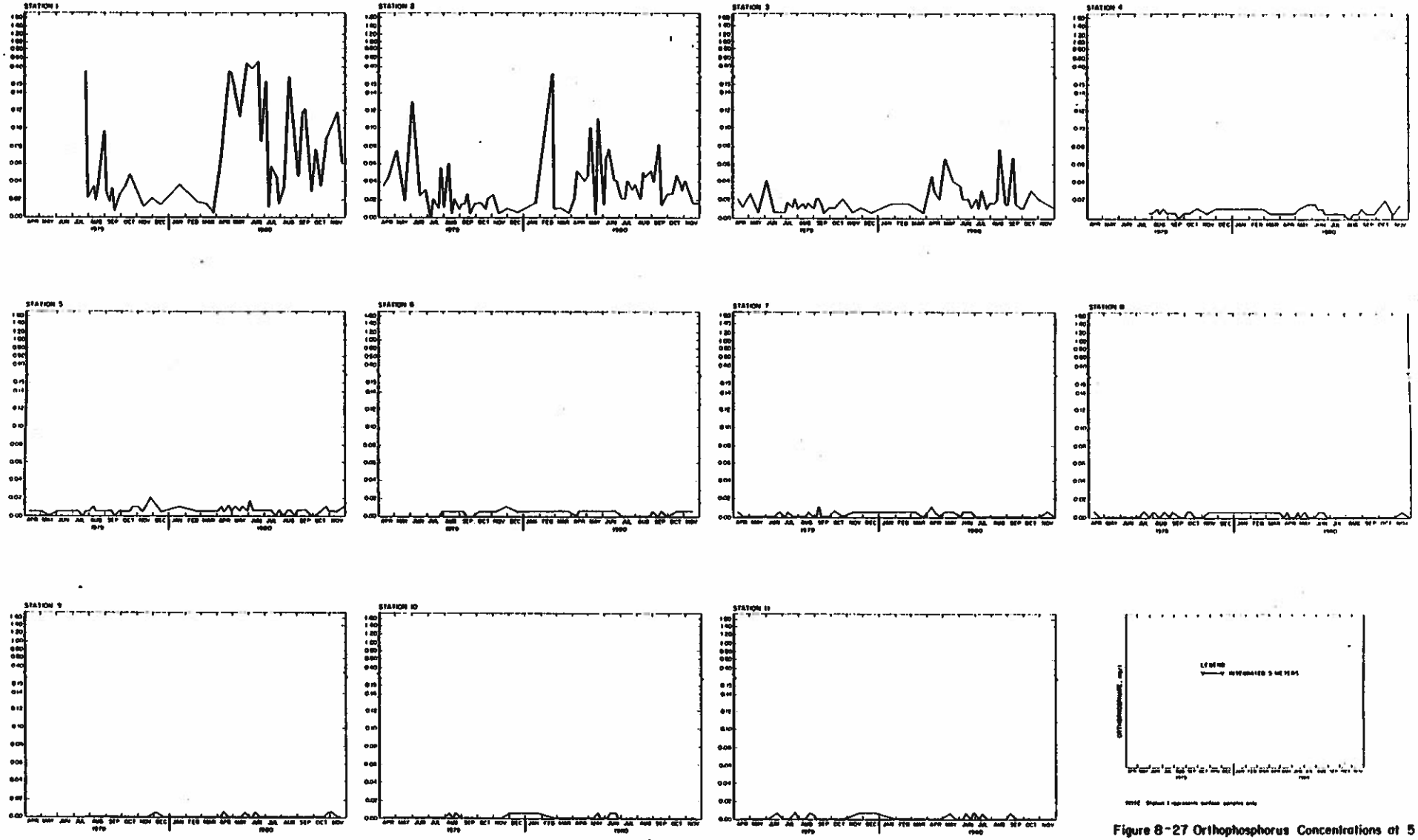


Figure 8-27 Orthophosphorus Concentrations at 5 Meter Integrated, 10 Meter, 25 Meter, and Bottom, Lake Stations 2-11

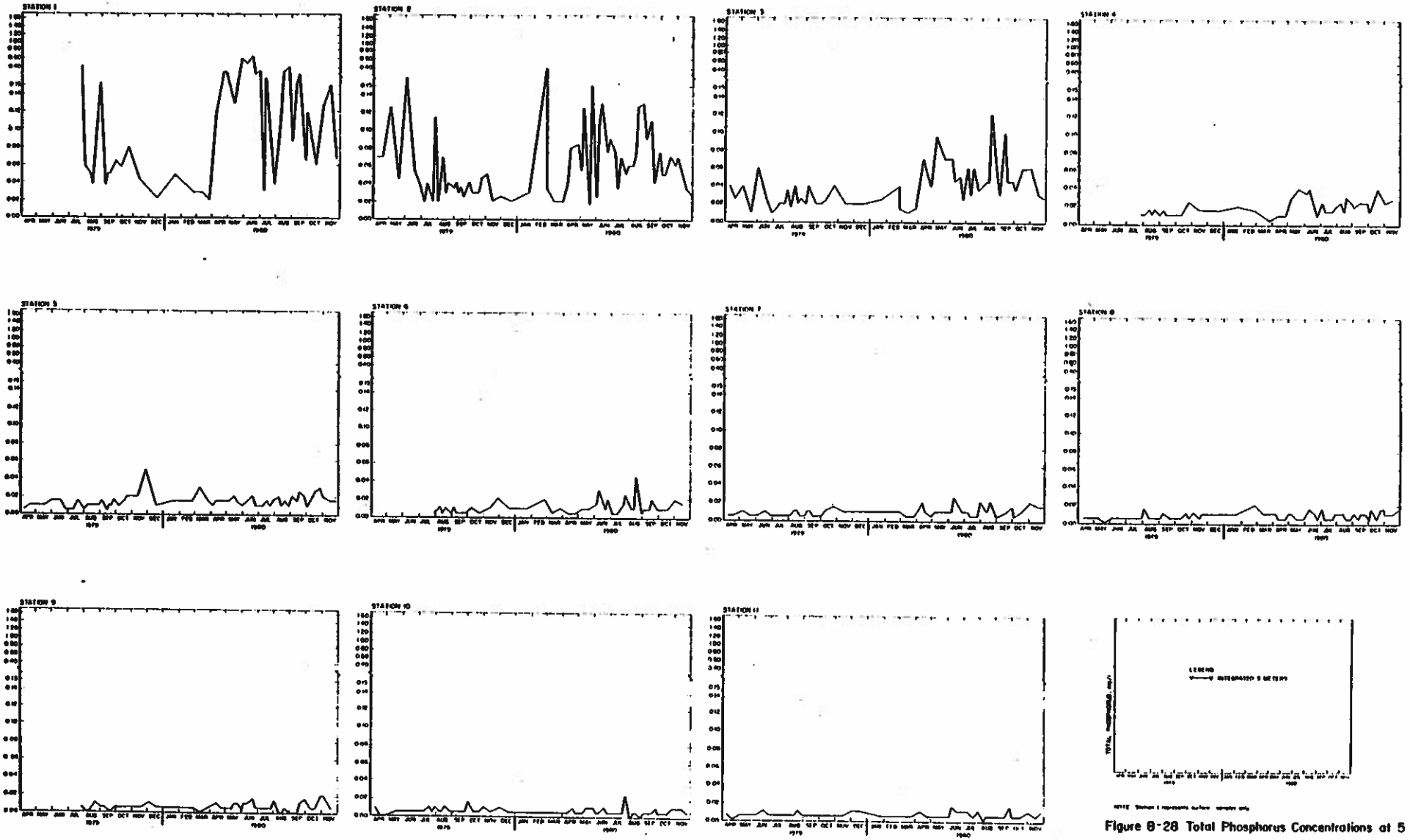


Figure 8-28 Total Phosphorus Concentrations at 5 Meter Integrated, 10 Meter, 25 Meter, and Bottom, Lake Stations 2-11

Some trends in the bottom concentration of inorganic nitrogen and total nitrogen occurred in Las Vegas Bay as far out as Station 5. The bottom concentration increased significantly in early fall, then dropped to a uniformly lower level in the November to February winter period. Levels rose significantly again in the spring, returning to more moderate mid-summer levels. No such trend was observed at Station 8 in Boulder Basin or at the background Stations 9 and 10. Total nitrogen levels at these stations were essentially constant at 400 to 450 ug/l. Inorganic nitrogen at Stations 8, 9, and 10 also remained approximately at 250 ug/l throughout the study period. Since the mid-winter total nitrogen and inorganic nitrogen levels at Station 5 were approximately the same as those in the deeper water stations, the higher levels observed in early fall and early spring are apparently due to greater contribution of the plume to the bottom concentrations in those periods. A possible explanation for the fall and spring peaks with the lower intermediate winter levels would be as follows: as decreasing temperatures caused the plume to sink deeper in the bay, progressively less dilution would occur at inner stations. Accordingly, concentrations should rise at a given station, such as Station 5. Apparently, following the early November sampling, the plume segregation was great enough that it was flowing completely on the bottom and not detected by the sampling procedures throughout the winter months. At about the beginning of March, however, as wash temperatures began to rise, the plume began to rise above the bottom. Under such conditions, it was again detected in bottom samples. By early May, however, the plume had risen far enough that it no longer contributed to high concentrations at the bottom. Inorganic and total nitrogen concentrations at the 25 meter depth confirm this general interpretation.

The variations in hypolimnetic orthophosphorus and total phosphorus concentrations were similar to those of the nitrogen concentrations. To some degree, the Las Vegas Bay stations all show the effect of the sinking and rising plume. Low mid-winter concentrations apparently reflect the lack of plume dispersion in Las Vegas Bay. No effect of such seasonal variation was observed at the background stations or at Station 8. Also, the phosphorus concentrations do not show the same pattern of summer depletion in the epilimnion followed by replenishment in the winter. This is due to the fact that phosphorus concentrations in the hypolimnion are low throughout the lake except where supplied by higher phosphorus concentrations from the plume. Accordingly, fall and winter mixing of deeper water does little to raise the concentrations of phosphorus in the epilimnion.

Spatial Distribution. Variations of inorganic and total nitrogen, orthophosphorus, and total phosphorus between the 11 WQSS stations are shown on Figures 8-29 and 8-30. The means and ranges of the nutrient concentrations decreased strongly from inner bay to outer bay. In each case, the concentrations decrease by a factor of from 5 to 7 between Stations 1 and 4. The decreases between Stations 4 and 8 were consistently less than a factor of 2. Concentrations observed at Stations 9, 10, and 11 were in each case comparable to those at Station 8 in Boulder Basin.

Four intensive surveys were conducted to define spatial variations during the different seasons. These surveys showed a similar gradient in nutrient concentrations between stations to that observed in the regular weekly samplings, Figures 8-29 and 8-30. Both nitrogen and phosphorus concentrations decreased continuously from Station 1 outward to Station 7. The concentrations varied little laterally at locations along the

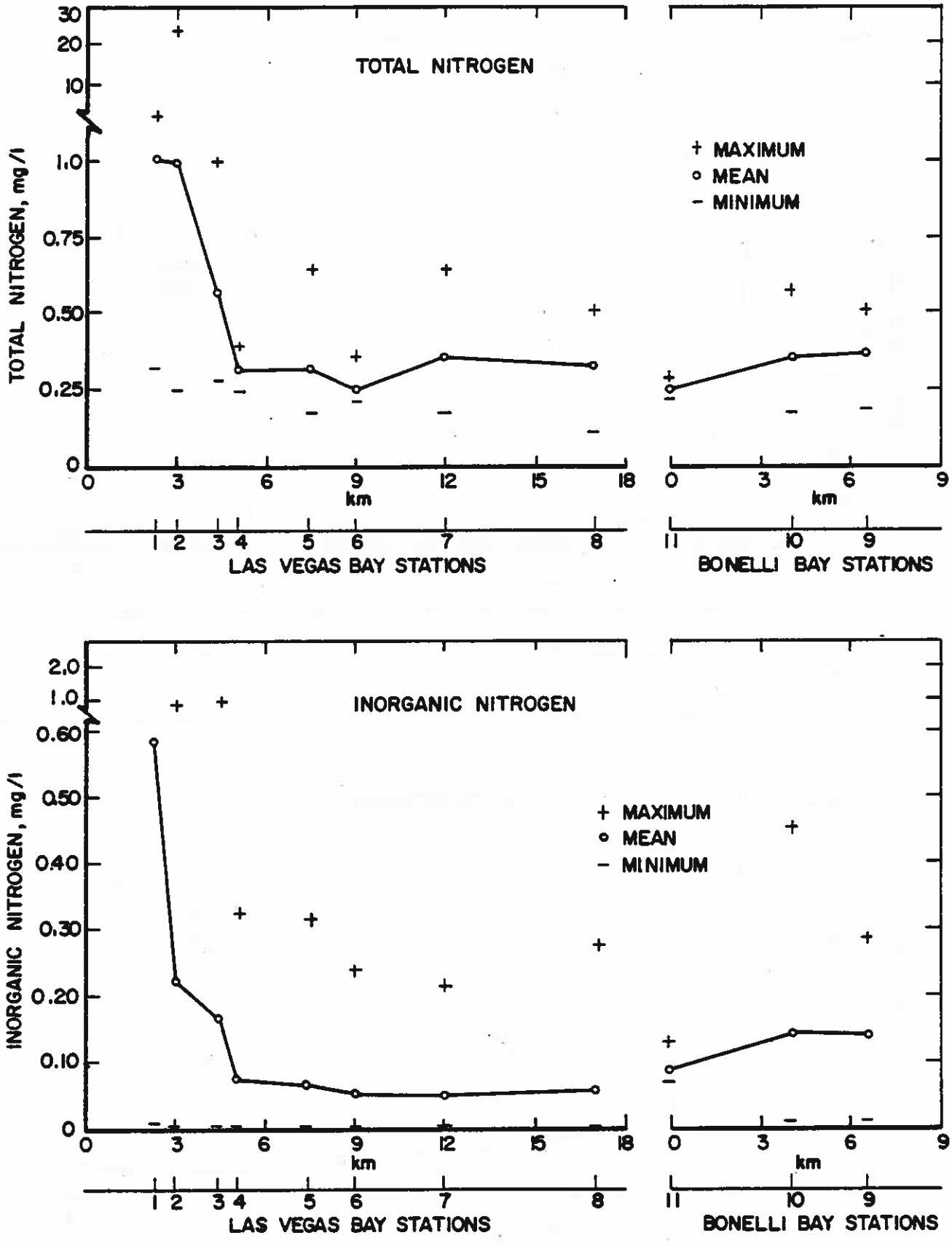
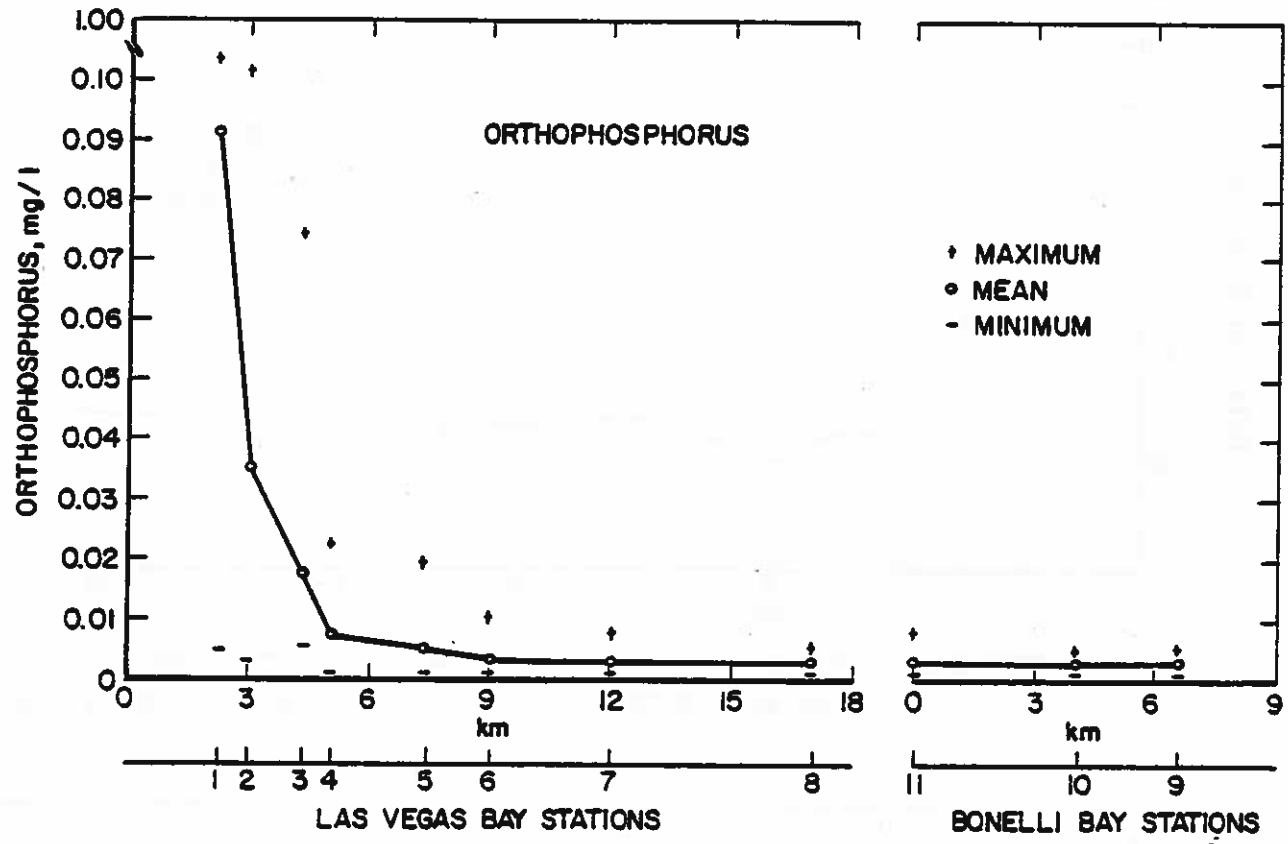


Figure 8-29 Total and Inorganic Nitrogen Means and Ranges, WQSS Stations I to II



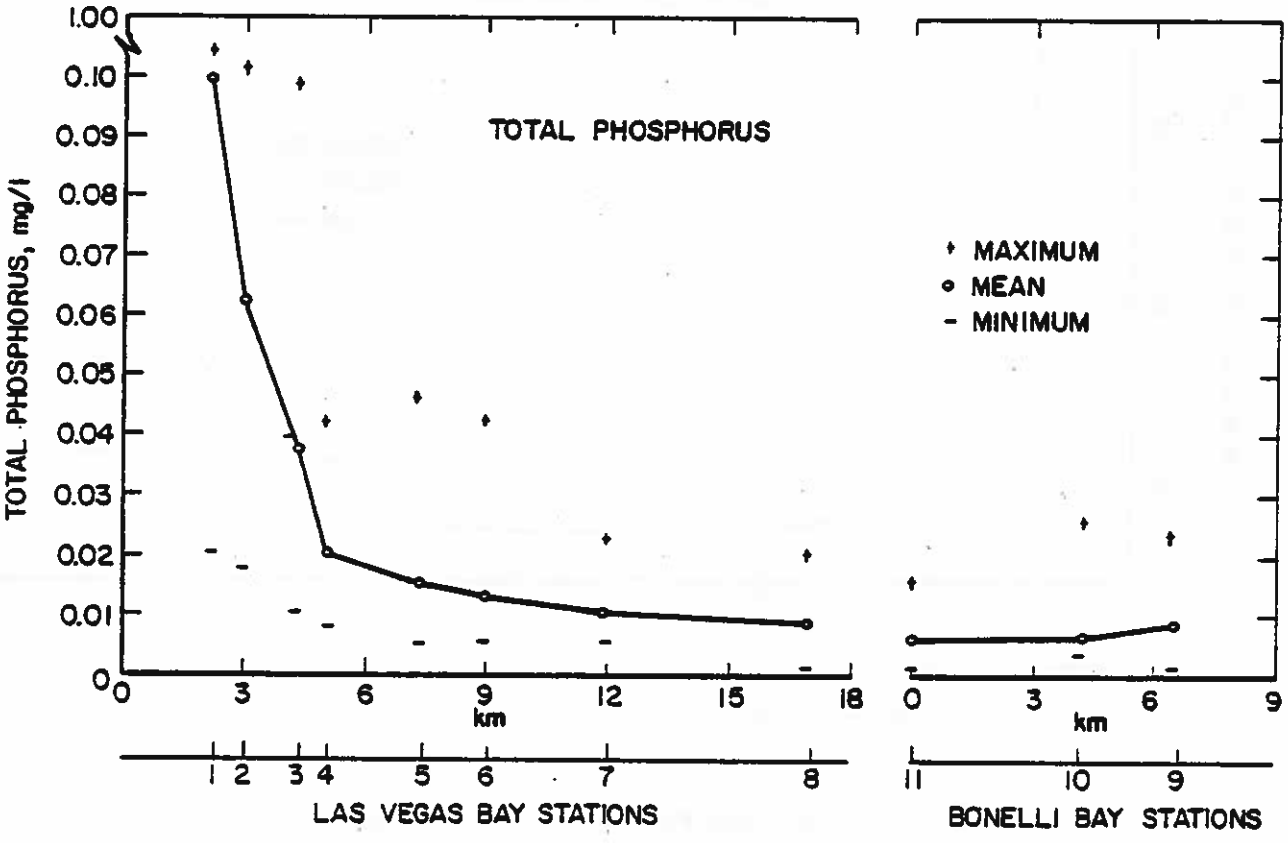
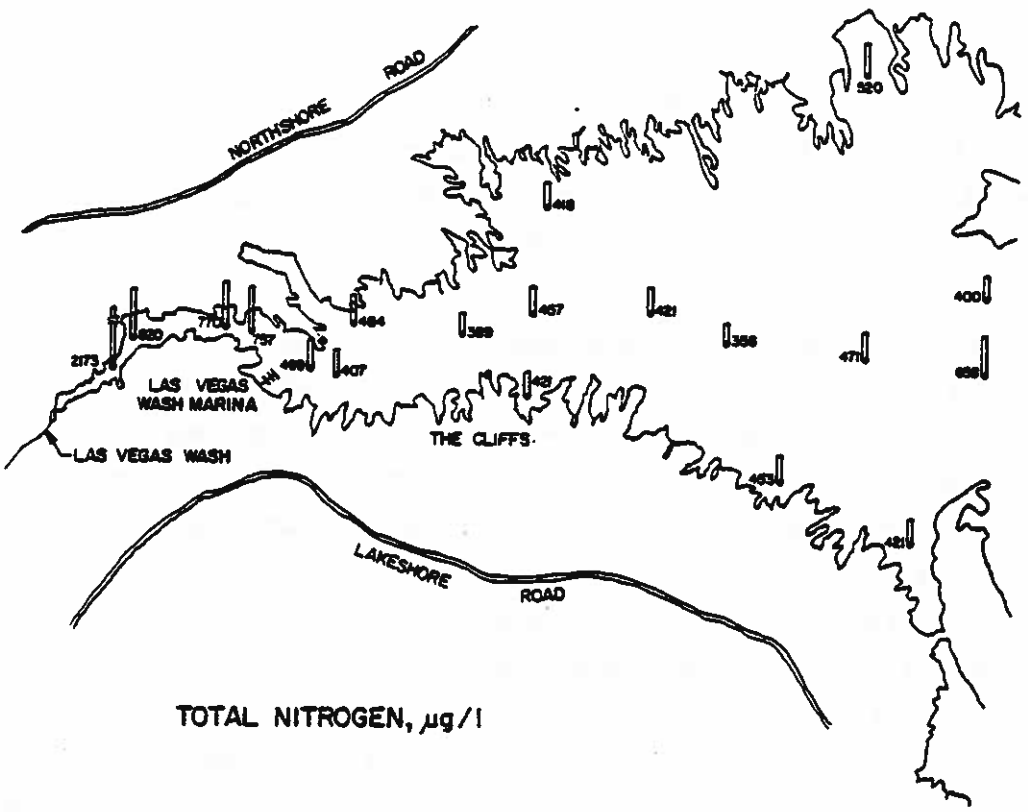


Figure 8-30 Total and Orthophosphorus Means and Ranges, WQSS Stations 1 to 11

axis of the bay. Nitrogen and phosphorus concentrations from the April 1980 survey are shown on Figures 8-31 and 8-32. Results of the other three surveys have been compiled and are available in the permanent STORET data file.

Frequency Distributions. Frequency distributions of inorganic nitrogen and total nitrogen, orthophosphorus, and total phosphorus are shown on Figures 8-33 and 8-34, respectively. Similar to Secchi depth and chlorophyll concentrations, 1980 nutrient concentrations were both higher and more variable than those observed in 1979. For example, the median inorganic nitrogen level for Station 2 in 1980 (Figure 8-33) was approximately 200 ug/l compared to approximately 100 ug/l in 1979. The median total nitrogen concentration for Station 2 in 1980 was approximately 730 ug/l compared to 480 ug/l in 1979. The median orthophosphorus concentration for 1980 at Station 2 was approximately 38 ug/l compared to 18 ug/l in 1979 (Figure 8-34). The median total phosphorus concentration for Station 2 in 1980 was approximately 73 ug/l compared to 40 ug/l in 1979. The steeper slopes of the frequency distributions for all nitrogen and phosphorus species in 1980 indicate greater variability compared to 1979. The variability of total nitrogen and total phosphorus was somewhat less than that of the inorganic nitrogen and orthophosphorus. Also, the variability of total nitrogen and total phosphorus decreased from Station 1 outward to Station 5. This appears to be a reflection of the decreasing influence of the dissolved fraction on the total nutrient concentrations with increasing distance from the wash and the inherently lower variability of the particulate fraction. The increasing dilution of the plume with increasing distance from the wash results in the decreasing input of dissolved nutrients.



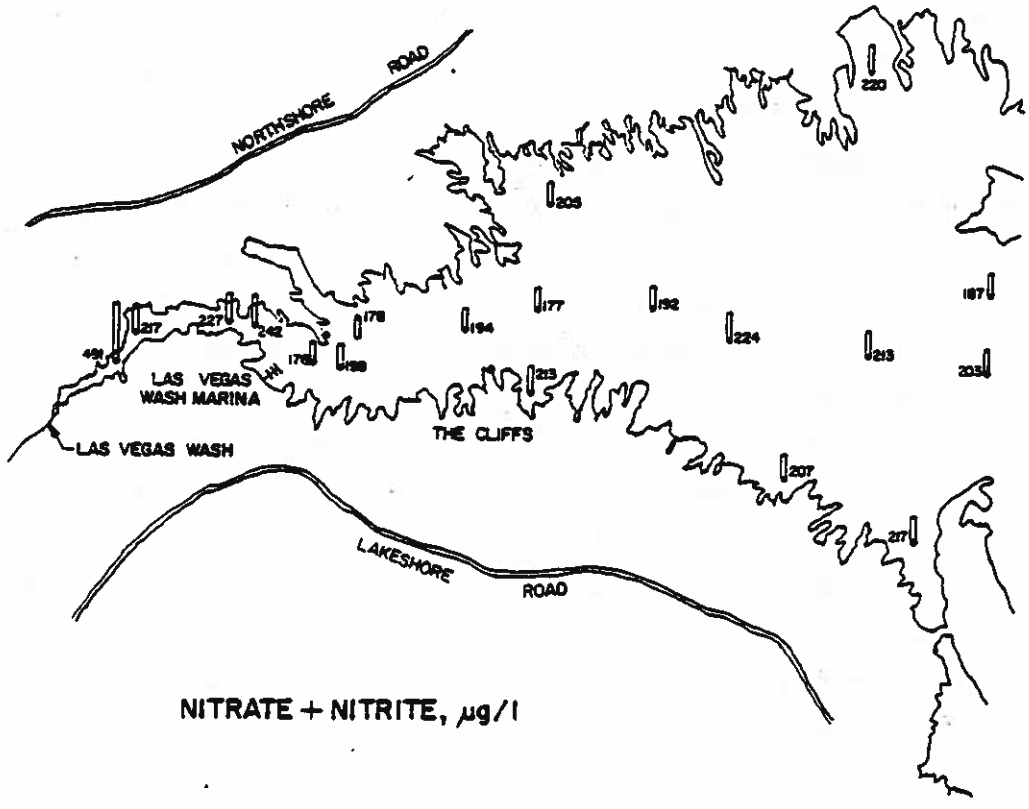
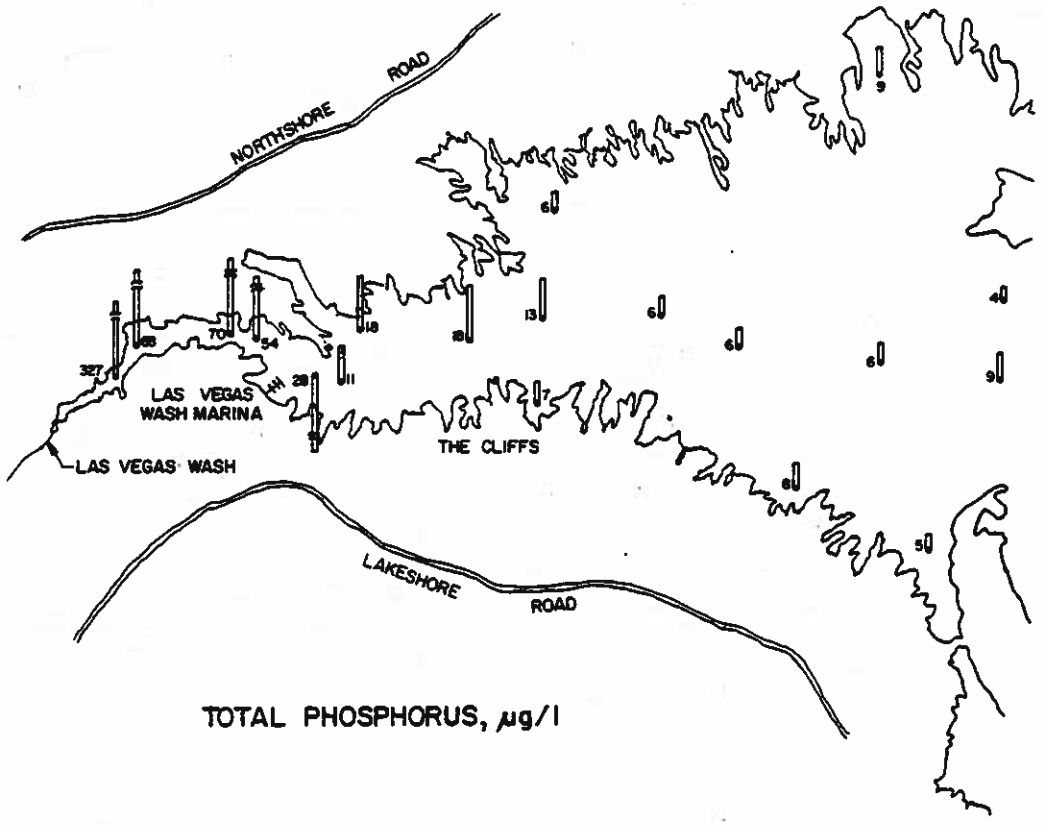


Figure 8-31 Total Nitrogen and Nitrate Plus Nitrite Intensive Survey Data, 4/17/80



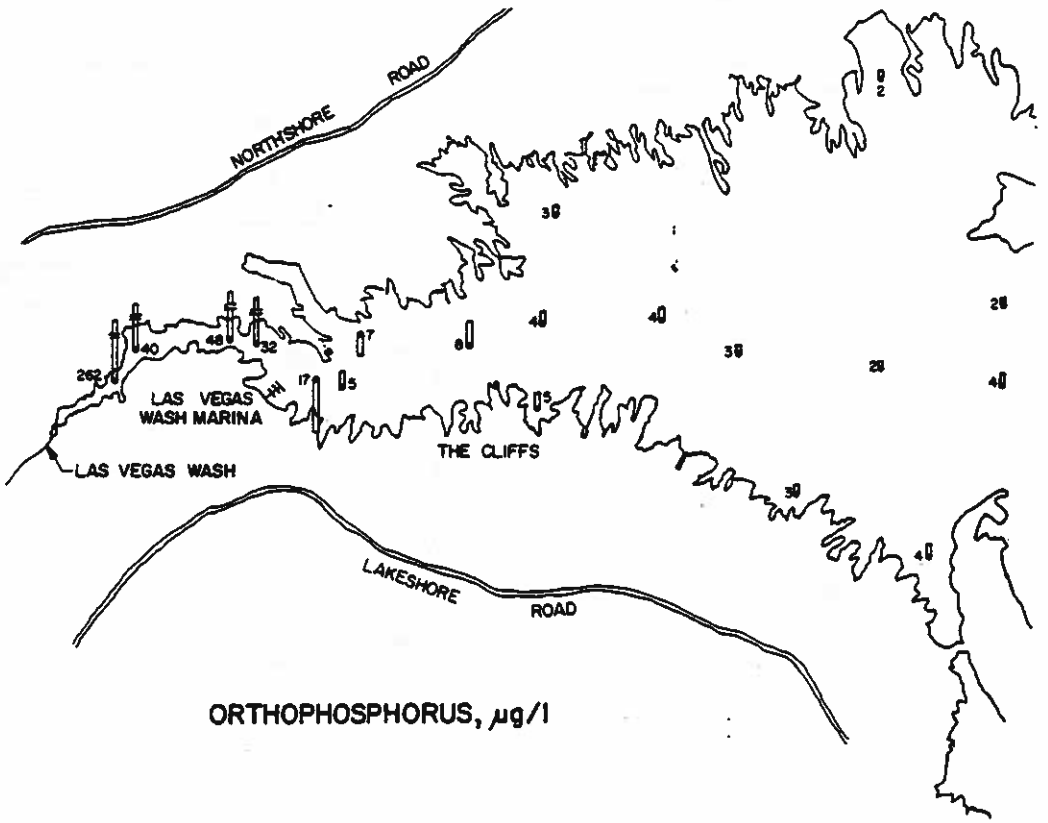


Figure 8-32 Total Phosphorus and Orthophosphorus Intensive Survey Data, 4/17/80

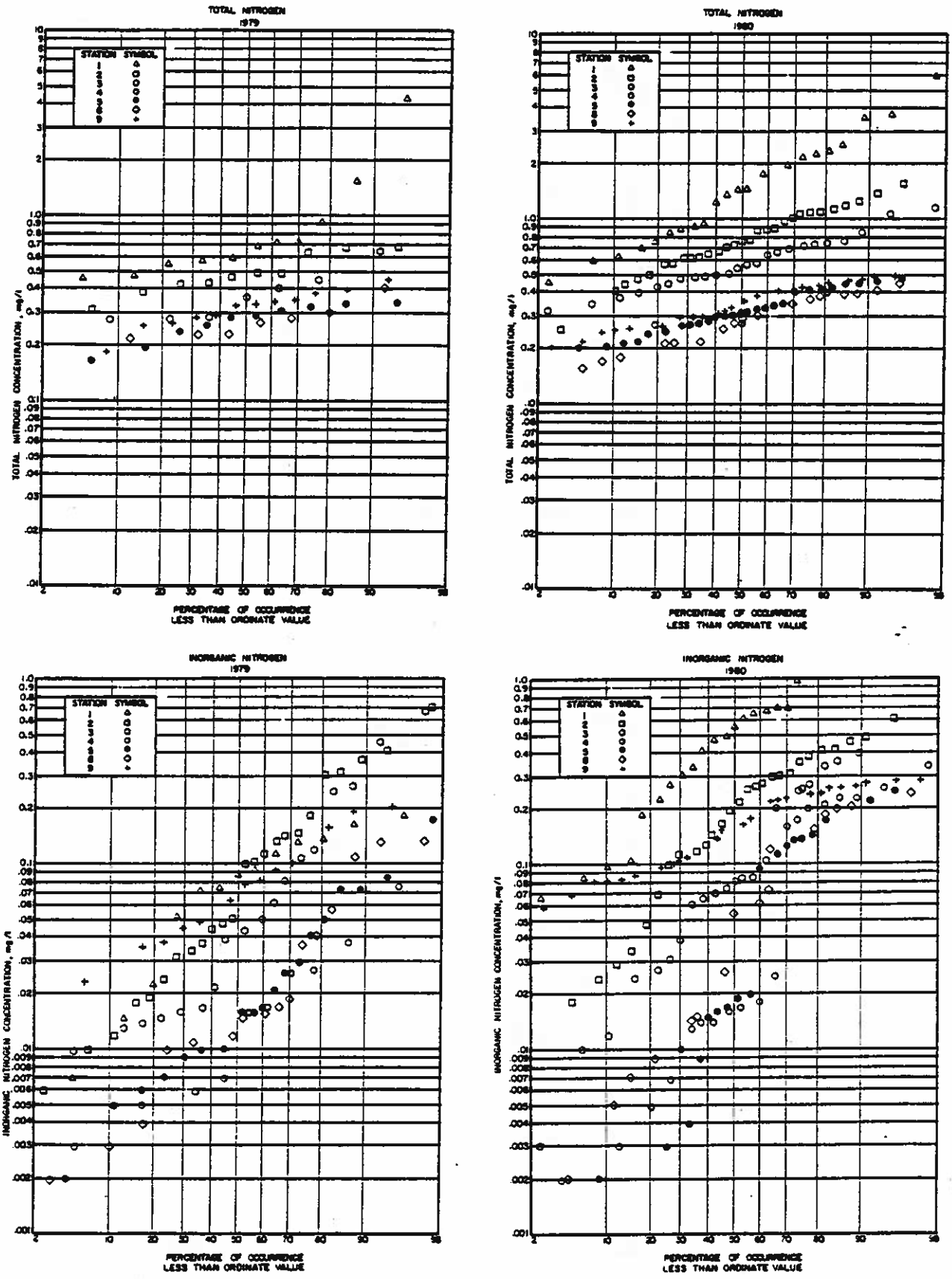


Figure 8-33 Total Nitrogen and Inorganic Nitrogen Frequency Distributions, 1979 and 1980

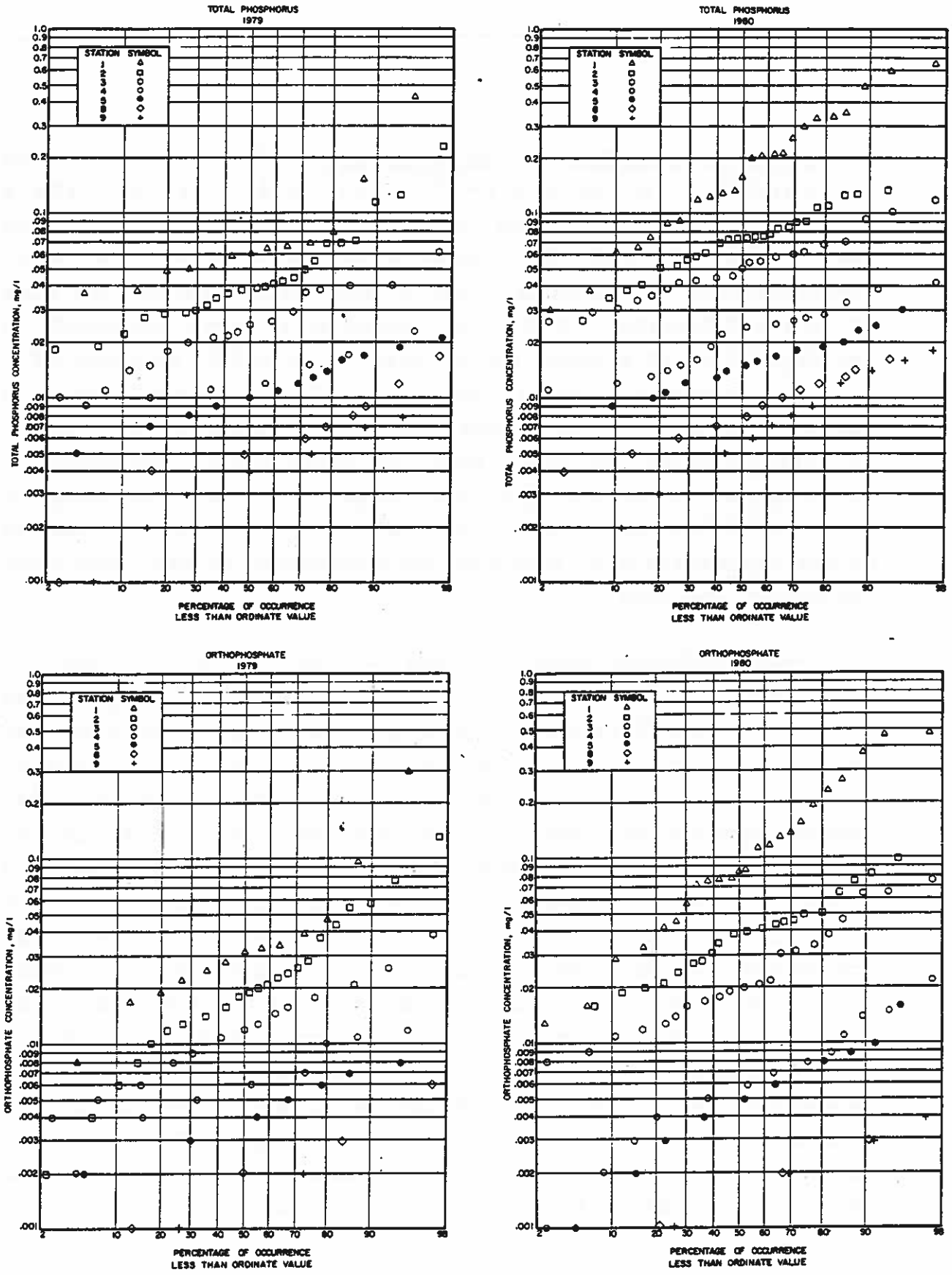


Figure 8-34 Total Phosphorus and Orthophosphorus Frequency Distributions, 1979 and 1980

Las Vegas Bay--Bonelli Bay Comparison. The data summarized on Figures 8-19 through 8-22, 8-33, and 8-34, provide a comparison of nitrogen and phosphorus concentrations between Las Vegas Bay and the background stations. Nitrogen concentrations at Stations 9 and 10 were approximately the same as the concentrations at the comparable depth stations in Las Vegas Bay and Boulder Basin, Stations 8 and 5, respectively. Nitrogen concentrations at Station 3, however, comparable in depth to Station 11 in Bonelli Bay, were substantially higher as influenced by the plume from Las Vegas Wash. Influence of the plume on middle and outer Las Vegas Bay stations is apparent from the higher concentrations. However, it is largely masked by the relatively high nitrogen concentrations in the hypolimion throughout the lake.

Orthophosphorus concentrations at Stations 9, 10, and 11, were very similar to those at Station 8 in Boulder Basin and Stations 6 and 7 in outer Las Vegas Bay. Concentrations at Station 5 in middle Las Vegas Bay, however, were approximately 50 percent higher than at the comparable background Station 10. Orthophosphorus concentrations at Station 3 were five to ten times those observed at Station 11, the comparable background station. Total phosphorus concentrations observed at the three background Stations 9, 10, and 11 were all lower than concentrations observed at Station 8 in Boulder Basin. Total phosphorus concentrations at Station 5 were higher than Station 3, and both were higher than at Stations 10 and 11, the comparable background stations. The higher total phosphorus concentrations as far from the wash as outer Las Vegas Bay and Boulder Basin reflect the phosphorus loading to Las Vegas Bay from the wash and the ability of the biological system to retain phosphorus in the epilimnion through recycling.

DATA COMPARISONS

Historical data on transparancy-algae-nutrient relationships in Las Vegas Bay and Lake Mead taken from previous studies are summarized in this section. Data on transparency and chlorophyll from other reservoirs along the Colorado River system, similar reservoirs elsewhere, and natural lakes in Nevada and nearby southwest states are also included. This information provides a description of conditions in Las Vegas Bay and Lake Mead over the last ten years and provides for comparison to other lakes in the region.

Efforts to draw conclusions concerning the current study and current conditions based on either the historical data or by comparison to other lakes in the region should be considered very carefully. Data included in the historic summaries were collected by several different study teams using differing sampling and analysis techniques and sampling from locations within the lake that are difficult to pinpoint precisely. In addition, conditions in the lake have changed substantially over the last ten to fifteen years, partly as a result of changing lake levels and the filling of Lake Powell, upstream of Lake Mead, on the Colorado River. While it is the intent of this study to identify relationships between wash input, nutrient concentrations in the lake, and resulting chlorophyll and transparency measurements, comparing current conditions to those of previous studies is difficult. For example, small differences in sampling location during periods of lower lake level, particularly in the inner region of the bay from WQSS Station 1 to Station 5, could potentially result in large differences in observed water quality at a fixed location. However, despite the potential variations between WQSS data and historic data, it is still possible to identify some general trends.

Historic Comparisons

Historic data on transparency, algal, and nutrient conditions in Las Vegas Bay and Lake Mead are summarized in this section.

Transparency History. Transparency measurements have been reported for various locations in Lake Mead in several studies conducted by different investigators since 1968 (Figure 8-35). Secchi depth measurements are available from three sources: U.S. Bureau of Reclamation (USBR) in 1968,[1] U.S. Environmental Protectection Agency (EPA), Environmental Monitoring and Support Laboratory (EMSL), Las Vegas, in 1976,[2] and by the current study in 1979 and 1980. Light transmittance measurements of transparency were reported by UNLV for the USBR in 1978.[3] Light transmittance measured at a water depth of 1 meter was reported by Deacon in 1977.[4] Percentage light transmittance measurements reported by UNLV in 1978 have been converted to Secchi depths using a correlation developed with light transmittance data in the WQSS. This showed that Secchi depth corresponds closely to the 10 percent light transmittance depth.

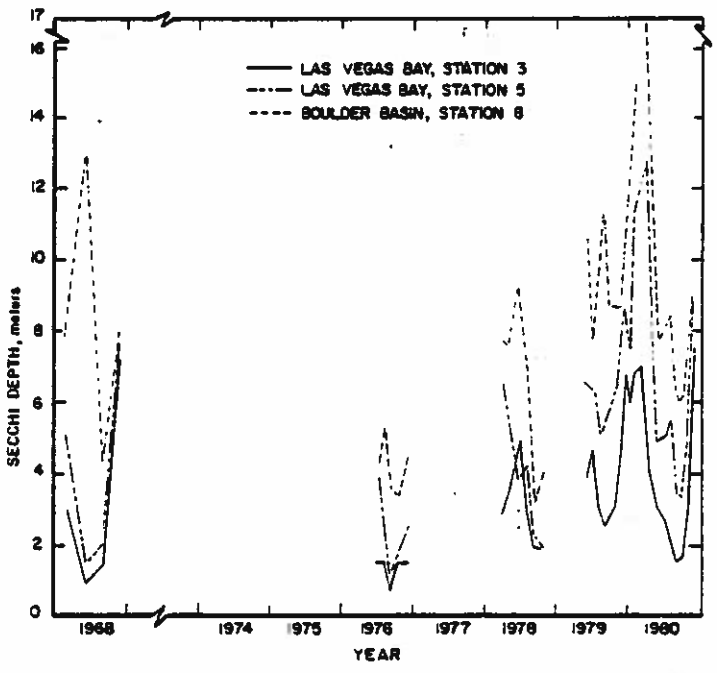


Figure 8-35 Historic Secchi Disc Depth at Lake Mead

Secchi depths for 1968, 1976, 1978, and the WQSS are shown on Figure 8-35. Secchi depths over this period at Stations 3, 5, and 8, range from 1 to 8, 1.5 to 12, and 3 to 17 meters, respectively. Lower water depths in previous years may even have affected transparency at Station 3. The water depth at Station 3 in 1968 was approximately 5 meters (16 feet). This was less than at Station 2 during the WQSS. In 1976 and 1978, the water surface elevation at Station 3 was approximately 358 meters (1,175 feet), corresponding to a water depth of approximately 12 to 13 meters (39 to 43 feet). This is roughly comparable to the water depth of Station 2 during the WQSS. Data summarized on Figure 8-35 indicate that transparency was lowest in 1976 at all three stations and was similar in 1968 and 1978 to that during the current study.

Data expressed in terms of alpha values, the natural log of the inverse of the percent light transmittance measured at a 1 meter depth, reported for June 1977, are shown on Figure 8-36. On two sampling dates, June 10, and June 22, 1977, alpha values corresponding to Secchi depths of 1 meter or less were reported inward of the location corresponding to WQSS Station 4, Figure 8-37. Data from the June 22 sampling showed a similar range of transparencies. Light transmittance levels corresponding to reported chlorophyll, Figure 8-36, were significantly lower than estimated from WQSS Secchi depth-chlorophyll relationships. This may be due to differences in light measurement methods, to differences in algal populations in the two periods, or to a combination of the two.

$\alpha = \log\left(\frac{1}{\%\text{ LIGHT TRANS.; METER}}\right)$

$e^{\alpha} = \frac{1}{\%\text{ L.T.}}$

$e^{-\alpha} = \frac{I_1 M}{I_0}$ $\quad e^{-K_e h'} = \frac{I_0}{I_1}$

$\alpha = K_e\ (m^{-1})$

20 %
50 %
90 %
95 %

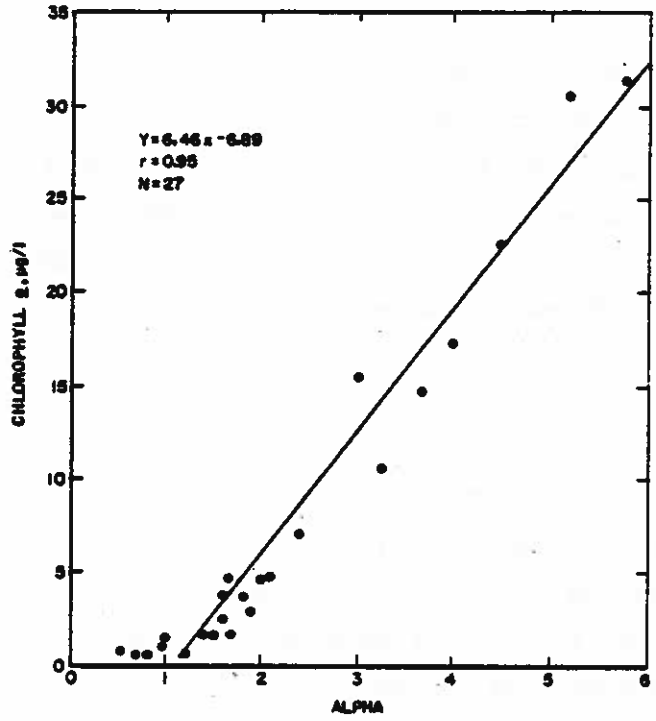
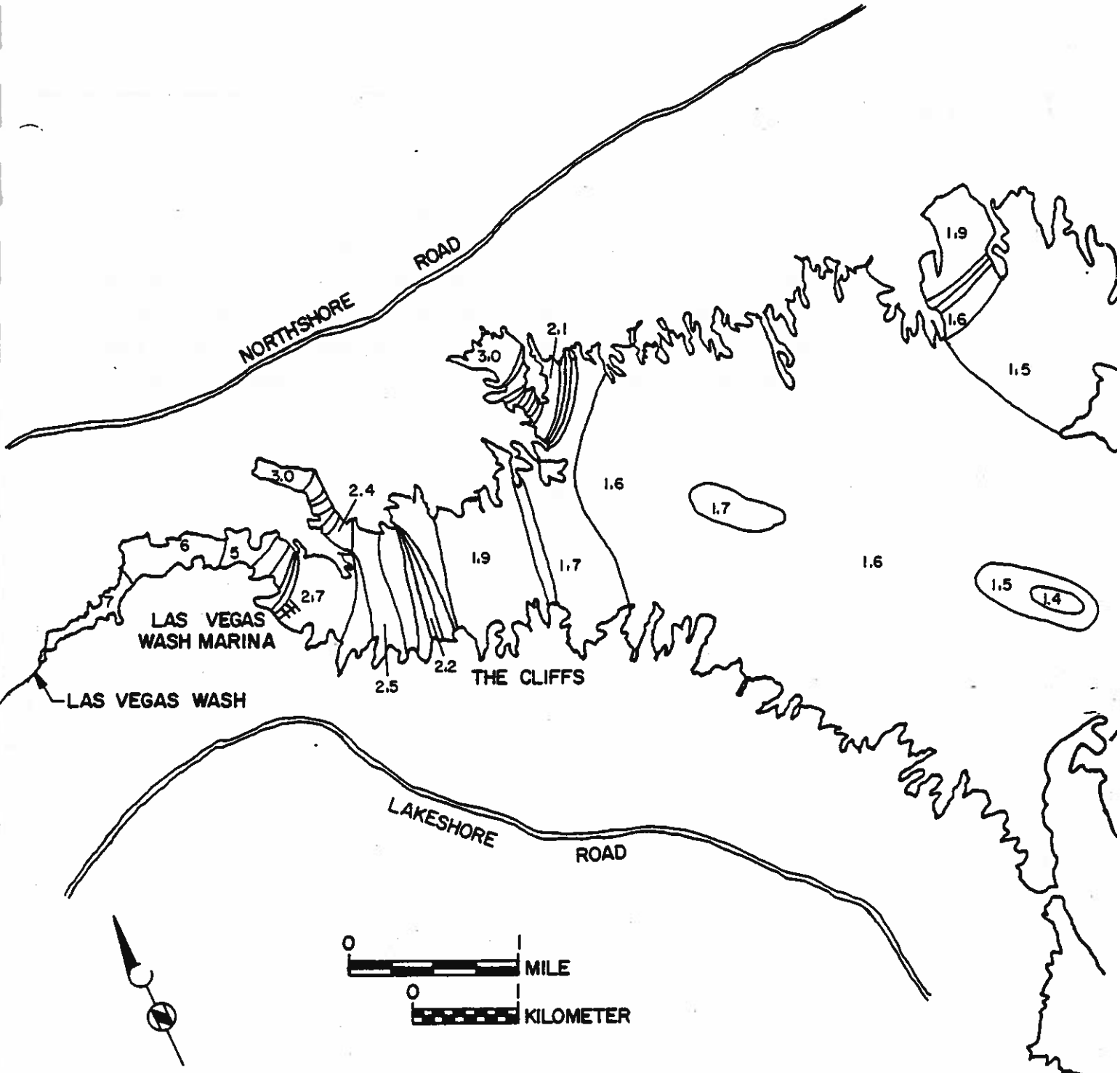


Figure 8-36 Linear Regression of Chlorophyll a Versus Alpha

Algae History. Chlorophyll concentrations have been reported by several investigators in the period from 1972 to the present. Measurements reported for stations equivalent to WQSS Stations 3 and 8 are summarized on Figure 8-38. Annual variation at Station 3 ranged from 20 to 30 ug/l. Peak values in spring and fall ranged from 10 to 35 ug/l. Minimum values in mid-summer and mid-winter range from 1 to 10 ug/l. Data reported for Station 8 show a similar seasonal pattern with a much narrower range of from 5 to 10 ug/l. Two trends are apparent from the data. First, both maximum and minimum chlorophyll values at Station 3 appear to decrease from 1972 through 1977. Maximum values decreased from approximately 30 to 35 ug/l to 20 to 25 ug/l at the end of this period. Minimum



NOTE: Lake Mead surface elevation 1200 feet (366 meters)

OVERLAY

Figure 8-37 Alpha Isopleths of Las Vegas Bay June 10, 1977

values decreased slightly from approximately 5 ug/l to 1 ug/l. Second, maximum and minimum chlorophyll values at Station 3 appear to increase from 1978 to the present. Peak values at Station 3 increased from approximately 15 ug/l in 1978 to approximately 45 ug/l in 1980. Minimum values at the same station increased from less than 1 ug/l to about 5 ug/l.

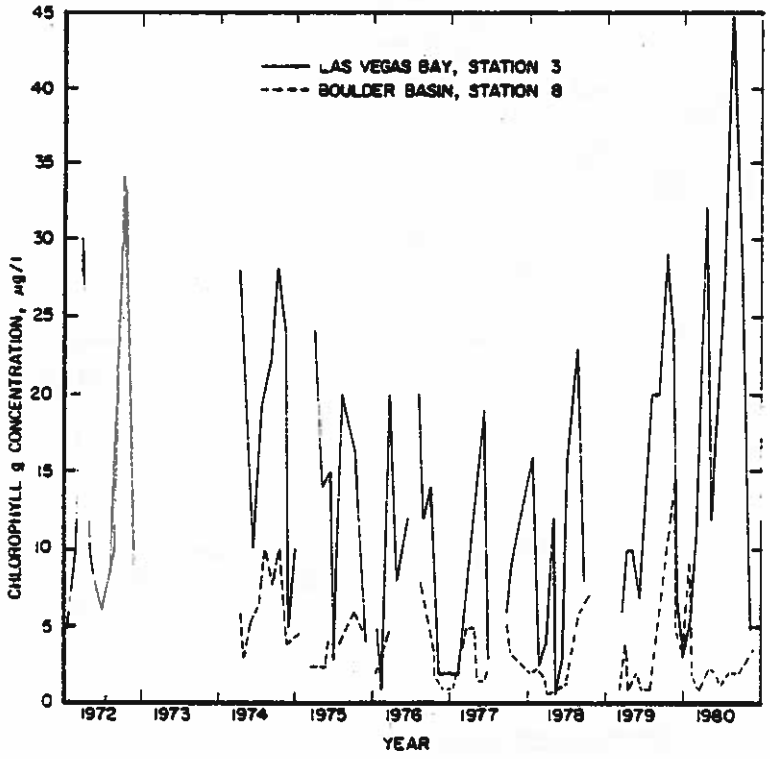


Figure 8-38 Historic Chlorophyll a Concentrations at Lake Mead (Surface Samples)

A similar but less distinct trend is evident at Station 8 with peak values decreasing from approximately 10 ug/l in 1974 to approximately 5 ug/l in 1977. Higher concentrations were observed at Station 8 in 1979, but the trend did not continue in 1980.

Efforts to understand the decreasing trend from 1972 to 1977 are complicated by the fact that the water surface elevation and corresponding water depth at the inner stations increased almost continuously over this period (Figure 3-8). Accordingly, the trend of decreasing chlorophyll concentrations reported for Station 3 from 1972 to 1977 could be interpreted as the effect of increasing water depth and dilution resulting in lower chlorophyll concentrations. It would be the same as if the monitoring station were moved outward continuously from a point approximately half way between Stations 1 and 2 in 1972 to one corresponding roughly to that of Station 3 by 1978. This effect was observed by Deacon in 1977 (Figure 8-39).[4]

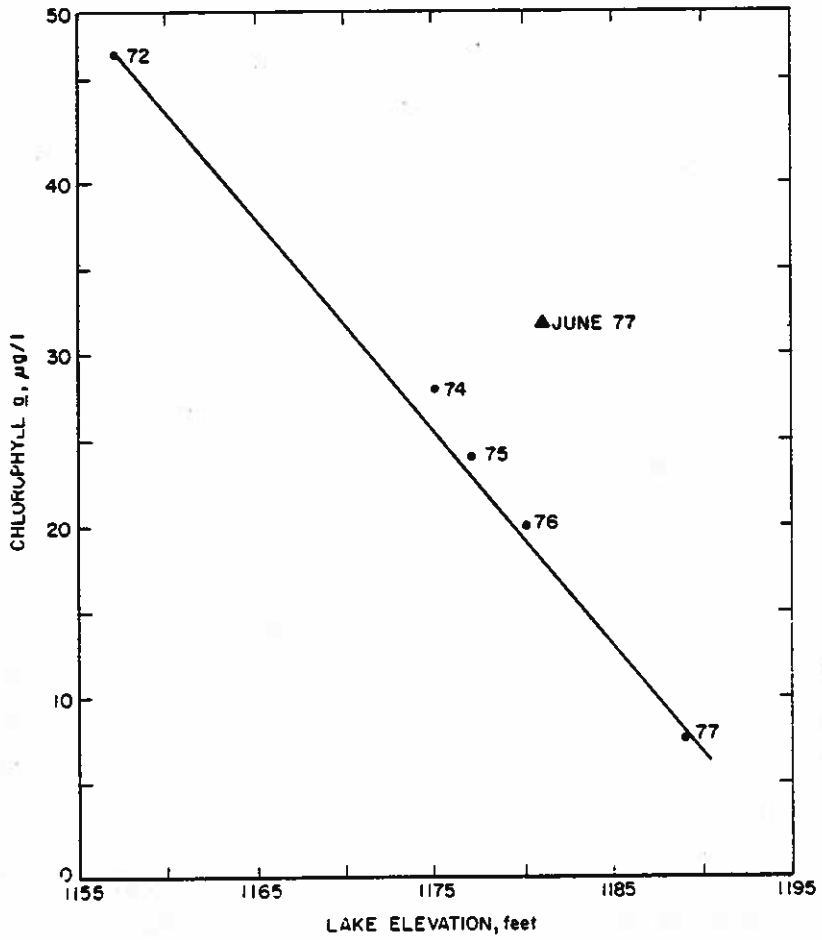


Figure 8-39 Chlorophyll a Versus Lake Elevation at Stations Approximately Equivalent to WQSS Station 3

Comparison of mean daily nitrogen and phosphorus loads to Las Vegas Bay from the wash with mean summer chlorophyll levels at WQSS Station 3 over the 1974 to 1980 period helps explain the chlorophyll trend, Figures 8-40. The changes in chlorophyll level at Station 3 bear little relation to changes in phosphorus load. However, they appear to correlate well with changes in nitrogen load. The increasing trend in chlorophyll concentrations from 1978 to the present is not complicated by changes in the water surface elevation. The lake level varied within a range of approximately 2 meters (7 feet) during the WQSS (1,198 feet to 1,205 feet). Thus, it appears that with the TN/TP load ratio ranging from about 3 to 6, nitrogen limiting conditions and increasing nitrogen loads have contributed significantly to the chlorophyll trend.

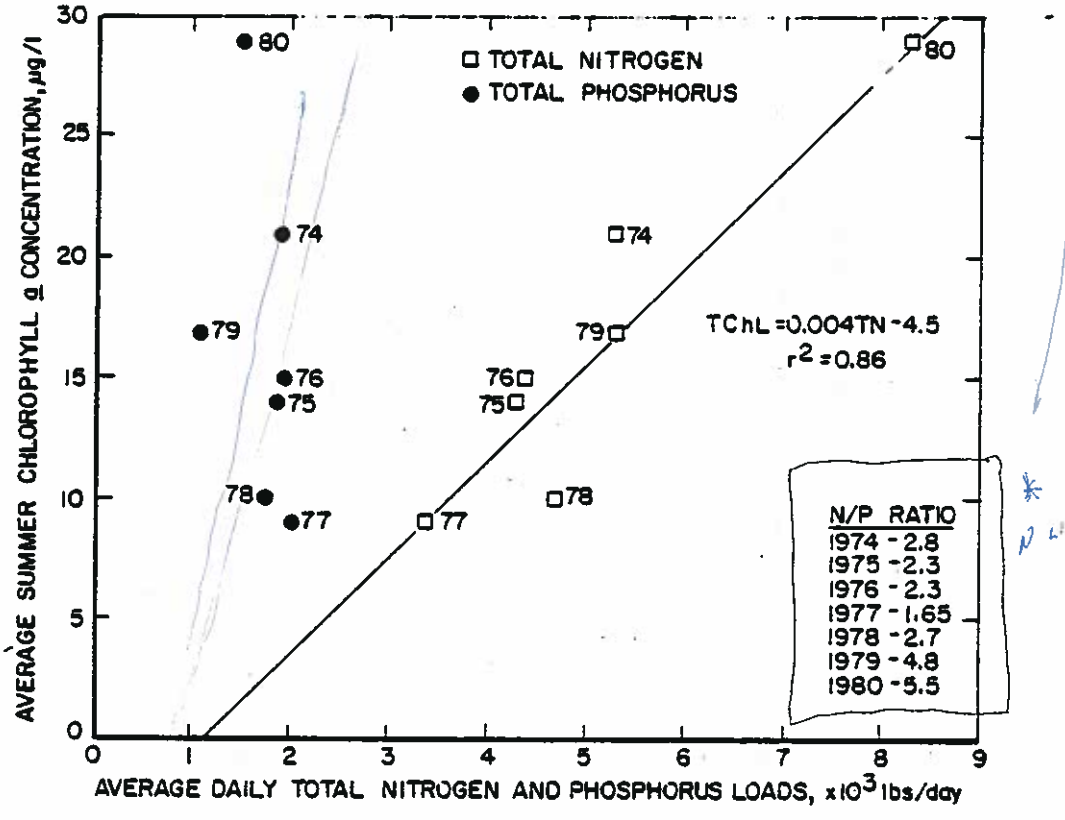


Figure 8-40 Chlorophyll a Concentration at Station 3 Versus Total Nitrogen and Phosphorus Loads at Northshore Road

The trend can be further assessed by looking at the frequency distribution of the chlorophyll data. Variations in chlorophyll concentrations during 1978 are illustrated by a cumulative frequency distribution (Figure 8-41). Comparison of median values and variability at Stations 3, 5, and 8, to comparable values observed during the WQSS (Figure 8-18), show an increase in concentration and decrease in variability over this three-year period. The median chlorophyll at Station 3 in 1978 was approximately 10 ug/l, increasing to 15 ug/l in 1979, and 25 ug/l in 1980. Similarly, the median concentration at Station 5 in 1978 was approximately 2 ug/l, increasing to 4 ug/l in 1979, and 5 ug/l in 1980.

A record of dominant phytoplankton species in Las Vegas Bay and Lake Mead is provided by earlier reports including that by Deacon in 1977 and Paulson, et al., in 1980. These studies cover observations made between September 1976 and May 1977, and from mid-1977 to fall 1978, respectively. Dominant species reported for 1976/1977 (Table 8-3) show very similar species composition at the three WQSS Stations 3, 5, and 7. The species succession is, in general, similar to that seen in the WQSS. Observations made in 1977 and 1978 (Table 8-4) show a similar pattern of species distribution in middle Las Vegas Bay and Boulder Basin, extending to the Virgin Basin with some differences. The Virgin Basin species were more dominated by the very small "nannoplankton" forms typical of water systems with low nutrient availability.

Nutrient History. Concentrations of total and inorganic nitrogen, and total phosphorus and orthophosphorus were reported in studies from 1972 to the present. Data are available for stations corresponding to WQSS Station 3 in Las Vegas Bay and

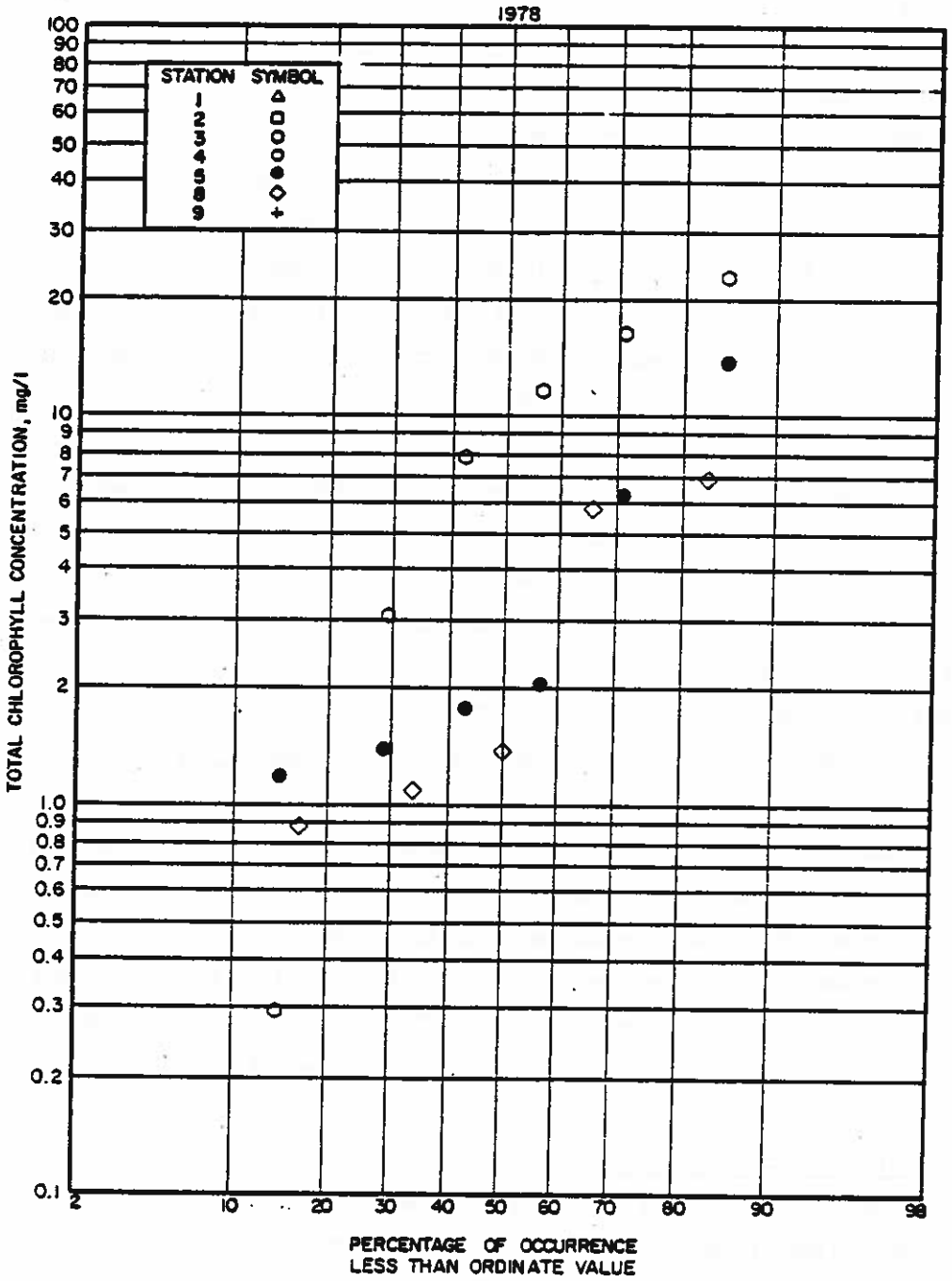


Figure 8-41 Total Chorophyll Frequency Distributions, WQSS Stations 3, 5, and 8, 1978

Table 8-3. Dominant Phytoplankton In Las Vegas Bay, September 1976 to May 1977

Date	Station 3		Station 5		Station 7	
	Species	Concentration number/ml	Species	Concentration number/ml	Species	Concentration number/ml
09/28/76	Raphidiopsis	9,613	Raphidiopsis	7,545	Raphidiopsis	12,994
	Flagellates	5,540	Flagellates	2,824	Flagellates	3,527
	Cryptomonas	631	Oscillatoria	843	Oscillatoria	1,718
	Peridinium	448	Cyclotella	485	Anabaenopsis	573
	Total	17,801	Total	13,509	Total	19,777
10/28/76	Dactylococcopsis	1,022	Dactylococcopsis	4,183	Dactylococcopsis	4,905
	Flagellates	264	Centriodiatoms	2,642	Cyclotella	2,061
	Cyclotella	264	Carteria	1,497	Cyanphytan	726
	Oscillatoria	264	Cyanophytan	1,233	Anabaenopsis	406
	Total	2,900	Total	11,404	Total	8,968
12/28/76	Cyclotella	159	Chroomonas	292	Cyclotella	247
	Chroomonas	159	Cyclotella	202	Chroomonas	180
	Cryptomonas	132	Total	495	Cryptomonas	45
	Carteria	26			Gymnodinium	22
	Total	603			Total	517
01/31/77	Cryptomonas	69	Cryptomonas	186	Cryptomonas	134
	Synedra	23	Chroomonas	83	Chroomonas	134
	Total	92	Carteria	21	Oocystis	27
			Dictyosphaerium	21	Total	295
			Total	331		
02/25/77	Chroomonas	269	Chroomonas	463	Chroomonas	89
	Cryptomonas	73	Cryptomonas	93	Cryptomonas	45
	Lagerheimia	24	Synedra	23	Carteria	45
	Navicula	24	Total	579	Synedra	22
	Total	392			Total	223
03/29/77	Asterionella	4,092	Asterionella	1,062	Chroomonas	1,129
	Chroomonas	447	Chroomonas	247	Cryptomonas	791
	Cryptomonas	89	Cryptomonas	123	Total	1,918
	Carteria	45	Chlamydomonas	25		
	Total	4,673	Total	1,516		
04/25/77	Fragilaria	1,755	Fragilaria	3,195	Fragilaria	3,892
	Chlamydomonas	353	Carteria	86	Melosira	214
	Asterionella	212	Chroomonas	65	Chroomonas	136
	Melosira	154	Chlamydomonas	43	Cryptomonas	58
	Total	2,657	Total	3,659	Total	4,3
05/18/77	Fragilaria	613	Fragilaria	845	Chroomonas	104
	Chlamydomonas	353	Ceratium	254	Cryptomonas	78
	Cryptomonas	130	Cryptomonas	225	Fragilaria	52
	Carteria	56	Flagellates	225	Oocystis	52
	Total	1,350	Total	2		
05/31/77	Aphanocapsa	1,157	Glenodinium	150	Aphanocapsa	990
	Chroomonas	222	Melosira	150	Chroomonas	110
	Cryptomonas	74	Chroomonas	113	Cryptomonas	55
	Glenodinium	49	Cyclotella	113	Sphaerocystis	37
	Total	1,614	Total	810	Total	1,256

Table 8-4. Dominant Phytoplankton Species in Lake Mead

Date	Station 5	Station 8	Hoover Dam	Station 9
10/77	Dactylococcopsis sp.			Cyclotella Rhodomonas minuta v. nannoplanctica
11/77	Dactylococcopsis sp.			Chrysochromulina parva
01/78	Rhodomonas minuta v. nannoplanctica	Cryptomonas sp.	Navicula sp.	Rhodomonaos minuta v. nannoplanctica
02/78	Cryptomonas erosa	Rhodomonas minuta v. nannoplanctica		
03/78	Rhodomonas minuta v. nannoplanctica		Chrysochromulina parva	Rhodomonas minuta v. nannoplanctica
04/78	Rhodomonas minuta v. nannoplanctica			
05/78	Cryptomonas erosa	Rhodomonas minuta v. nannoplanctica		Chrysochromulina parva
06/78	Chrysochromulina parva		Navicula sp.	Dinobryon sp.
07/78	Anabaenopsis raciborskii	Lyngbya limnetica	Chrysochromulina parva	Dinobryon sp.
08/78	Anabaenopsis raciborskii			Cyclotella sp.
09/78	Dactylococcopsis	Anabaenopsis raciborskii	Dactylococcopsis sp.	Dinobryon sp.

WQSS Station 8 in Boulder Basin (Figures 8-42 and 8-43). In general, the historic nutrient concentration data show trends similar to those for historic Secchi depth and chlorophyll, summarized above. Concentrations of total nitrogen and total phosphorus were high during spring and fall peak algal growth periods, and low in mid-summer and winter low growth periods.

Examination of total nitrogen concentrations on Figure 8-42, does not reveal any particular trend at either Station 3 or Station 8, between 1975 and the present. The inorganic nitrogen trend is similar to that observed for chlorophyll from 1974 to 1980. Peak and minimum inorganic nitrogen appears to decrease from 1974 to 1977 and then increase from 1978 to the present. The apparent decreasing trend from 1974 to 1977 is possibly due to the increasing lake levels described over that period in the discussion concerning chlorophyll concentration. The increasing trend from 1977 to the present appears relatable to the increasing load of nitrogen delivered by Las Vegas Wash as described in the previous chapter on the wash and as shown on Figure 8-40.

Examination of Figure 8-43, summarizing total and dissolved phosphorus concentrations, does not seem to reveal any significant trends. This is likely due to the more labile nature of the dissolved nutrient forms. They are assimilated rapidly by algae, resulting in relatively low residual concentrations.

The variability of dissolved nutrient concentrations in 1977 and 1978 is described by frequency distributions (Figures 8-44 and 8-45). The median inorganic nitrogen concentration at Station 3 was approximately 80 ug/l in 1977 and 100 ug/l in

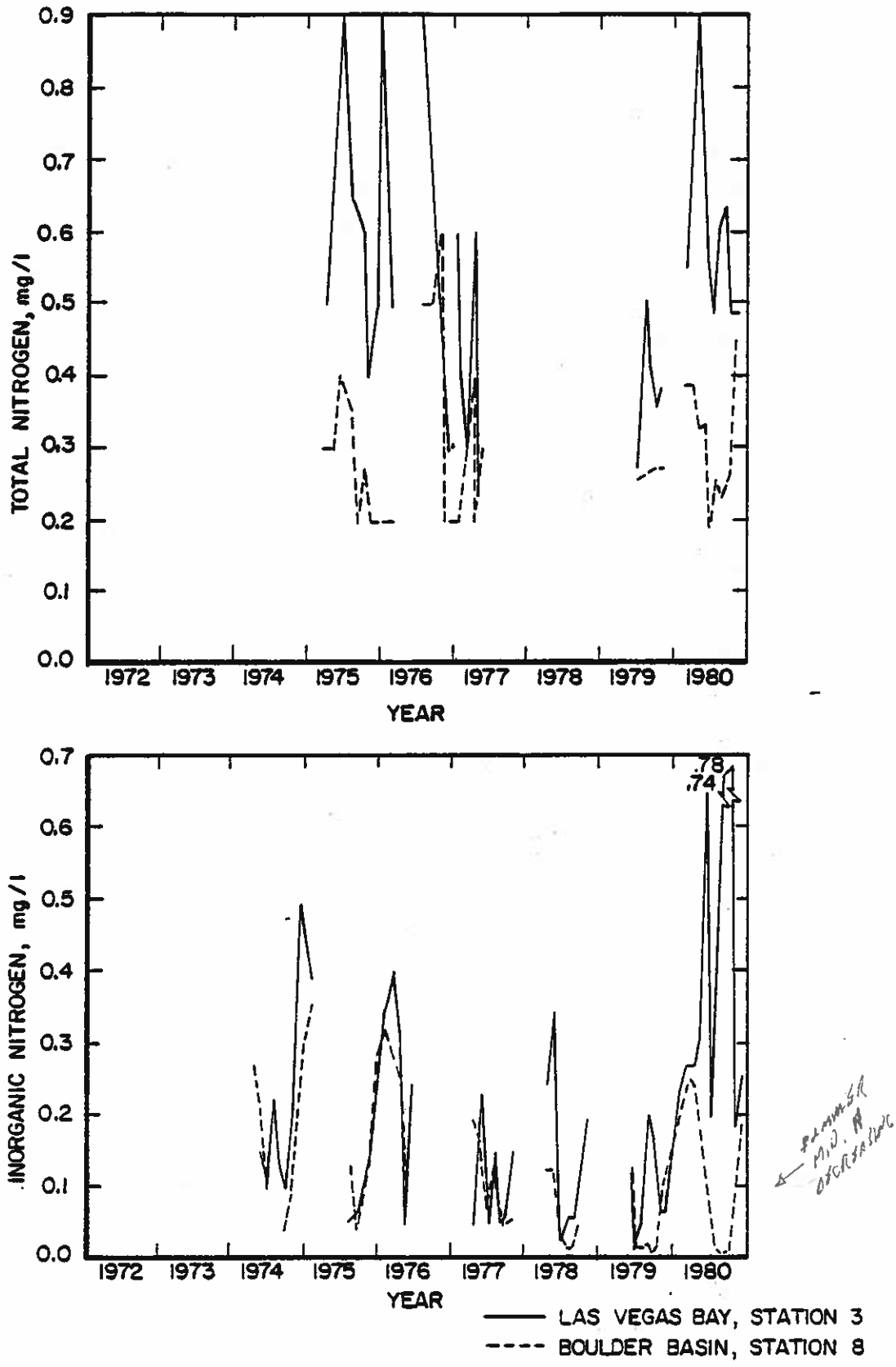
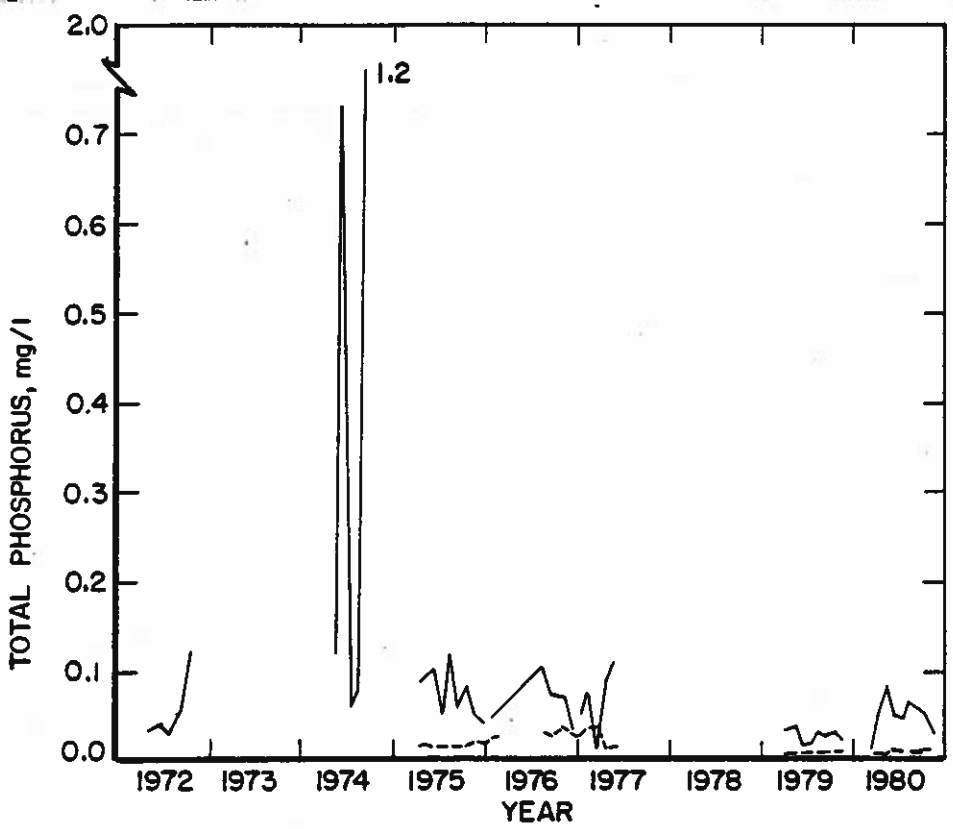


Figure 8-42 Historic Inorganic and Total Nitrogen Concentrations at Lake Mead (Surface Samples)



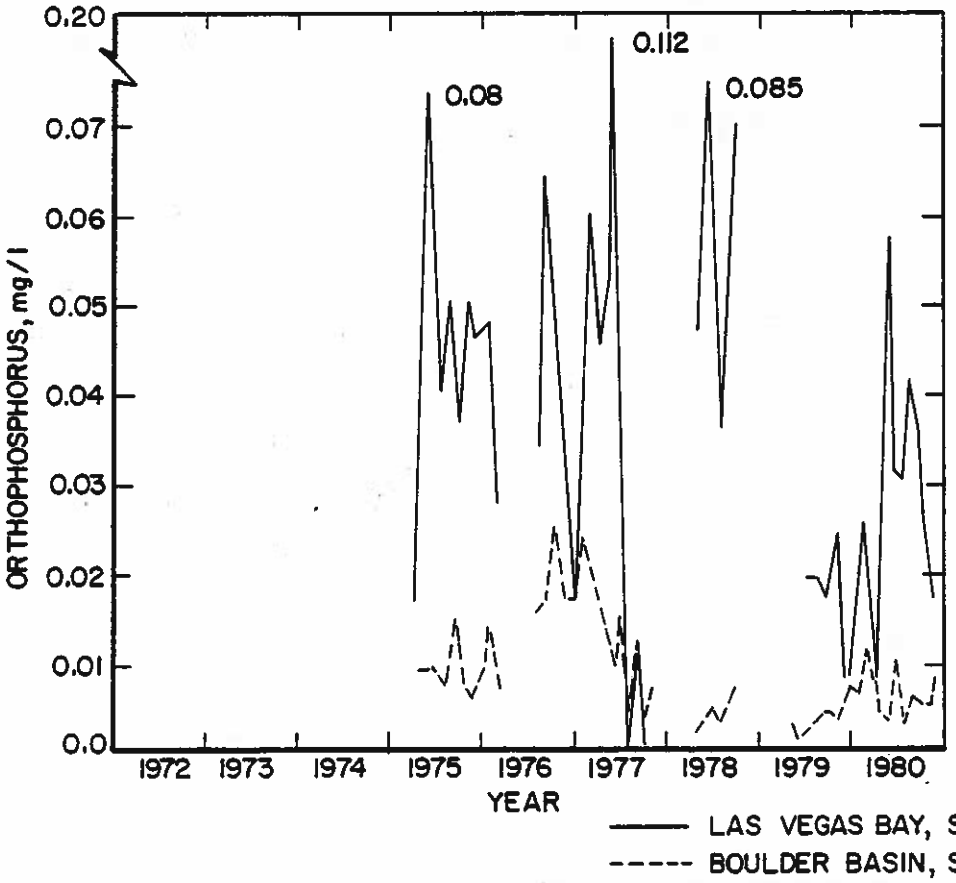


Figure 8-43 Historic Phosphorus and Orthophosphorus Concentrations at Lake Mead (Surface Samples)

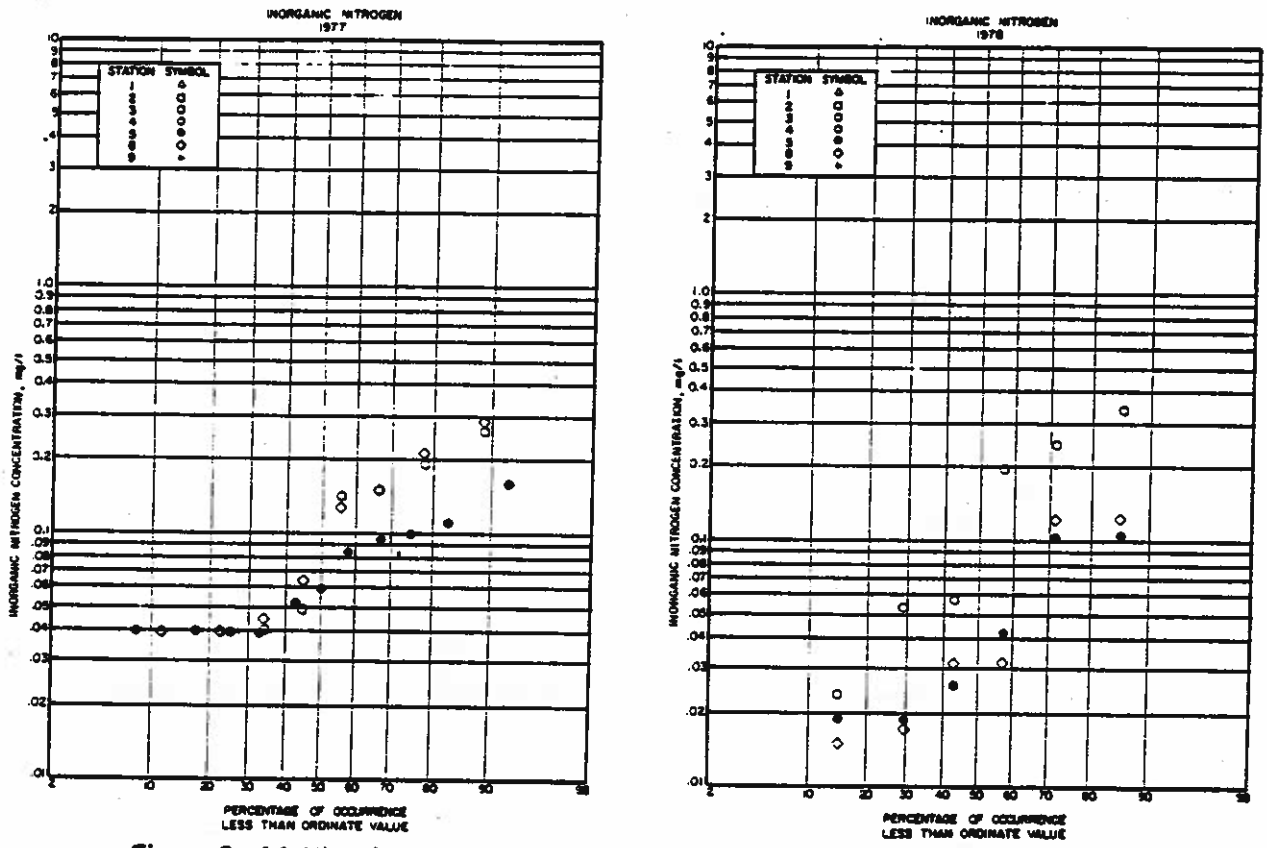


Figure 8-44 Historic Inorganic Nitrogen Frequency Distributions, 1977 and 1978

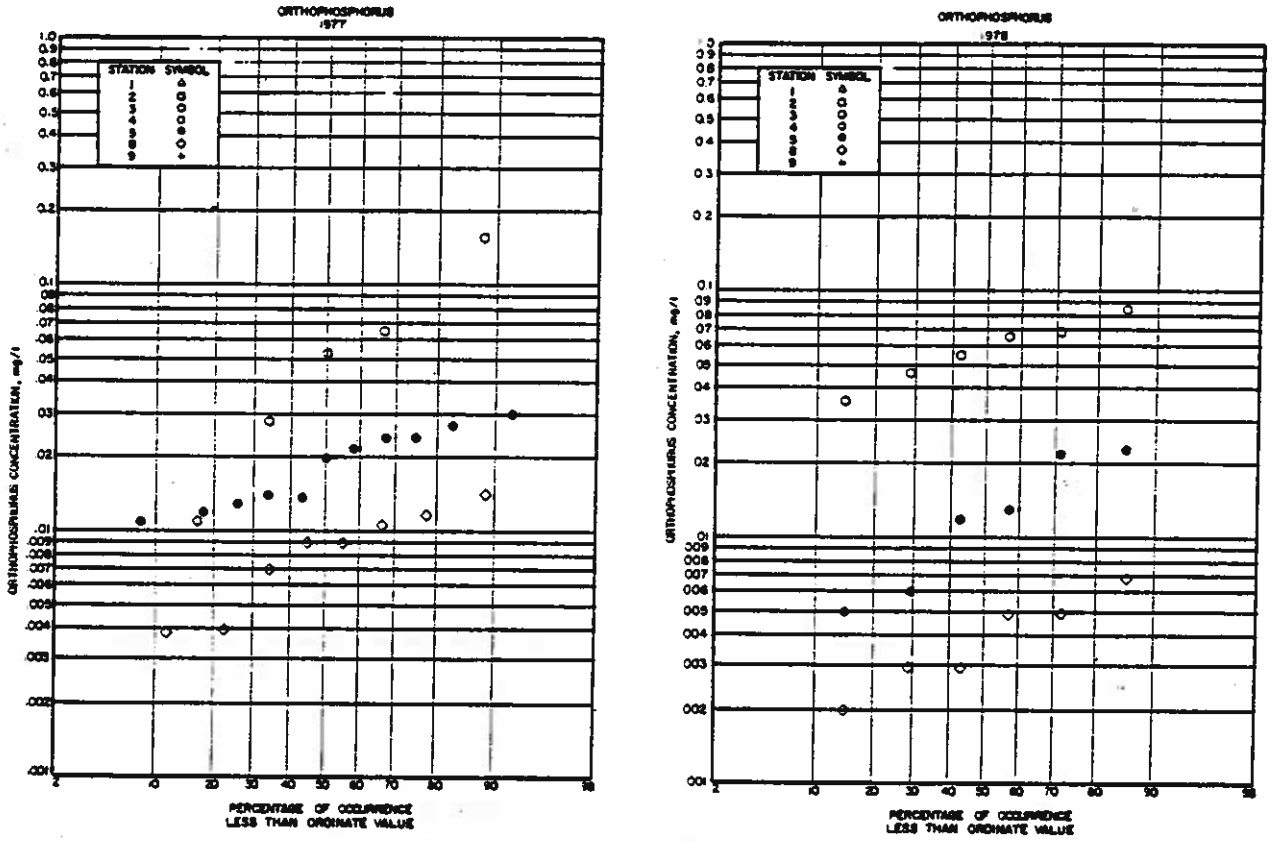


Figure 8-45 Historic Orthophosphorus Frequency Distributions, 1977 and 1978

1978. Median concentrations in 1979 and 1980 (Figure 8-33) were approximately 43 ug/l and 80 ug/l, respectively. At Station 5 in 1977, the median concentration was approximately 60 ug/l, decreasing to 35 ug/l in 1978. Median concentrations in 1979 and 1980 at Station 5 were approximately 14 and 17 ug/l, respectively. The median orthophosphorus concentration at Station 3 was approximately 52 ug/l in 1977 and 60 ug/l in 1978 compared to 12 ug/l in 1979 and 20 ug/l in 1980 (Figure 8-34). At Station 5, the median orthophosphorus concentration was approximately 20 ug/l in 1977 and 13 ug/l in 1978, but only 4 ug/l in 1979 and 5 ug/l in 1980. Thus, both the inorganic nitrogen and orthophosphorus concentrations in the epilimnion at Stations 3 and 5 were lower in 1979 and 1980 than in 1977 to 1978.

Comparison to Other Lakes

Data on transparency, chlorophyll, and nutrients in other lakes are presented in this section for comparison to Lake Mead conditions.

Transparency in Other Lakes. Measurements of Secchi disc transparency collected by the EPA at 22 western lakes during the National Eutrophication Survey in 1977[5] are summarized with mean Secchi depths measured for Lake Mead stations in the WQSS on Figure 8-46. The numbers used are the average of four samplings from each lake during the year-long study. Lakes selected for comparison range from Lake Tahoe, well known for its high degree of transparency, to several major reservoirs along the Colorado system, including Lake Powell, Lake Mojave, and Lake Havasu. Also included are several large reservoirs on major river systems in the west: Lake Koocanusa and Canyon Ferry

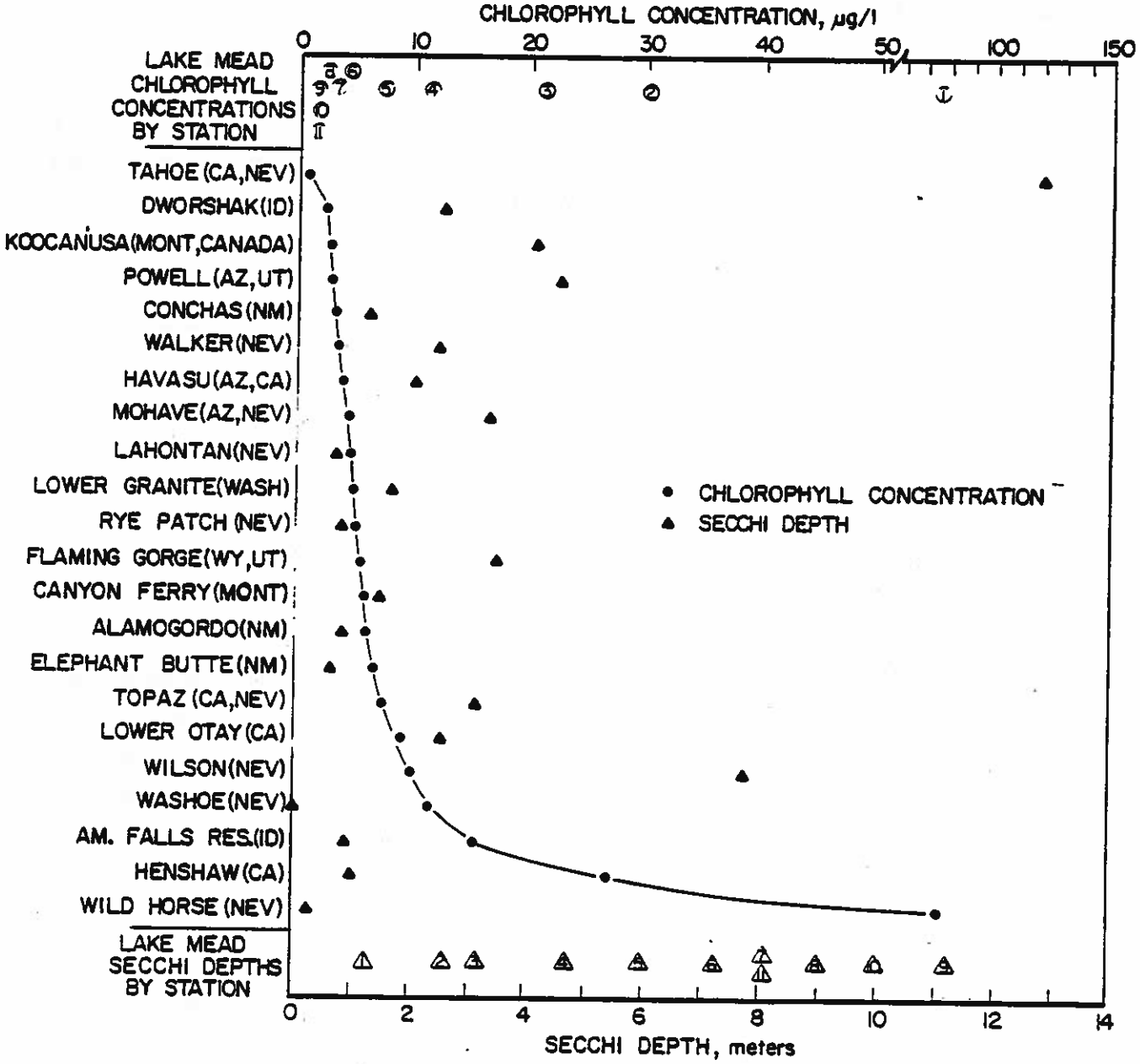


Figure 8-46 Secchi Depths and Chlorophyll in Lake Mead and Other Lakes

Reservoir in Montana; American Falls in Idaho; and Lower Granite Reservoir in Washington on the Snake River; Flaming Gorge Reservoir in Wyoming and Utah on the Green River; Elephant Butte on the Rio Grande River in New Mexico; and several additional lakes from Nevada and surrounding states. Across the bottom of the figure are mean values of Secchi disc transparency for Lake Mead, Stations 1 through 11, from the WQSS. The range of Secchi depths from different parts of Lake Mead covers the entire range of transparencies from Lake Tahoe to Washoe Lake.

Chlorophyll in Other Lakes. Chlorophyll concentrations reported by the EPA from samples collected from 22 western lakes and reservoirs during the National Eutrophication Survey in 1977 are summarized along with mean chlorophyll concentrations from Stations 1 through 11 of Lake Mead on Figure 8-46. Data for the selected western lakes are arranged in ascending order of chlorophyll concentration from Lake Tahoe, widely known for its high transparency and low chlorophyll levels, to Wild Horse Reservoir, Nevada, with a reported chlorophyll concentration of approximately 75 mg/l comparable to the mean value reported for Station 1 in Las Vegas Bay. While several lakes had chlorophyll concentrations greater than 10 ug/l comparable to mean concentrations observed during the WQSS inward of Station 4, the majority of lakes had chlorophyll concentrations less than 10 ug/l comparable to mean values for stations outward of Station 5. Mean chlorophyll concentrations in Virgin Basin and Bonelli Bay are comparable to those in Lake Tahoe.

Nutrients in Other Lakes. The summary of nitrogen and phosphorus concentrations in the 22 western lakes used for comparison of Secchi depth and chlorophyll levels is provided

in Table 8-5. Phosphorus and nitrogen concentrations in these lakes covers a range comparable to that observed from Station 1 in inner Las Vegas Bay to Stations 9, 10, and 11 in the background area of Virgin Basin.

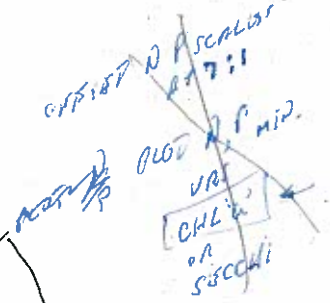


Table 8-5. Lakes Survey

Name	Number	State	Secchi	Chlorophyll	Total P	Ortho P	Total N	Inorganic N	Total annual loading	
									Phosphorus, kg/year	Nitrogen, kg/year
Havasu	728	AZ,CA	2.0	3.9	0.015	0.005	0.540	0.170	281,720	8,074,100
Mohave	731	AZ,NV	3.3	4.4	0.017	0.010	0.600	0.240	252,960	12,216,425
Powell	733	AZ,UT	4.5	2.8	0.010	0.009	0.600	0.410	—	—
American Falls	776	ID	0.9	15.4	0.105	0.035	0.575	0.080	610,015	8,178,700
Divorshak	779	ID	2.5	2.4	0.010	0.009	0.260	0.080	115,315	3,247,950
Canyon Ferry	790	MT	1.4	5.8	0.047	0.029	0.440	0.170	329,310	4,186,900
Koocanusa	795	MT, Canada	4.1	2.7	0.045	0.044	0.300	0.100	26,590	415,970
Lahontan	807	NV	0.7	4.6	0.198	0.148	—	0.350	187,625	854,410
Mead	808	NV	5.9	3.1	0.016	0.005	0.550	0.340	3,692,835	26,880,405
Rye Patch	809	NV	0.8	4.9	0.095	0.039	0.620	0.050	54,445	291,585
Tahoe	810	CA,NV	12.8	0.6	0.005	0.003	0.220	0.040	20,675	831,030
Topaz	811	CA,NV	3.1	7.5	0.058	0.042	0.440	0.160	13,180	125,870
Upper Pahranagat	812	NV	0.8	—	0.173	0.026	0.800	0.125	1,265	11,295
Walker	813	NV	2.4	3.4	0.601	0.574	2.020	0.080	—	—
Washoe	814	NV	0.0	11.6	0.403	0.268	1.340	0.130	1,735	34,770
Wild Horse	815	NV	0.3	75.5	0.114	0.065	0.920	0.320	7,985	133,465
Wilson	816	NV	7.7	10.0	0.049	0.016	0.520	0.120	700	10,520
Alamogordo (Sumner)	817	NM	0.8	5.9	0.025	0.003	0.320	0.050	28,060	117,605
Conchas	819	NM	1.2	3.3	0.020	0.004	0.350	0.040	11,450	181,410
Elephant Butte	821	NM	0.6	6.8	0.083	0.052	0.440	0.110	2,569,270	7,244,725
Lower Granite	876	WS	1.6	4.9	0.033	0.022	0.330	0.150	—	—
Flaming Gorge	885	WY,UT	3.4	5.6	0.014	0.003	0.900	0.605	186,240	2,826,435
Henshaw	748	CA	1.0	26.8	0.138	0.073	0.620	0.070	2,115	70,365

Chlorophyll-Nutrient Loading Relation in Other Lakes. One of the most widely used means of assessing lake chlorophyll levels and relation to nutrient loading is that developed by Vollenweider. The method relates average chlorophyll a concentration to an effective phosphorus loading parameter that combines effects of absolute loading in pounds per year, residence time, and mean depth of the lake. An example of this comparison for a range of American lakes is shown on Figure 8-47.[6] As noted in the accompanying description, the authors indicate that the relationship between observed chlorophyll levels and effective loading is quite good for low and medium productivity lakes, but far less certain for highly productive lakes.

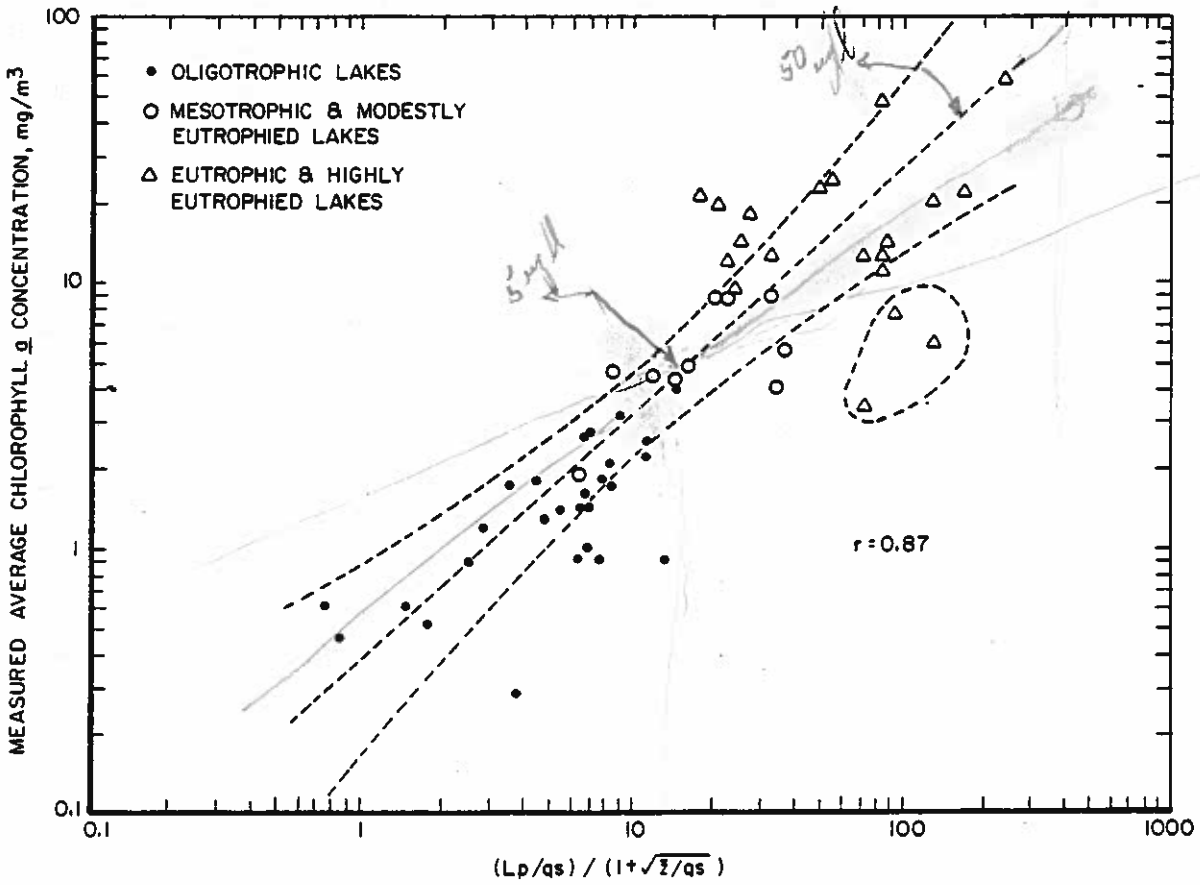


Figure 8-47 Vollenweider Prediction of Chlorophyll from Phosphorus Loading Characteristics

Phosphorus concentrations and effective loadings were calculated for the inner bay from the mouth of the wash to Station 5. Calculations were made based on a schematic description of the system as shown on Figure 8-48. This was done to allow for distribution of the inflowing wash contents by the plume between the surface layer and the deeper water of the bay. Effective loadings to each segment, 1 through 5, were calculated based on wash loads identified in Table 8-6 and by partitioning the plume flow based on specific conductance measurements. Volumes, areas, and flow rates used for the five inner bay sections are summarized in Table 8-7. Dilution coefficients derived from specific conductance used as a conservative tracer are summarized in Table 8-8. Average chlorophyll concentrations during the 1979 and 1980 growing seasons are plotted on Figure 8-49 as a function of the effective loading parameter calculated for segments 1 through 5. In general, chlorophyll concentrations observed at Stations 1 through 4 are significantly lower than estimated by the Vollenweider model for the phosphorus loadings calculated for these inner bay segments. It is likely that this results from major differences between the physical system of inner Las Vegas Bay and that of typical lakes used in development of this model. The continuous input and resulting flushing in inner Las Vegas Bay evidently contribute to the substantially lower chlorophyll concentrations than might otherwise result from current phosphorus loadings.

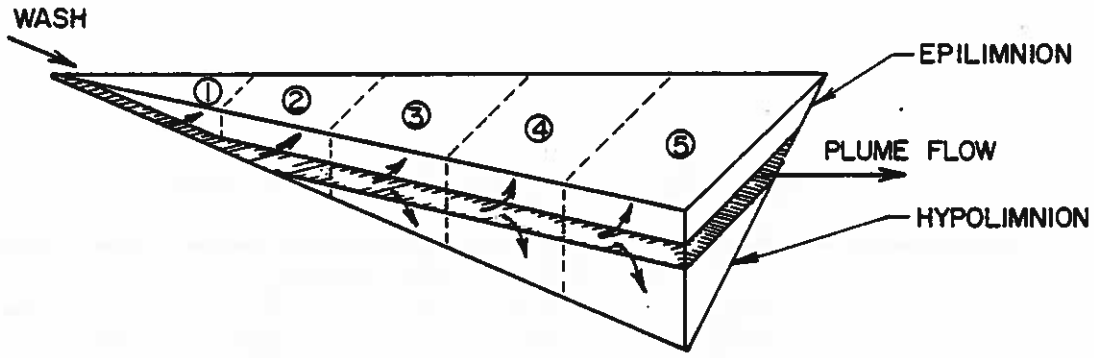


Figure 8-48 Las Vegas Bay System Schematic for Vollenweider Phosphorus Loading Analysis

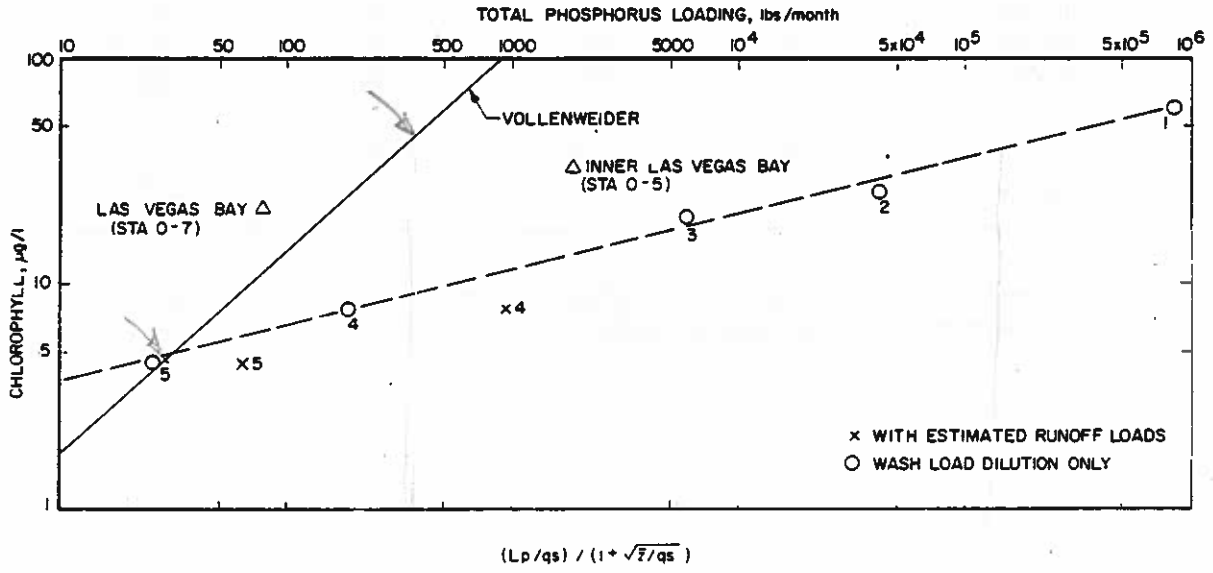


Figure 8-49 Vollenweider Chlorophyll Prediction for Las Vegas Bay

Table 8-6. Las Vegas Wash Nutrient Loads

Month	Load,[a] 1,000 kg/month			
	Ortho P, as P	Total P, as P	Inorganic N, as N	Total N, as N
07/79	11.0	11.0	57.3	64.0
08/79	9.9	9.2	67.2	70.8
09/79	10.0	12.0	68.9	75.6
10/79	13.2	15.3	82.7	83.4
11/79	12.8	15.5	116.9	126.3
12/79	15.0	17.8	98.3	103.3
01/80	12.0	14.6	95.5	107.4
02/80	8.9	32.2	66.2	95.2
03/80	11.7	45.8	152.5	169.5
04/80	15.3	18.3	93.8	114.4
05/80	9.3	12.1	79.0	96.1
06/80	10.5	11.8	65.0	82.0
07/80	11.8	22.1	71.8	98.6
08/80	12.2	16.5	78.7	93.0
09/80	13.4	17.1	83.5	96.9
10/80	14.5	18.3	104.2	114.1
11/80	9.2	14.4	88.2	94.7
12/80	14.6	16.0	104.2	111.2

[a]Based on samples taken at Northshore Road and U.S. Geological Survey streamflow measurements.

Table 8-7. Vollenweider Phosphorus Loading Analysis for Las Vegas Bay; Physical Characteristics and Loading Parameters

Section	Volume, m^3	Area, m^2	Inflow, m^3/yr	$\bar{z}$, meters	t_w, [a] years
1	24.0×10^4	8.43×10^4	9×10^7	2.85	2.7×10^{-3}
2	17.5×10^5	2.26×10^5	9×10^7	7.74	1.9×10^{-2}
3	6.0×10^6	4.70×10^5	9×10^7	12.77	6.7×10^{-2}
4	4.7×10^7	2.57×10^6	9×10^7	18.29	5.2×10^{-7}
5	14.3×10^7	5.93×10^6	9×10^7	24.11	1.6

$\bar{z}$ = mean depth = volume/surface area

t_w = hydraulic residence time = volume/inflow
$q_s = \bar{z}/tw$

[a]This parameter has little physical meaning. Actual residence times are considerably different due to density stratified flow.

Table 8-8. Vollenweider Loading Analysis for Las Vegas Bay; Inflow-Surface Segment Dilution Factors

Segment	Mean dilution[a]
1	15
2	27
3	36
4	56
5	80

[a]Dilutions calculated from specific conductance at Wash Station 5 (C_w), by surface Stations 1-5 (C_s), and bay Station 8 (C_b) using the formula $D = \frac{C_w - C_s}{C_s - C_b}$

DATA ANALYSIS

As described in Chapter 2, the Consent Decree, paragraphs 18, 19, and 20, and the WQSS work plans provide the basic framework for data analysis. The scope of analysis extends to development of maximum daily load limitations, but does not include waste load allocation or determination of effluent limitations. Possible differences in load limitations between different seasonal periods are examined.

Approach

During WQSS work plan development, study participants agreed that data analysis would be restricted to empirical methods and that no mathematical or dynamic modeling would be used. Accordingly, preliminary analysis methods described in the Segment I Data Analysis Report and in the Contract 6 work plan were based on the use of empirical and statistical procedures for development of required quantitative relationships. Such methods are applied in this section to the development of correlations between Las Vegas Bay transparency, algae, and nutrient concentrations, and wash loadings of nitrogen and phosphorus. The following description of data analysis methods is divided into four sections:

1. Development of correlations between transparency, algae, and nutrient concentration.
2. Analysis of algal growth dependence on nutrient concentrations.
3. Analysis of the distribution of wash input into the bay and the surface layer.
4. Procedures used to determine the wash input nutrient load required to maintain a specific Secchi depth. The

procedures draw on correlations, limiting nutrient analysis, and input distribution analysis described above. Figure 8-50 indicates the interrelationships of these key data analysis components.

Transparency, Algae, Nutrient Correlations. The approach used to develop quantitative relationships between transparency, algae, and nutrient concentrations was essentially a trial and error process of refining empirical relationships using simple linear regressions. The same procedures were followed to develop quantitative relationships both between transparency and algal concentration and between algal concentration and nutrient concentration. While the transparency-algae and algae-nutrient analyses were in separate portions of the data analysis, Figure 8-50, the common procedures applied to both in four basic steps are described below:

1. In the initial step, multiple parameter correlations were used to test the influence of various water quality factors on the primary parameters of interest. The dependence of transparency on chlorophyll, inorganic turbidity (NVSS), and color was tested by analysis of variance for multiparameter linear correlations. The dependence of algal concentration as measured by chlorophyll on nitrogen, phosphorus, iron, and silica concentrations was tested by this same procedure. The multiple correlations were performed using the computer program entitled, "General Linear Models," (GLM) of the Statistical Analysis System (SAS).[7] Linear relationships were similarly assumed between chlorophyll and the concentration of nutrients, nitrogen, phosphorus, iron,

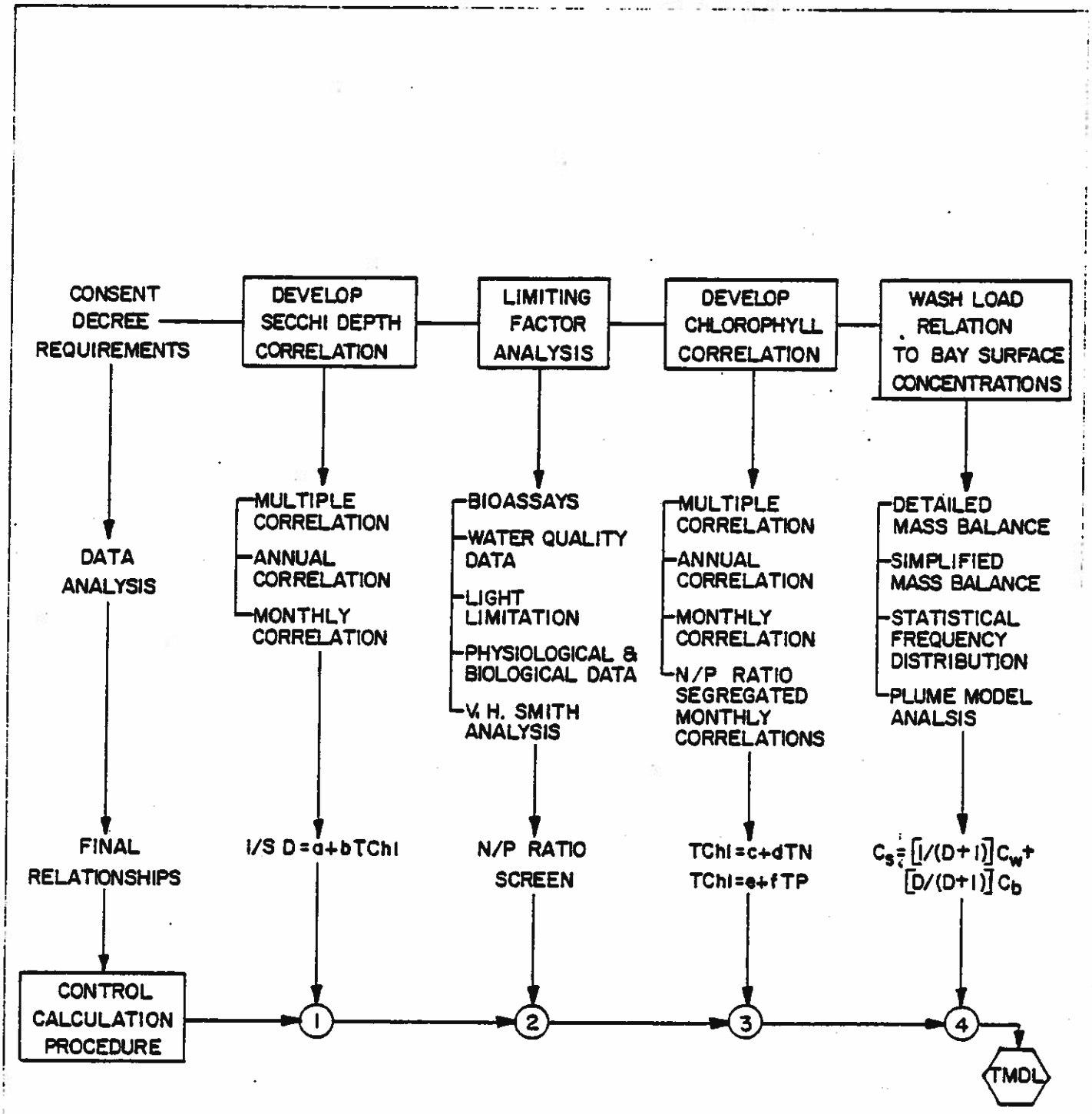


Figure 8-50 Data Analysis Procedure Schematic

and silica. The linearity of these relationships was suggested by members of the Technical Advisory Board (TAB) and supported by regressions of early portions of WQSS data presented and discussed in the January and June data review meetings.

The inverse Secchi depth (1/SD) relationship was selected as previously noted largely because of the approximate linear relationship it had with chlorophyll concentrations. Analysis of data using this relationship is simpler than if the curvilinear relationship between Secchi depth and chlorophyll was used. Curve fitting techniques would be required and the results would not be as readily compatible with the linear chlorophyll versus nutrient concentration relationships. The relative relation of transparency measurements and corresponding chlorophyll values differ between use of SD and 1/SD, e.g., low SD corresponds to high chlorophyll, but high 1/SD corresponds to high chlorophyll. However, this does not affect ability to develop or evaluate resulting correlations using appropriate statistical procedures.

2. The second step is development of quantitative relationships focused on single parameter correlations suggested by the multiparameter correlations. These are principally between SD and chlorophyll, and between chlorophyll and nitrogen and phosphorus concentrations. The single parameter correlations were analyzed also using the SAS/GLM program. The program produces a regression line of best fit and an analysis of variance. This was the beginning of the process of

examining correlations between 1/SD, chlorophyll, and nutrient concentrations to develop the best possible relationships.

Principal statistical measures used were the R-square (r^2) statistic and the PR$\geq$1T1 statistic. The r^2 statistic is a measure of the degree of correlation between two variables. It can have values from zero to one. It is the square of the commonly used correlation coefficient, r, which can have values from zero to plus or minus one. A value of r or r^2 of zero indicates no correlation between the two variables. A value of one indicates a perfect correlation, or that one variable is an extremely good measure of the other. The correlation coefficient can be interpreted as a measure of the proportion of variance in one variable explained by variation in the other. For example, an r value of 0.5 for a correlation of chlorophyll with total phosphorus (TP) would mean that half of the variance in chlorophyll is explained by variance in TP. In general, the higher the value of r or r^2, the better the correlation. A correlation coefficient of 0.5 or greater (r^2 = 0.25) between two natural system variables with complex interrelationship, such as nutrient concentration and chlorophyll, would be considered good.

The PR>1T1 statistic is a measure of the statistical significance of the slope of regression line determined by least squares fitting. Specifically, the value of PR>1T1 is the fractional probability (PR) that if, in fact, the slope of the line was equal to zero, a value of t greater than that measured will be found. The

value of t results from application of Student's t test to the hypothesis that the slope equals zero. Values of PR>|T| range from zero to one. A value of one indicates virtually no significance to the slope measured, i.e. it cannot be distinguished from a slope of zero by the Student's t test. The smaller the value, the greater the significance of the slope. The smallest value reported by the GLM program is 0.0001. This would indicate that there is only one chance in 10,000 that the slope measured differed from zero by chance alone.

At this stage, water quality data were examined to determine if transparency in the lake was affected by the discharge of nutrients from the wash year-round. Of particular interest was the effect of nutrients discharged in winter on transparency in the spring.

3. The third step consisted of refining the correlations. This was done to develop quantitative relationships giving the best or most accurate prediction of chlorophyll and Secchi depth levels recognizing the influence of seasonal changes. The approach taken was to subdivide the data set into shorter periods having less opportunity for seasonal factors to affect the correlations. At each step, analysis of variance statistics were compared as the measure of the quality of the correlations.

4. The final step consisted of selecting the final data groups giving the best correlations for the principal periods of interest. Tests of statistical significance between correlations developed for different time periods were used as the principal basis for selecting final data groups.

Limiting Factor Analysis. Algal growth dependence on physical factors and various water quality constituents were established by a combination of specific algal tests and analysis of water quality data. As described in the introduction to this chapter, several independent approaches were used to assess limiting conditions due to physical factors or nutrients. This was done because of the complexity of the physical and biological systems and the acknowledged difficulty of demonstrating clearly which factors limit algal growth. Light limitation is a possibility in the inner bay where high chlorophyll levels in peak growth periods reduce transparency. If physical conditions do not limit growth, it will be limited by the nutrient least available relative to algal nutritional needs. Algal growth may possibly be inhibited by chemicals such as heavy metals. Three primary types of data were collected for use in identifying limiting nutrient conditions: bioassay data, various segments of water quality data, and data on physiological and biological water quality parameters. Procedures used to establish the nutrients limiting conditions to algae in the lake throughout the study for the above three indicators are as follows:

Bioassays--Nutrient enrichment bioassays were conducted to determine which nutrients stimulated algal growth at representative locations in the bay. Details of procedures used in the bioassays are provided in the bioassay report, Appendix C. Results of the bioassays are the principal and most direct indicator of nutrient limiting conditions.

Due to limitations on the scope of bioassay work approved, the bioassays were designed to produce only qualitative information on which nutrient enrichments resulted in growth response statistically greater than that measured

in the controls. Growth response in each bioassay was monitored by monitoring in vivo fluorescence and by checking correspondence of fluorescence and chlorophyll measurements within individual bioassays. The possibility of the fluorescence to chlorophyll relationship changing with season was of no consequence since comparisons between bioassays were to be made only in relative terms. Bioassay results are expressed in terms of the ratio of the maximum fluorescence level reached to the initial fluorescence level for each enrichment. This is termed the fractional maximum response. The Student's t test at the 95 percent significance level was used to determine if the fractional maximum response for each enrichment was statistically significant compared to the change in fluorescence in unenriched control samples.

Water Quality Data--Water quality data were examined for indications of light limitation, nutrient limitation, and possibly inhibitory substances.

The light level in the epilimnion can be compared to light requirements of algae for photosynthesis. This provides direct evidence of the existence or absence of light-limiting conditions. The linearity of chlorophyll nutrient correlations from Station 1 to background stations provides an indirect indication of light-limiting conditions. Light-limiting conditions that would presumably occur in the inner bay during high chlorophyll periods would cause reduced chlorophyll levels per unit quantity of the limiting nutrient. The slope of chlorophyll in limiting nutrient regressions would be lower at the upper end of the chlorophyll range.

Water quality data on chemical constituents were examined for indications of nutrient limitation. Principal elements considered include nitrogen, phosphorus, iron, and silica. Concentrations were examined in the epilimnion and the hypolimnion, and variations from station to station were considered. The potential influence of iron and silica was assessed in comparison to nitrogen and phosphorus by means analysis of variance in multiple correlations with chlorophyll. Iron and silica limitations were also tested in the bioassays.

Particular attention was devoted to potential nitrogen and/or phosphorus limitation. Theoretical requirements of algae are established by the stoichiometry of photosynthetic reactions. According to Stumm and Morgan,[8] 1979, the stoichiometric ratio of nitrogen to phosphorus by weight required for photosynthetic algal growth is 7.2 to 1. Departure from this ratio towards a lower one indicates an increasing abundance of phosphorus relative to nitrogen and is indicative of nitrogen-limiting conditions. Departure toward a higher ratio similarly indicates an increasing abundance of nitrogen and is indicative of phosphorus-limiting conditions. The dividing line between nitrogen and phosphorus-limiting conditions is not a sharp one for at least two reasons: (1) nutritional requirements and, hence, the ratio at which nitrogen or phosphorus (N/P) would become limiting vary with the species of algae, and (2) many species of algae have been shown to grow over a substantial range of N/P ratios. It was assumed in this study that nitrogen was limiting when the N/P ratio was 5 or less and that phosphorus was limiting when the N/P ratio was about 15 or greater. The degree of certainty

concerning which nutrient has the greatest limiting effect for N/P ratios between 5 and 15 becomes less as the ratio approaches the point of stoichiometric equivalence. For the purposes of this study, with the principal interest being on phosphorus-limiting conditions, a nitrogen to phosphorus ratio of 10 to 1 was taken as the dividing line between nitrogen and phosphorus-limiting conditions.

Several different ways of expressing the N/P ratio are possible. The N/P ratio can be formed using dissolved, total, or particulate N and P measurements. Dissolved inorganic nitrogen and dissolved orthophosphorus are the principal forms of the nutrients used by algae. The ratio of dissolved N/P formed from these components should indicate their proportions available for algal nutrition. However, the rate at which algae use dissolved nutrients is rapid. Thus, N and P concentrations measured in the eplimnion during seasons of active growth reflect proportions remaining after algal use rather than proportions available for growth. To avoid this complication, the ratio of total nitrogen to total phosphorus (TN/TP) is frequently used. This has disadvantages also. Proportions of dissolved and particulate nutrients comprising the TN and TP differ for different sampling locations and times. Since it is difficult to assess how this affects algal growth other alternatives were considered. The particulate N/P ratio is useful because the N/P ratio of algae has been shown to depend on relative availability of nitrogen and phosphorus. The ratio is high under phosphorus limiting conditions and low when nitrogen is limiting. This ratio is difficult to use in natural systems because of the impracticality

of differentiating between algal and other particulate materials in water samples. The dissolved N/P ratio was selected for use in identifying nitrogen and phosphorus limiting conditions. To avoid problems associated with algal uptake, measurements of dissolved N and P from samples taken immediately below the thermocline were used to form the ratio. This was done because the origin of nutrients in the epilimnion at any point in the lake throughout the growing season appears to be the water underlying the thermocline.

At the suggestion of the TAB, a method of data analysis proposed by Smith,[9] a variable yield chlorophyll-phosphorus model for lakes, was tested for applicability to data observed in Lake Mead. The model was developed from data on midwestern lakes covering a wide range of nitrogen to phosphorus ratios. The hypotheses show a regular change in the log/log relationship between total chlorophyll and total phosphorus concentration as a function of nitrogen to phosphorus ratios as shown on Figure 8-51. Data accumulated in this study were analyzed according to the proposed Smith relationships by dividing them according to the nitrogen to phosphorus ratios ranging from less than 10/1 to 32.6/1 or greater, and by determining lines of best fit for the data in those groups using the SAS/GLM regression program described previously.

Physiological and Biological Indicators--Physiological and biological indicators of nutrient limitation were examined and compared to bioassay and water quality indicators. The relative level of alkaline phosphatase activity (APA) per unit of chlorophyll is an indicator

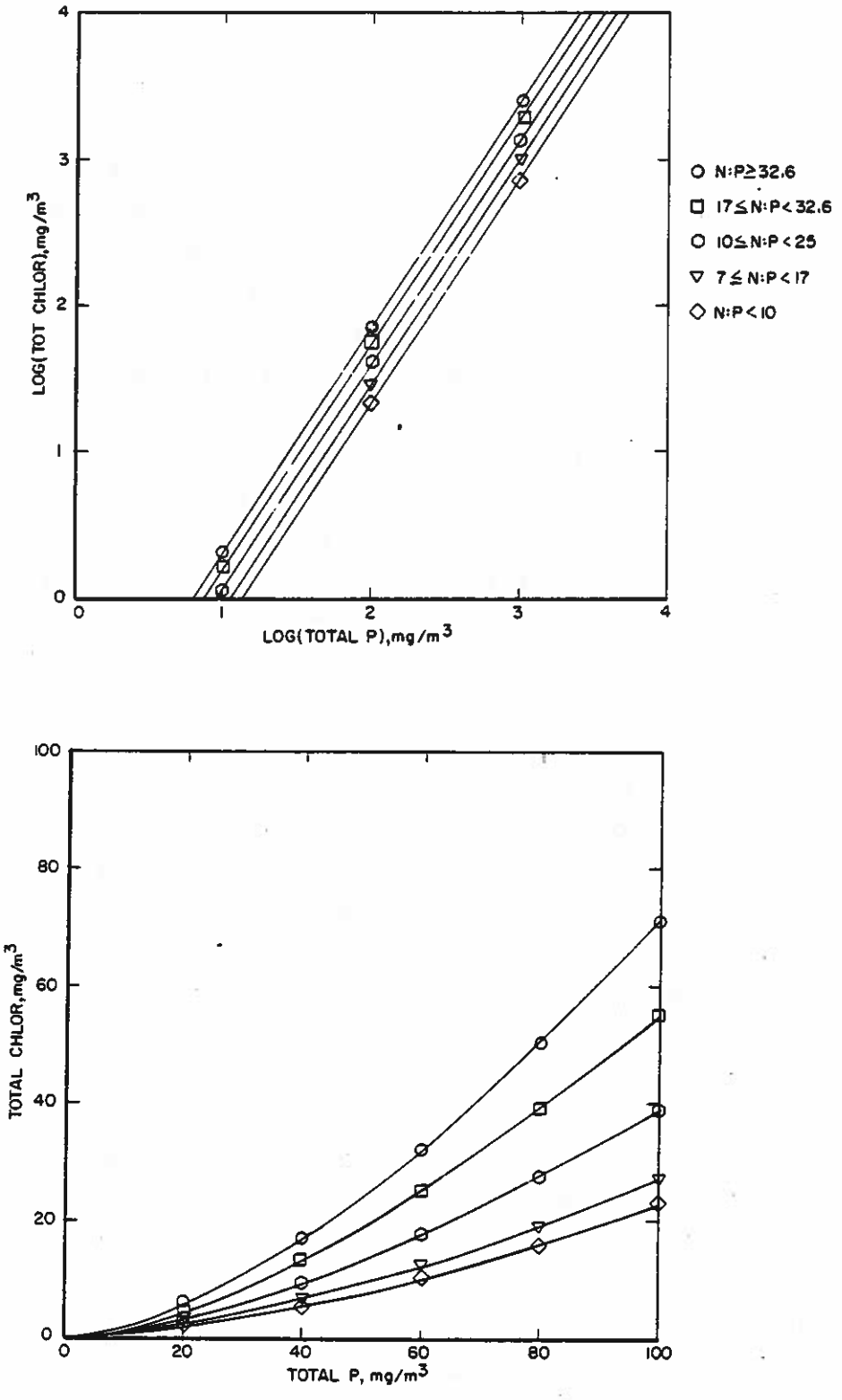


Figure 8-51 Total Chlorophyll Dependence on Total Phosphorus for Different N/P Ratios, After Smith (1981)

of phosphorus limitation. The higher the level of APA/chlorophyll, the stronger the indication of phosphorus limitation. The amount of phosphorus extractable by boiling water from filtered algae samples is an indicator of phosphorus availability. It is expected to be inversely related to phosphorus limitation. The amount of ammonia uptake by algae incubated in the dark is directly related to the degree of nitrogen limitation. Also, the presence of certain blue-green algal species and their ability to fix nitrogen are indicators of nitrogen limitation. Algal species were identified and examined for presence of heterocysts to assess nitrogen fixation potential. Direct measurements were also made of nitrogen fixation.

The three procedures just described are indicators of what nutrient is limiting. However, the degree of nutrient limitation can vary and may be important to the design of transparency control procedures. Nitrogen to phosphorus ratios, indicative of N and P limiting conditions, vary both from station to station and from season to season. Annual trends in nitrogen and phosphorus concentrations suggest the possibility that a greater proportion of phosphorus than nitrogen may be retained and recycled in the epilimnion. If this occurs, it may affect nitrogen and/or phosphorus control requirements.

Estimates of recycling or loss rates of nitrogen and phosphorus in the epilimnion can be made. This requires applying material balances to concentrations of N and P in the epilimnion measured over suitable periods of the WQSS. Solutions of the material balance equations can be used to estimate transport rates of nitrogen and phosphorus into and out of the epilimnion. The rates can be compared to

identify possible differences in recycling of N and P in the epilimnion. Material balance equations were developed for total N and P in a unit volume segment of the epilimnion by equating input from mixing to outputs from mixing and sinking.

Material balance equation solutions for TN and for TP in the epilimnion are:

$$TN_e = q/k_{sn}\ (TN_h) + c_{ne}^{-(q + k_{sn})t}$$

$$\text{and } TP_e = [q/(q + k_{sp})]TP_h$$

where: subscript e refers to epilimnion concentrations
subscript h refers to hypolimnion concentrations
q = the turnover or dilution rate of the epilimnion, T^{-1}
k_{sn}, k_{sp} = sinking constant or loss rate due to sedimentation for TN and TP, respectively.
c_{ne} = constant of integration
t = time, days.

The equations are applied in the next section to estimate the turnover rate and sinking loss rates for nitrogen and phosphorus in the epilimnion. This is used to assess potential effects of differences between nitrogen and phosphorus loss (or retention) from the epilimnion on the use of empirical correlations for nutrient control calculations.

Several approaches to limiting nutrient analysis are described above. They will all be considered in drawing conclusions about cause and effect relationships between algal and nutrient concentrations in the lake. Effort will be made to develop a concensus of the methods or to reconcile differences between various indicators. This will be important in application to transparency control calculations. Potential effects of differential loss rates of TN and TP from the epilimnion on application of the correlations to transparency control calculations will also be assessed.

Wash Input Distribution. The distribution of nutrients from the wash into the bay, and in particular the epilimnion, appears to be a major factor determining nutrient, chlorophyll, and transparency levels. Therefore, estimation of nutrient load limits for transparency control requires definition of nutrient distribution. The basic need is to identify the relationship between the nutrient input concentration, or load, and corresponding concentrations in the epilimnion. Several different approaches have been taken to quantify wash input load distribution; nutrient balances, simplified dilution calculations, statistical analysis of concentrations, dilution frequency distributions, and plume model formulation (Hydraulic Study).

Material Balances--The relationship between influent flow and concentration of a conservative substance and its concentration at locations in the bay can be established by application of material balances. A schematic description of the bay is given on Figure 8-52. Important features of the system are:

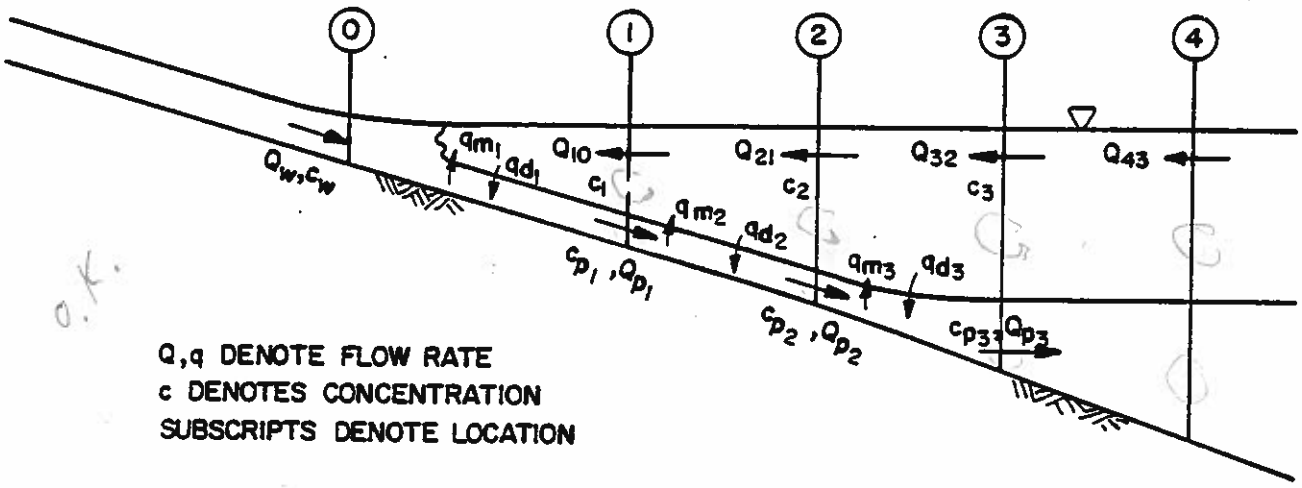


Figure 8-52 Wash - Bay Material Balance Schematic

1. The bay is divided into segments corresponding to the WQSS sampling stations.

2. The homogeneous wash flow enters the bay at point 0.

3. The plume sinks to the bottom in Segment 0-1.

4. The plume flows along the bottom to a point of neutral density. A typical summer condition is shown in the schematic with separation occurring between Stations 2 and 3.

5. Three concentration gradients have been measured; in the plume decreasing outward with increasing distance from the wash, in the surface layer decreasing outward with increasing distance from the wash, and in the water column increasing downward from the surface layer to the plume.

6. To satisfy principles of conservation of mass and continuity of flow, given the above concentration gradients, mass transfer or simply flow must occur as shown by the various arrows between the segments described on Figure 8-52. The major flow component is from the wash, Q_w, following a path through the plume from Q_{p1} to Q_{p3}. To provide for dilution of the plume, a reverse flow must occur in the surface layer following a path from Q_{43} to Q_{10}. To account for surface concentrations roughly in proportion to plume concentrations, mixing exchange must occur between the surface and plume portions of

any segment, qd_1 and qm_1. The term qd_1 may be conveniently thought of as the diluting flow from the surface layer into the plume in any segment, and qm_1 the flow from the plume into the surface layer.

Mass balance equations for a conservative chemical component in the wash can be written for individual segments. Equations can also be developed for either the surface or the bottom layer alone by equating appropriate inputs and outputs.

Solutions of the material balance equations can be developed to identify the relation between wash inflow and the surface concentration for Segment 1:

$$Q_{10} = Q_w \left(\frac{c_w - c_{p1}}{c_{p1} - c_1}\right) \quad (1)$$

$$Q_{p1} = Q_w \left[1 + \left(\frac{c_w - c_{p1}}{c_{p1} - c_1}\right)\right] \quad (2)$$

$$q_{d1} = Q_w \left(\frac{c_w - c_{p1}}{c_{p1} - c_1}\right)\left[1 + \left(\frac{c_1 - c_1}{c_{p1} - c_1}\right)\right] \quad (3)$$

$$q_{m1} = Q_w \left(\frac{c_w - c_{p1}}{c_{p1} - c_1}\right)\left(\frac{c_1 - c_1}{c_{p1} - c_1}\right) \quad (4)$$

Each of these equations can be rearranged to form expressions of "dilution" ratios between individual flow components and the wash flow that depend on various concentrations. Based on the schematic description of the system, the dilution ratio of principal interest to surface concentrations resulting from plume input would be q_{m1}/Q_w, equation (4). The relationship between wash concentration, c_w, and surface concentration, c_1, is linear. But, the dependence on other concentrations that also may vary with flow suggests a more complex relationship.

Material balances can be applied to each segment of the bay to develop desired wash-surface concentration relationships. The result for Segment 1-2 comparable to equation (4) is:

$$q_{m2}/Q_w = \left(\frac{c_w - c_{p1}}{c_{p1} - c_1}\right)\left(\frac{c_1 - c_2}{c_{p2} - c_2}\right) - \left[\left[1 + \left(\frac{c_w - c_{p1}}{c_{p1} - c_1}\right)\right]\left(\frac{c_{p1} - c_{p2}}{c_{p1} - c_1}\right) + \left(\frac{c_w - c_{p1}}{c_{p1} - c_{p2}}\right)\left(\frac{c_{p2} - c_1}{c_{p2} - c_2}\right)\right]\left(\frac{c_2 - c_2}{c_{p2} - c_2}\right) \quad (5)$$

Equation (5) indicates the increasing complexity of the relationship between wash and surface concentrations with increasing distance from the wash.

Simplified Dilution Calculations--Simplification of the detailed mass balance approach described above was required for practical application. A simplified schematic description of a typical bay segment, Figure 8-53, was developed. Basic features of the system are retained. Inward surface flow, Q_s, originates from the background region at, Q_b, where the concentration is c_b. The high input concentration, c_w, is mixed from below at a low rate, Q_m.

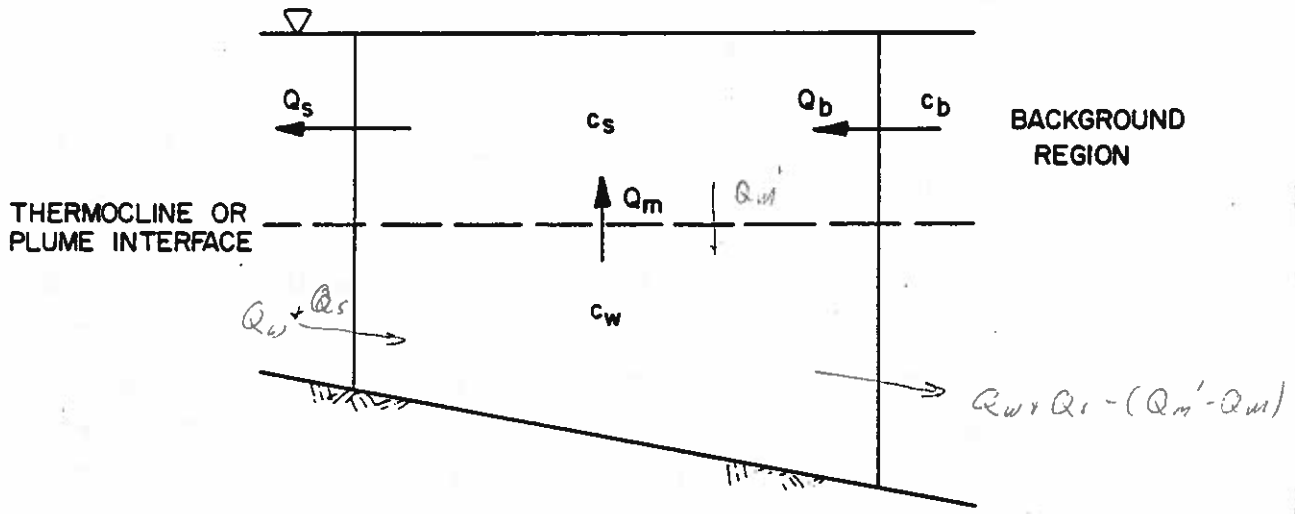


Figure 8-53 Simplified Bay Surface Layer Dilution Schematic

Mass balance equations on this segment are:

Flow continuity:

$$Q_s = Q_m + Q_b$$

Mass balance on C:

$$Q_s c_s = Q_m c_w + Q_b c_b$$

The solution of these equations for the dilution ratio $Q_b/Q_m = D$ results in:

$$D = Q_b/Q_m = \frac{c_w - c_s}{c_s - c_b} \qquad (6)$$

This can be rearranged to illustrate the relationship between wash and surface concentrations:

$$c_s = [1/(D + 1)]\ c_w + [D/(D+1)]\, c_b \qquad (7)$$

This is the form of a straight line with slope = $1/(D + 1)$ and intercept = $[D/(D+1)]c^b$, where the background concentration, c_b, is assumed constant.

Statistical Analysis of Concentrations--The validity of equation (6) for describing dilutions actually occurring in the bay was tested by regression analysis of wash and surface concentrations.

Dilution Frequency Distributions--The relationship between the influent wash load or concentration and the concentrations of nitrogen or phosphorus in the hypolimnion or epilimnion at any station can be defined simply by the statistical distribution of relative concentrations between the two points expressed in terms of effective dilution. The term dilution as applied to nonconservative substances, such as the nutrients, includes other factors affecting concentration such as loss to sediments and biological

uptake in addition to simple dilution. Wherever the term dilution is applied to nonconservative substances in this chapter, it includes all factors and means effective dilution as measured by equation (6). The percentage dilution observed between the wash and any station can be calculated by equation (6). Cumulative frequency distributions of dilution can then be formed. The slope of the frequency distribution for any location is a measure of physical characteristics of the system contributing to dilutions observed at that point.

Plume Model--The plume model developed as part of the hydraulic study provides the only means available for predicting dilutions along the centerline of the plume for conditions of flow rate, temperature, and salinity substantially different from those observed during the WQSS sampling period. Details of the plume model are described in the Hydraulic Study Report, Appendix F.

Clarity Control Calculation Procedure. A procedure was developed for calculating nutrient loads needed to achieve a specific clarity level at any location in Las Vegas Bay. The procedure is based on application of the quantitative relationships developed between Secchi depth and chlorophyll, and between chlorophyll and nutrient concentrations, and the relationships between wash and surface concentrations in the bay as described in the previous sections. The procedure can be applied to either nitrogen or phosphorus limiting conditions with one additional step required if phosphorus control is desired for existing nitrogen limiting conditions.

The clarity control calculation procedure consists of four basic steps, which are shown on Figure 8-54 and described below:

The clarity control calculation procedure consists of four basic steps, which are shown on Figure 8-54 and described below:

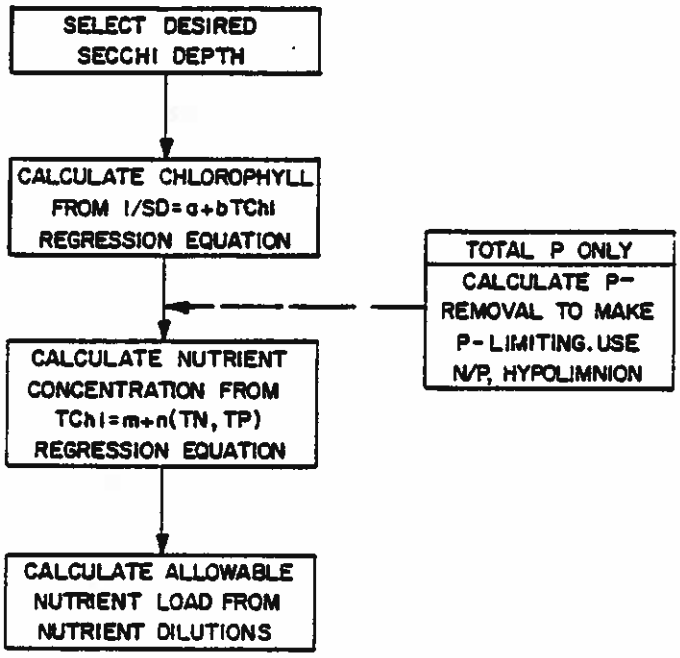


Figure 8-54 Transparency Control Calculation Procedure

1. Select a specific Secchi depth clarity level to be maintained. Frequency distributions of observed Secchi depths provide a convenient means of selecting clarity levels corresponding to any given statistical recurrence interval.

2. Calculate a target chlorophyll level from the Secchi depth-chlorophyll correlation. If the quantitative correlation between Secchi depth and chlorophyll is found to vary over the period of interest, i.e., the

recreation season, the period may be subdivided with individual correlations characterizing conditions for each period.

3. Calculate the required nutrient concentration in the epilimnion from the quantitative correlation between chlorophyll and the limiting nutrient concentration. As with the Secchi depth-chlorophyll correlations, the recreation season may be divided into more than one period with correlations developed for each.

4. Compute the allowable load discharged from the wash using the dilution relationship developed to relate wash load to surface concentrations.

One additional step is required if nitrogen limiting conditions exist, and it is intended to control transparency by limiting phosphorus discharge to the lake. This step consists of calculating the amount of phosphorus removal required to raise the dissolved N/P ratio in the hypolimnion from that currently observed to a level of 10/1.

Application of the transparency control calculation procedure is facilitated by a graphical presentation of the correlations with appropriate construction of nutrient concentration and wash load scales. As will be discussed in presentation of the graphical control calculation figures in the following section, two alternative methods can be used. The first follows the procedures described above, based on the two-step development of individual correlations between Secchi depth and total chlorophyll and between total chlorophyll and nutrient concentration. The second is based on the single-step

development of correlations directly between Secchi depth and nutrient concentrations. The two-step process has the advantage of being relatable to similar work elsewhere and perhaps being easier to visualize in terms of physical significance. It has the disadvantage, however, of being difficult to develop confidence ihtervals. The validity of using the single-step procedure depends on demonstrating that the intermediate variable, total chlorophyll, does not add significantly to explaining variance in 1/SD independent of that explained by nutrient concentrations. The advantage of the one-step procedure is in the straight-forward development of confidence intervals. Examples of both procedures are presented in following sections.

Analysis Application and Results

Data from the WQSS have been analyzed using procedures described in the previous section. Description of the analysis results is divided into five major groups: transparency dependence, limiting factor analysis, algae-nutrient dependence, wash input distribution, and clarity control calculations.

Transparency Dependence. The analysis of transparency dependence followed the four basic steps outlined in the approach section: multiple correlations, single-parameter correlations, refining the data set, and selecting the final data set.

Multiple Correlations--Multiple regressions of inverse Secchi depth, 1/SD, were run against total chlorophyll,

nonvolatile suspended solids (NVSS), and color. Values of R-square from analysis of variance (Table 8-9) indicate that color and NVSS do not contribute significantly to the correlation for May through October 1979. However, NVSS appear to contribute substantially to the total variance for May through October 1980. This dependence was further examined to clarify the suggested influence of NVSS. Data on volatile suspended solids (VSS), total suspended solids (TSS), and NVSS (Table 8-10) indicate:

1. The proportions of volatile and nonvolatile solids are approximately constant from station to station.

2. The NVSS levels in 1979 and 1980 were nearly the same.

3. The NVSS at all bay stations was about 1 percent or less of NVSS at Wash Station 5. This corresponds to visual observations at the mouth of the wash. A very distinct line of demarcation was always visible at the point where the plume sank below the bay surface. No residue of the brown wash turbidity was visible beyond that point. As noted in Table 8-9, $r^2 = 0.12$ was found for 1/SD versus TOTCHLOR for the 28 observations used in the multiple correlation for 1980. The low n (28) was dictated by the limited number of color measurements. Regression of 1/SD versus TOTCHLOR for the full data set (n = 302) for May to October of 1980 gives $r^2 = 0.47$. This indicates that, while NVSS apparently contributed to variability in Secchi depth transparencies in 1980, the relationship between transparency and chlorophyll was still a strong one.

Table 8-9. 1, 2, 3 Variable Models for Predicting 1/Secchi Depth (RECIPSEC)

	Number in model	r^2	Variables in model
May to October 1979			
	1	0.17	COLOR
	1	0.21	NVSS
	1	0.81	TOTCHLOR
n = 59	2	0.28	NVSS, COLOR
	2	0.81	TOTCHLOR, NVSS
	2	0.84	TOTCHLOR, COLOR
	3	0.85	TOTCHLOR, NVSS, COLOR
n = 185	1	0.88	TOTCHLOR
May to October 1980			
	1	0.12	TOTCHLOR
	1	0.24	COLOR
	1	0.52	NVSS
n = 28	2	0.24	TOTCHLOR, COLOR
	2	0.57	TOTCHLOR, NVSS
	2	0.60	NVSS, COLOR
	3	0.60	TOTCHLOR, NVSS, COLOR
n = 302	1	0.47	TOTCHLOR

Table 8-10. Suspended Solids Summary, Volatile and Nonvolatile Components

	April to October 1979 and 1980			April to October 1979	April to October 1980
Station	VSS/TSS	TSS, mg/l	NVSS, mg/l	NVSS, mg/l	NVSS, mg/l
Wash					
5			480.0	144.3 (n=3)	542.6 (n=16)
Lake					
1	0.55	12.3	6.1		6.1
2	0.65	5.9	2.2	1.7 (n=13)	2.4 (n=31)
3	0.64	5.0	1.9		1.9 (n=24)
5	0.63	2.3	0.9	0.7 (n=13)	1.0 (n=30)
8	0.63	1.6			
9	0.52	1.2			
10	0.49	1.3			

Single Parameter Correlations--Based on results of the multiple correlations, further examination of correlations between inverse Secchi depth and total chlorophyll were made. Values of the r^2 statistic and the SAS statistic indicating significance of the slope, PR>|T|, are summarized in Table 8-11. The data indicated strong positive and significant correlations between transparency and total chlorophyll for April to October of 1979 and 1980.

Table 8-11. Transparency-Chlorophyll Correlation Statistics, Annual Data Sets

Analysis description	r^2
1/Secchi depth versus total chlorophyll	
All data, April to October 1979 and April to October 1980	0.56
Annual data, April to October 1979	0.88
and April to October 1980	0.47
Percent light transmittance versus total chlorophyll	
Annual data, April to October 1979	0.83
and April to October 1980	0.71

To examine the potential effect of human error in measuring transparency by Secchi depth, transmissometer measurements of transparency were examined as an alternative. The depths reported at constant light transmittance levels ranging from 5 percent to 12 percent were correlated with

Secchi depth. Values of the r^2 were uniformly greater than 0.65 with highly significant PR>1T1 values. The 10 percent light level was selected as the best alternative measure of transparency. The inverse 10 percent light level was then correlated with total chlorophyll. Values of r^2 (Table 8-11) indicate that Secchi depth was a slightly better predictor of chlorophyll in 1979, but the 10 percent light depth was better in 1980. Based on the r^2 for the 1980 Secchi depth-chlorophyll correlation (correlation coefficient r = 0.69) and lack of significant improvement provided by transmittance measurements, further refinement of the transparency-chlorophyll correlation was conducted using Secchi depth.

Refining the Data Set--The next step in analysis of transparency data was to divide the data into monthly subsets and to examine the resulting correlations with chlorophyll.

Characteristics of regression lines and r^2 values for monthly subsets of the data are summarized for the period from May 1979 to November 1980 on Figure 8-55. Significant variation was observed in both the slope and the intercept of the inverse Secchi depth-chlorophyll relationship over the annual cycles. The slope indicates the change in transparency per unit change in chlorophyll concentration. The greater the slope, the greater the transparency reduction (or the shallower the Secchi depth) for a given chlorophyll level. The intercept is a measure of the contribution of nonchlorophyll substances to transparency reduction. It would determine the Secchi depth if the chlorophyll concentration was zero.

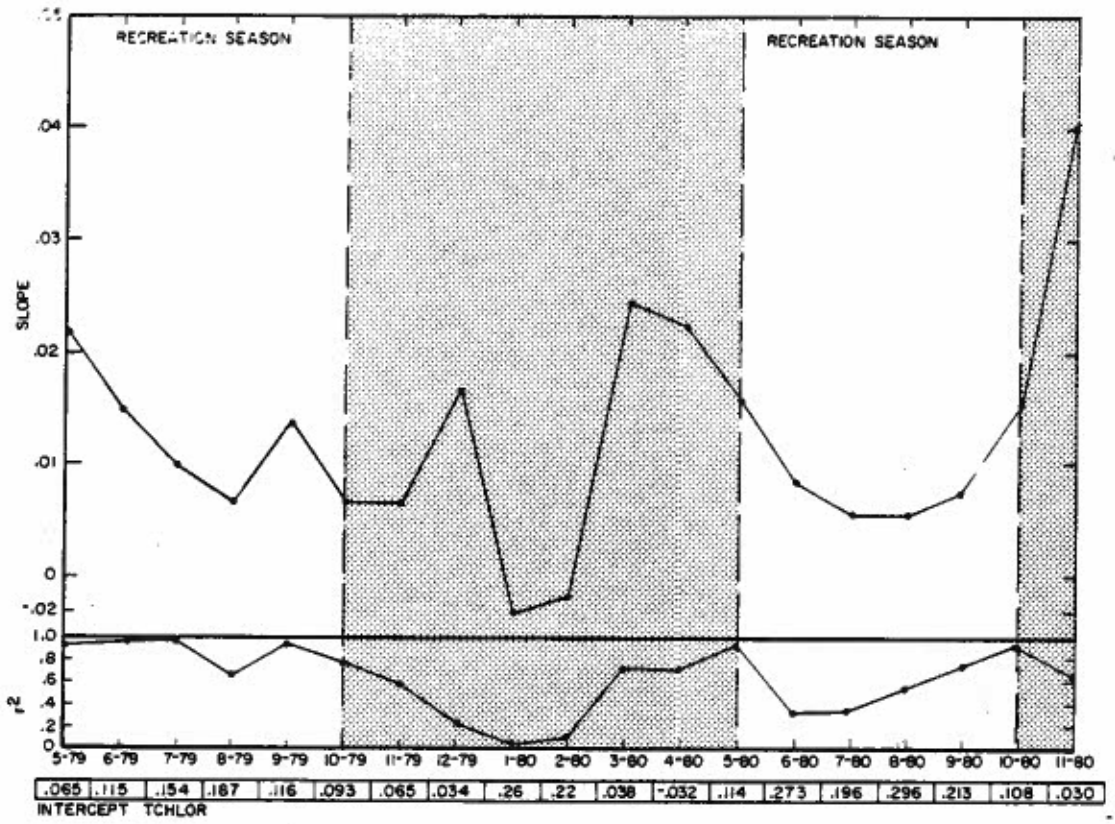


Figure 8-55 Annual Variation in 1/SD Versus Total Chlorophyll, Regression Line Slopes and Intercepts

Relatively high slopes of the regression line were observed in spring and fall periods with low slopes in late summer and in mid-winter. Mid-winter values, however, are less certain (low r^2) because of the smaller number of data points. Trends in regression slopes and intercepts ran in opposite directions during the WQSS (Figure 8-55). Lowest slopes and highest intercepts occurred in mid-summer. Highest slopes and lowest intercepts occurred in early spring and late fall. Winter conditions were not well defined because of low sample numbers.

The cause of seasonal variation in the slope (and intercepts) of Secchi depth-chlorophyll correlations is of

interest as it may affect predictability. The change from high to low slopes suggests a shift in algal species or characteristics. Although the chlorophyll concentration might remain constant, it apparently became concentrated in a smaller number of larger, less light attenuating units. A shift from small species to large species could cause such a change. However, algal species distribution data (Figure 8-11) do not indicate an obvious shift in species size following the slope trend of Figure 8-55. It is possible that changes in chlorophyll per unit algal biomass occur in response to seasonal light level changes. Some algal species have been reported to adapt to increasing light levels in the seasonal cycle by reducing the amount of chlorophyll per cell. This could also account for the slope changes, Wetzel.[10] The changes in intercept suggest higher levels of nonchlorophyll, light-attenuating suspended solids in the summer period. Such solids may include dead and decaying algae, other biological fragments (detritus), and inorganic solids such as silt from the wash or storm runoff. Because wash discharge is relatively constant year round and storm runoff is very infrequent, and because the algal population increases with the season resulting in associated detrital material, the latter seems the more likely cause of the intercept variations.

Frequency distributions of Secchi depths at Stations 1 to 5 for the spring (April to June) and summer (July to September) periods of 1979 and 1980 were significantly different as shown on Figure 8-56. The differences correspond to differences in the 1/SD-TChl regression characteristics for the same seasonal periods. These frequency distributions will be used later in the transparency control calculations.

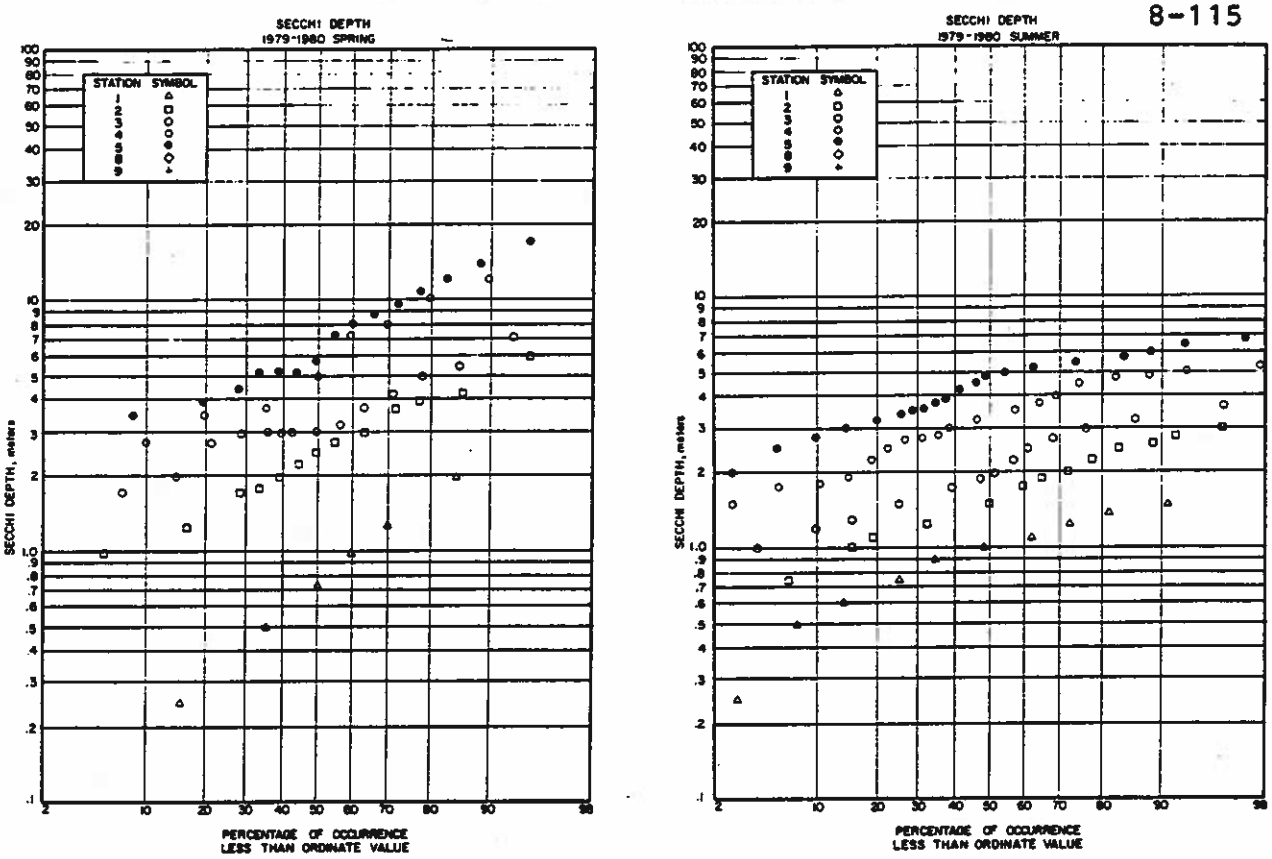


Figure 8-56 Secchi Depth Frequency Distributions, Spring and Summer, 1979 to 1980

Selecting the Final Data Set--Based on the pattern of seasonal variation in the Secchi depth-chlorophyll correlation slopes, the recreation season was divided into spring and summer periods. Final quantitative relationships were developed with the SAS/GLM linear regression program using independent spring and summer data sets, each including 1979 and 1980 periods. The resulting quantitative relationships between Secchi depth and total chlorophyll for spring and summer periods are summarized in Table 8-12.

Table 8-12. Secchi Depth-Chlorophyll Correlations Final Quantitative Relationship

Time period	Regression equation	Significance PR>|T|
Spring months (April to June) (1979 and 1980)	1/SD = 0.077 + 0.014 TChl	0.0001
Summer months (July to September) (1979 and 1980)	1/SD = 0.179 + 0.013 TChl	0.0001

directly related to chlorophyll levels to varying degrees, depending on location, through the growing season. Examination of water quality data indicated general correspondence of limiting nutrient indicators with the bioassay results. Light limitation did not significantly affect chlorophyll levels in Las Vegas Bay. Iron and silica were also found not to limit algal growth. Nitrogen and phosphorus were found to be directly related to chlorophyll levels to varying degrees, depending on location, through the growing season.

Chlorophyll levels did not appear to be inhibited by any chemical substances in the lake. Physiological and biological indicators of nutrient limitation also showed general correspondence with both the bioassays and water quality data. Data and analysis leading to these general observations are detailed in the succeeding paragraphs.

Bioassays--Bioassay results analyzed include those of the regular, special, in situ, and AAP bioassays. Detailed data and description of methods are included in the Bioassay Report, Appendix C. Descriptions of the individual bioassay components are provided below.

Results of the regular bioassays, Figure 8-57, indicate that various periods occur throughout the year when algae are limited by nitrogen alone, by phosphorus alone, and by nitrogen and phosphorus together. Periods of limitation by phosphorus alone were predominant at Station 8. Periods of nitrogen limitation alone were predominant at Station 2. Stations 4 and 5 had the longest

periods of limitation by nitrogen and phosphorus together. Nutrient limiting conditions were apparently different in 1979 and 1980. The bioassays indicated nitrogen limitation at all stations through late summer and early fall of 1979. Only Station 2 was limited solely by nitrogen in the comparable period of 1980.

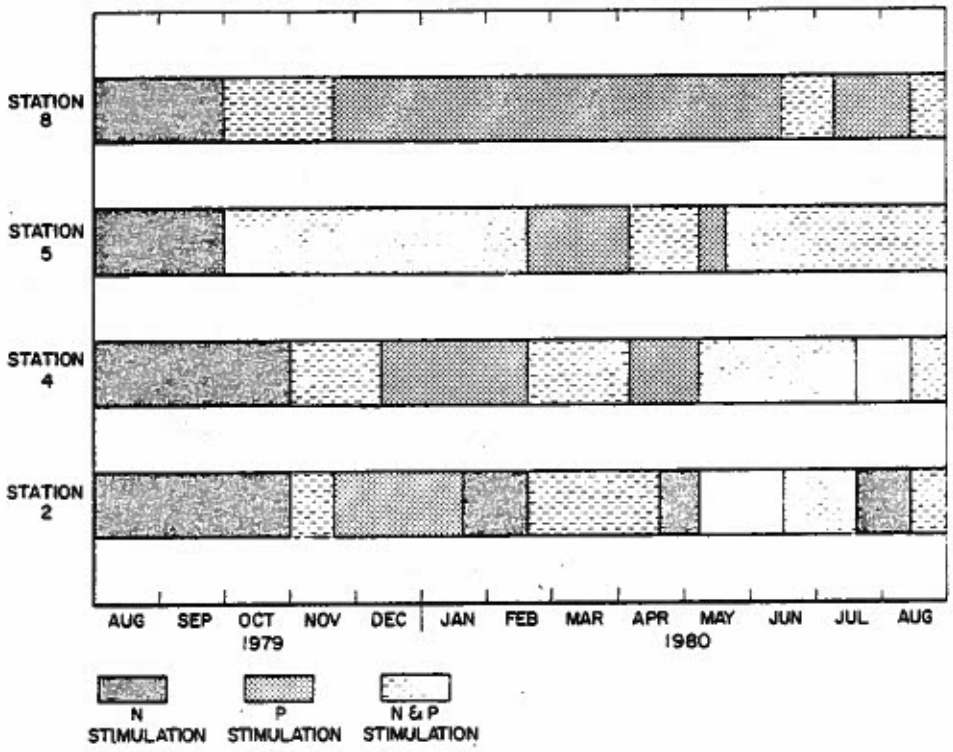


Figure 8-57 Bioassay Summary

Special bioassays and components of the regular bioassays, as described in the Bioassay Report, were conducted to assess effects of wastewater and phosphorus removal on growth stimulation of algae sampled from the lake. This was done by comparing growth response to three enrichments: (1) Las Vegas Wash water diluted 50:1 with distilled water; (2) lake water enriched with N and P to equal the N and P

concentrations measured in the 50:1 diluted wash water (N+P)*; and (3) lake water enriched with nitrogen comparable to the 50:1 diluted lake water and a low standard phosphorus concentration (N_2+P_1) where N_2 = 166 ug/l. Results of 24 regular and special bioassays showed consistently that these three enrichments produced approximately comparable response relative to control samples but generally two or more times the response to N and P only enrichments. The response to Las Vegas Wash, (N+P)*, and (N_2+P_1) enrichments typically differed by 10 to 20 percent. Response to the wash water treatment was almost always the highest of all enrichments. The slightly higher response to wash water enrichments than to (N+P)* and N_2+P_1 enrichments suggests a slight but detectable contribution to algal growth of factors other than inorganic N and P in the wash and treatment plant discharges.

Other special bioassays were conducted to assess the effects of varying laboratory conditions and the effects of wastewater effluent. Table 8-13 lists the special bioassays that were conducted and briefly describes the results. Detailed results for each special bioassay are contained in Appendix C. Of particular interest are the bioassays that compared growth stimulation effects of diluted wastewater effluent from the Clark County Sanitation District (CCSD) treatment plant before and after alum addition. They showed that alum treated secondary effluent was less stimulating than secondary effluent prior to alum addition.

Large volume (1 to 2 cubic meters) <u>in situ</u> bioassays that were conducted in October 1979 and July 1980 agreed closely with results of regular bioassays conducted simultaneously.

Water quality data and physiological measurements made in the large volume bioassays also agreed with the bioassay indications of nitrogen and phosphorus limitation.

Table 8-13. Summary of Special Bioassays and Special Treatments Included in Regular Bioassays

Special treatment	Bioassay Identification																
	Reg No. 1	Sp No. 3	Sp No. 7	Reg No. 9	Sp No. 10	Reg No. 11	Sp No. 13	Reg No. 14	Sp No. 15	Reg No. 16	Sp No. 17	Sp No. 19	Sp No. 24	Reg No. 25	Reg No. 26	Sp No. 27	Sp No. 32
Alum treated		X	X				X		X		X	X					X
Untreated 2° effluent		X	X				X		X		X	X					
Unfiltered alum treated effluent			X														X
Artificial alum + P Floc																	X
Artificial Alum + PO_4			X				X										
Alum treated + N							X										
Plume enrich (Station 2, 8 meters)	X																
Unfiltered LVW						X											
Broad range of N + P conc.										X			X				
Serial additions of P								X									
Vitamins, Fe, Si, EDTA	X (Fe)												X	X (Fe)	X (Si)		
Virgin Basin enrich		X															
Storm effect on response to LVW										X							
Mechanisms of light shock				X		X	X										
In situ bioassays					X											X	

Standard AAP bioassays conducted by EPA, Appendix C, agreed with results of the regular and in situ bioassays conducted at the same time. In the October 1979 test, AAP bioassays indicated co-limitation by nitrogen and phosphorus. Phosphorus was the principal element with secondary nitrogen influence at Stations 2, 4, and 8. The reverse was true at Station 5. The corresponding regular bioassays showed N and

P limitation at all stations. In the July 1980 test, AAP bioassays indicated N + P limitation at Station 2 and P limitation at Stations 4, 5, and 8. The comparable regular bioassays indicated co-limitation by N and P at Stations 4 and 5 but were otherwise the same as AAP results. The AAP bioassays also indicated that the standard test species used in the laboratory tests were inhibited by relatively high metals concentrations in Lake Mead. Indigeneous algae are adapted to those conditions and showed no apparent effects of metals inhibition in bioassays 1, 25, and 26 (Table 8-13).

In summary, the bioassays showed that nitrogen and phosphorus either alone or together were limiting to the algal populations. Tests conducted on iron and silica and other minor nutrient elements did not show stimulation of the bioassay populations. Special bioassay results showed that dilutions of Las Vegas Wash water taken from Northshore Road were generally at least as stimulating or more so than combinations of nitrogen and phosphorus. Similarly, dilutions of sewage treatment plant effluent were also stimulating except in high concentrations when they appeared to inhibit algal growth. Diluted wastewater effluent following alum treatment was generally found to be less stimulating than secondary effluent without alum treatment. Tests using alum floc as an addition to bioassays did not show stimulation.

Light Limitation--The occurrence of low transparency in conjunction with high chlorophyll levels in areas of the inner bay raises the question of possible light limitation. If light were actually the principal factor limiting chlorophyll levels during WQSS investigations, its effects would have to be accounted for in designing any

transparency control plan. Accordingly, data were examined to determine if chlorophyll levels during the WQSS may have been limited by light. Light levels measured at the mean depth in the well-mixed surface layer provide one indication of light sufficiency as shown in Table 8-14. The well-mixed layer was typically about 10 meters deep during the recreation season, extending to the bottom at Stations 1 and 2. Average mid-depth light levels at Station 2, 60 foot-candles, appear sufficient for algal growth. The relationship between chlorophyll should also indicate any effects of light limitation. If light was limiting, the slope of regression lines for chlorophyll as a function of TN or TP would not be constant for low and high chlorophyll levels, and r^2 values would be reduced. However, regressions of chlorophyll versus TN and TP had uniformly high r^2 values through the high chlorophyll months of the recreation season, as will be described on Figure 8-67. Thus, light levels were apparently not limiting to chlorphyll levels during the recreation season.

Table 8-14. Mean Light Levels at High Chlorophyll, Stations 1, 2, and 3

Station[a]	Water depth, meters	Secchi depth, meters	Chlorophyll, ug/l	Light, foot candles
1	1.5	0.82	200	50[b]
2	5	1.48	64.5	60
3	5	2.39	32.5	114
4	5	4.13	16.5	430

[a]7/25/79, 9/5/79, 10/25/79, 6/26/80, 8/20/80, 9/4/80.
[b]Estimated at 1 percent of surface light at a depth double the Secchi depth.

Water Quality Data--Water quality data were examined to assess the influence of nitrogen, phosphorus, iron, and silica on algae growth. The chemical indicators were compared to bioassay results to determine their correspondence. Also, correlations between chlorophyll and phosphorus were examined according to N/P ratios following the approach of Smith[9] to determine correspondence of Lake Mead conditions with this general model.

Silica concentrations averaged about 8 mg/l (Figure 8-24) and were far in excess of algal (diatom) nutritional requirements. This was the case at all sampling stations and for all sampling dates. Iron concentrations in the lake were relatively low (Figure 8-23). Bioassays were conducted in spring and summer, peak algal growth periods, to test for stimulation by iron and silica. No stimulation resulted from iron or silica enrichment, indicating that they were not limiting.

Data on nitrogen and phosphorus were examined for indications of nutrient limitation and compared with the bioassay results. Figure 8-58 summarizes the observed N/P ratios in both the epilimnion and the hypolimnion over the 1979 to 1980 period and compares them with bioassay results. Ratios of N to P less than 10 to 1 corresponded generally to periods of nitrogen limitation while N/P ratios greater than 10 to 1 corresponded generally to periods of phosphorus limitation. Bioassay results indicated that algal growth conditions in the lake alternated between nitrogen and phosphorus limiting conditions over the annual cycle. Water quality data indicate changes over an annual cycle

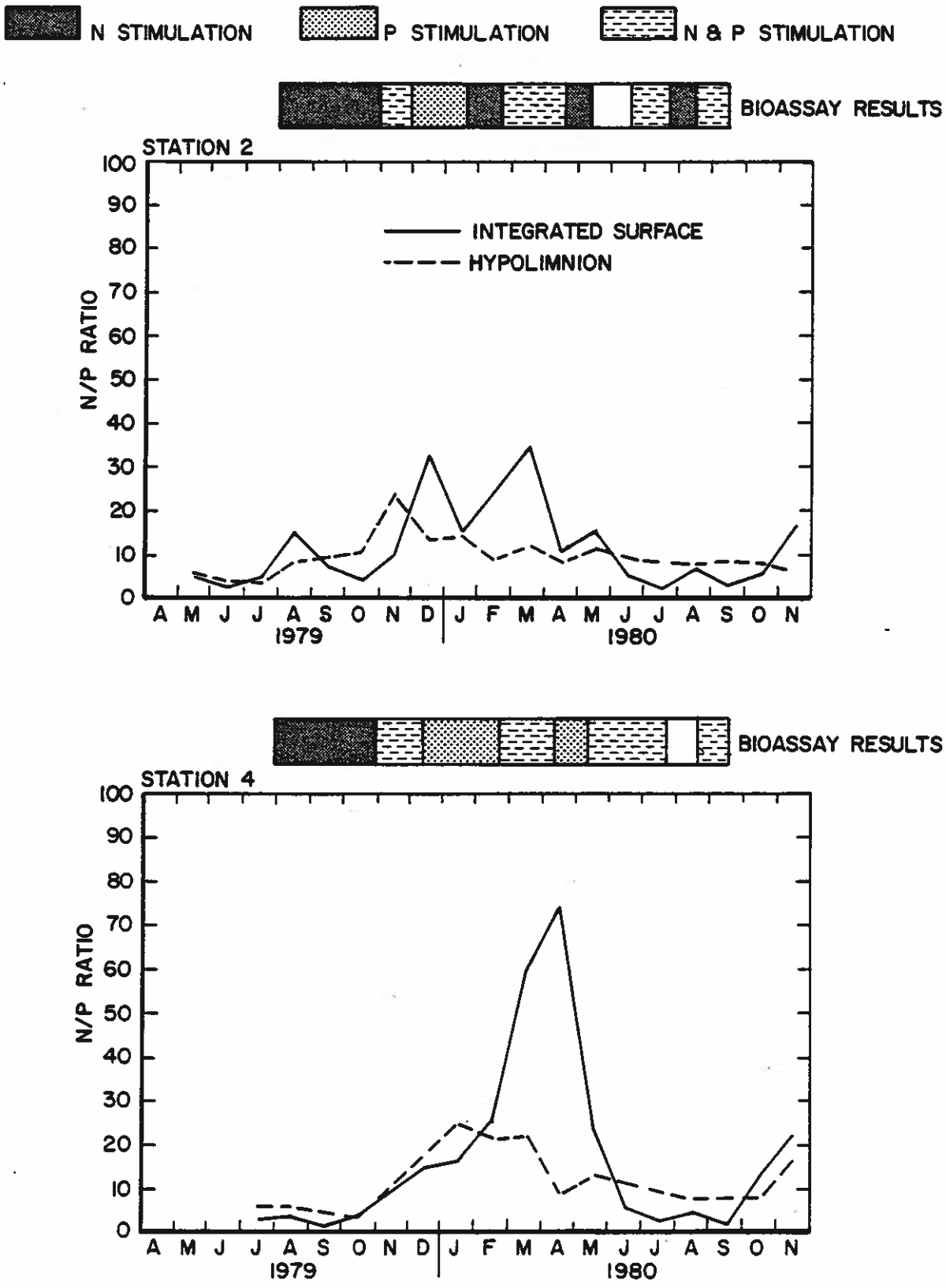


Figure 8-58 Indicators of Nutrient Limitation at WQSS Stations 2, 4, 5, and 8, N/P Ratios and Bioassay Results

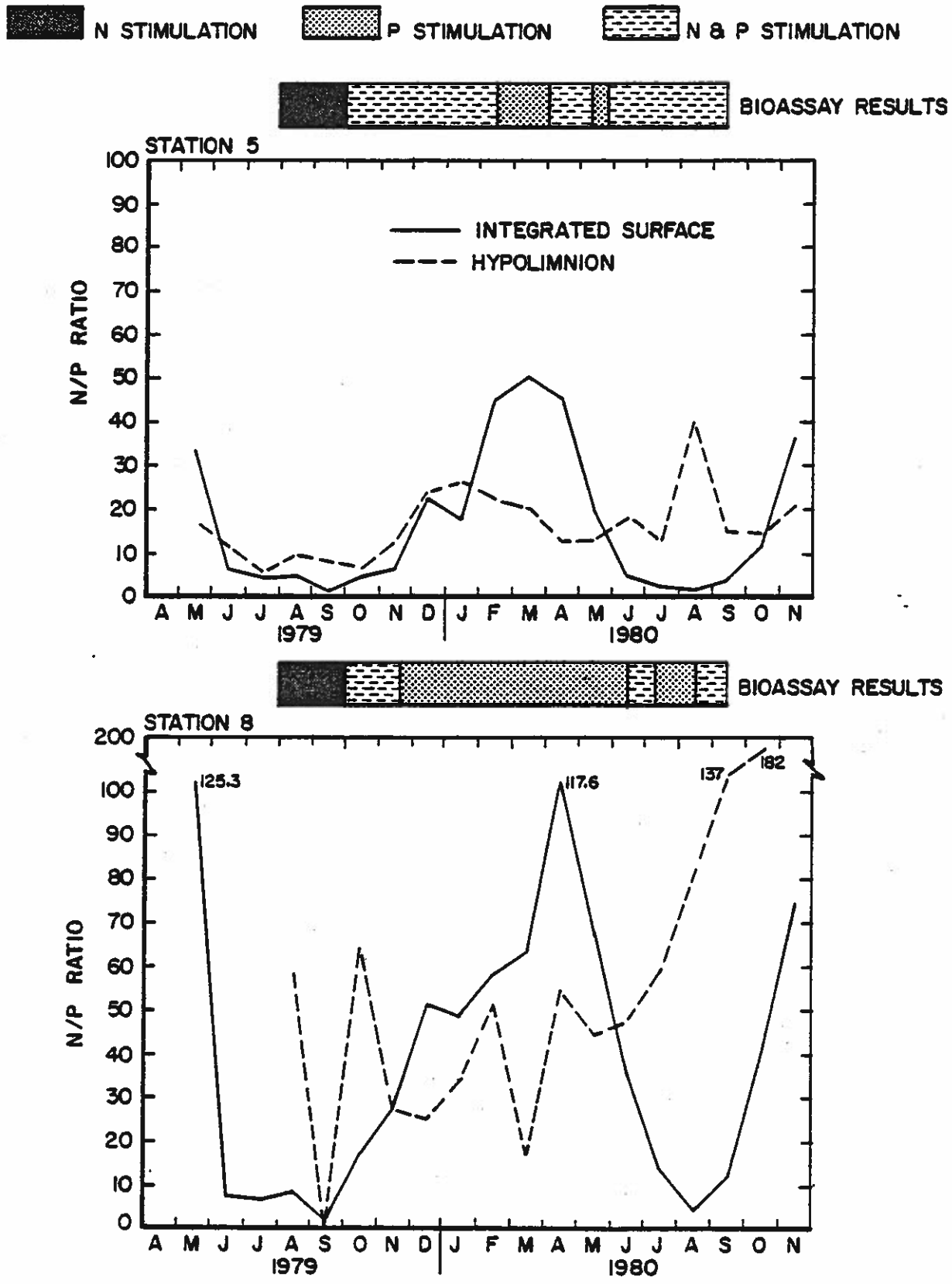


Figure 8-58 Continued

compatible with the bioassay results (Figures 8-20 and 8-22 to 8-24). Phosphorus limitation occurred in the winter when lake contents were largely mixed. This is because of the large reservoir of inorganic nitrogen in excess of phosphorus concentrations in the deeper waters of the lake. When the epilimnion became isolated by thermal stratification in the spring and summer months, the algal population began to use the available nitrogen and phosphorus. Phosphorus concentrations were reduced to minimal levels earlier in the year than nitrogen. But dissolved nitrogen concentrations continued to decrease at all stations until they were ultimately exhausted in mid- to late summer, except at Stations 9, 10, and 11. The continued disappearance of dissolved nitrogen with dissolved phosphorus concentrations at very low levels appears to be due to the ability of the biological system to recirculate phosphorus within the epilimnion more efficiently than nitrogen.

The rate at which dissolved nitrogen concentrations in the epilimnion are exhausted increased with increasing proximity to the wash. This is apparent from the chronological record of dissolved nitrogen concentrations presented previously (Figure 8-19). This can be seen even at Station 3 in spite of the heavy influence of wash input. As the dissolved nitrogen and phosphorus are used up by algal growth in the epilimnion, replenishment of nitrogen and phosphorus by mixing from deeper water becomes increasingly important to controlling the growth of the phytoplankton population. Accordingly, the N/P ratio of water in the hypolimnion at the outer stations, and of the plume at inner stations, appears to be the principal factor contributing to nutrient

limitation in the latter half of the biological or recreation seasons.

Efforts to interpret the results of individual bioassays requires integration of the bioassay results with the water quality data. Summaries of the regular bioassay results superimposed on chronological records of the inorganic nitrogen, orthophosphorus, chlorophyll, zooplankton, and wind intensity are shown on Figures 8-59 through 8-62. Examination of these figures shows that the bioassay results correspond well to overall variations in the water quality data. The degree of response exhibited by individual bioassays can be related both to the trend of the chlorophyll concentration at the time the bioassays began and to observed levels of nitrogen and phosphorus in the lake. For example, at Station 5 (Figure 8-61) bioassays 20, 21, and 23 indicate phosphorus stimulation in the period when the inorganic nitrogen concentration was still 100 ug/l or more. By Bioassays 28 and 29, following exhaustion of the inorganic nitrogen excess, both nitrogen and phosphorus stimulation occurred. Effects of internal storage of nutrients are apparent also, as can be seen at Station 2 (Figure 8-59), where the bioassay response closely parallels the chlorophyll trend in the lake. Bioassays 23 and 25, initiated during rising chlorophyll periods in the lake, showed similar response. Bioassays 28 and 29, which were begun during falling chlorophyll periods, showed little if any response.

Analysis of chlorophyll and nutrient data according to the model by Smith[9] were described previously. All data and monthly averages for the recreation season were examined as

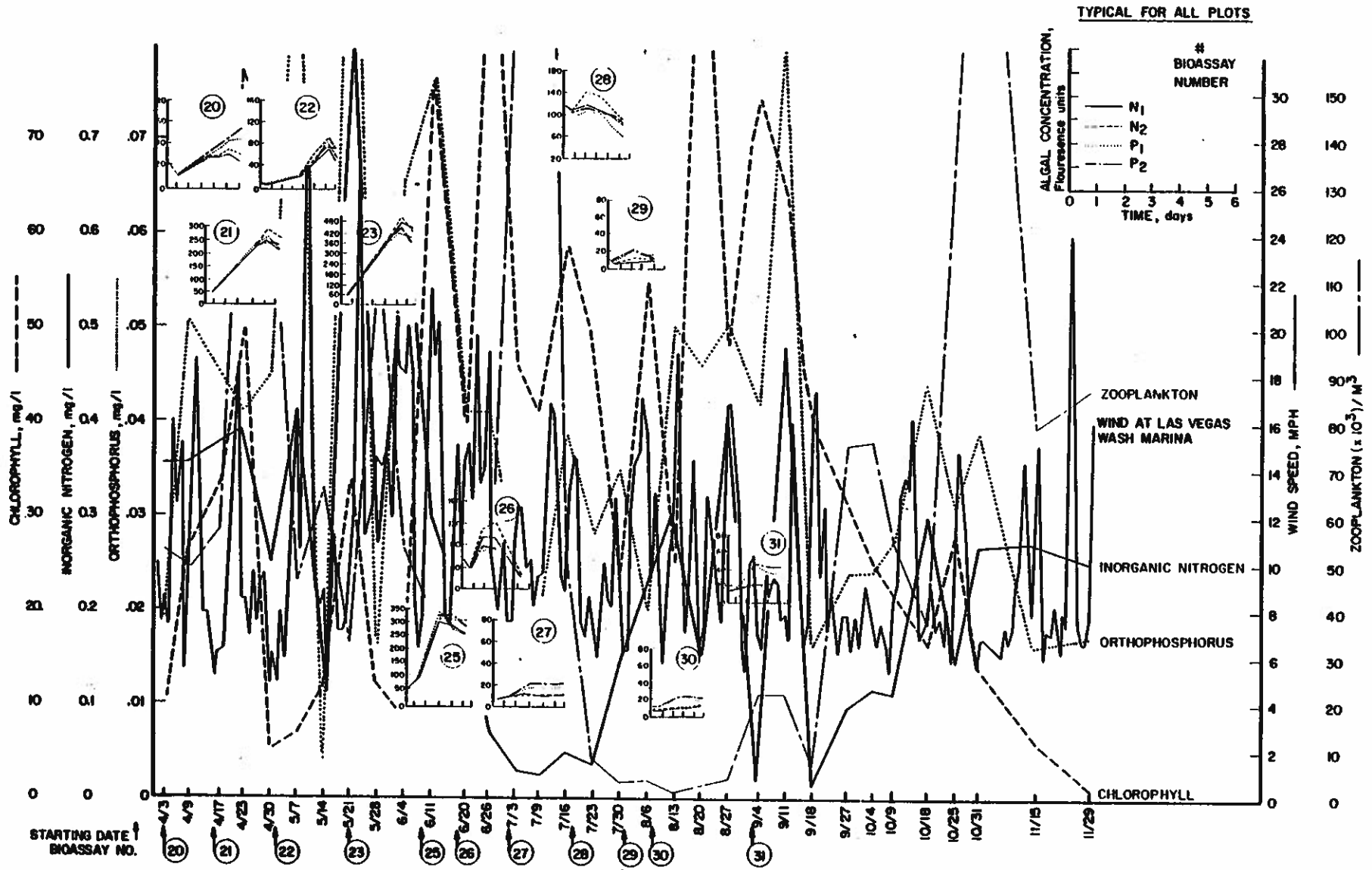


Figure 8-59 Water Quality and Bioassay Chronology, Station 2, 1980

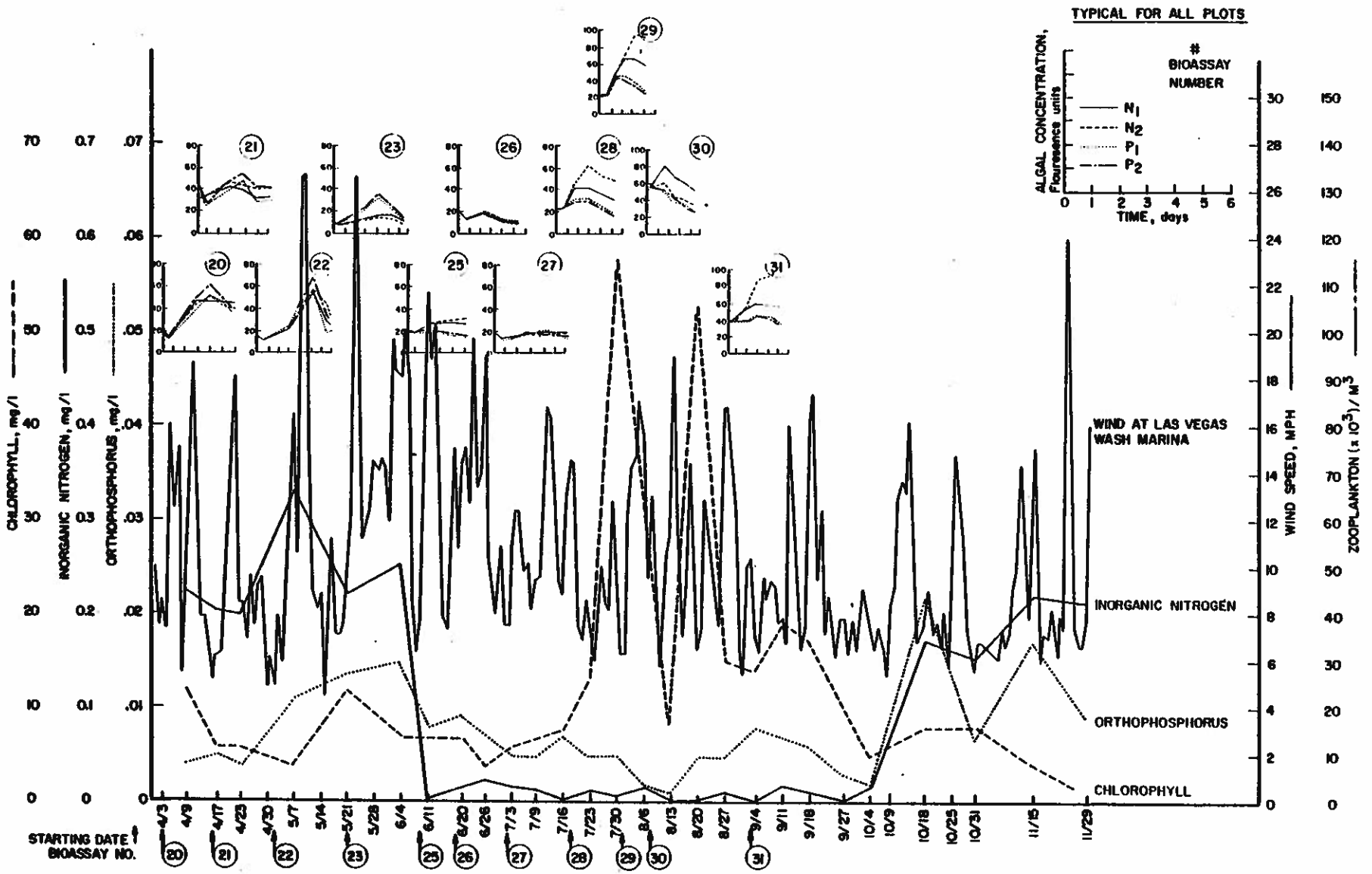


Figure 6-60 Water Quality and Bioassay Chronology, Station 4, 1980

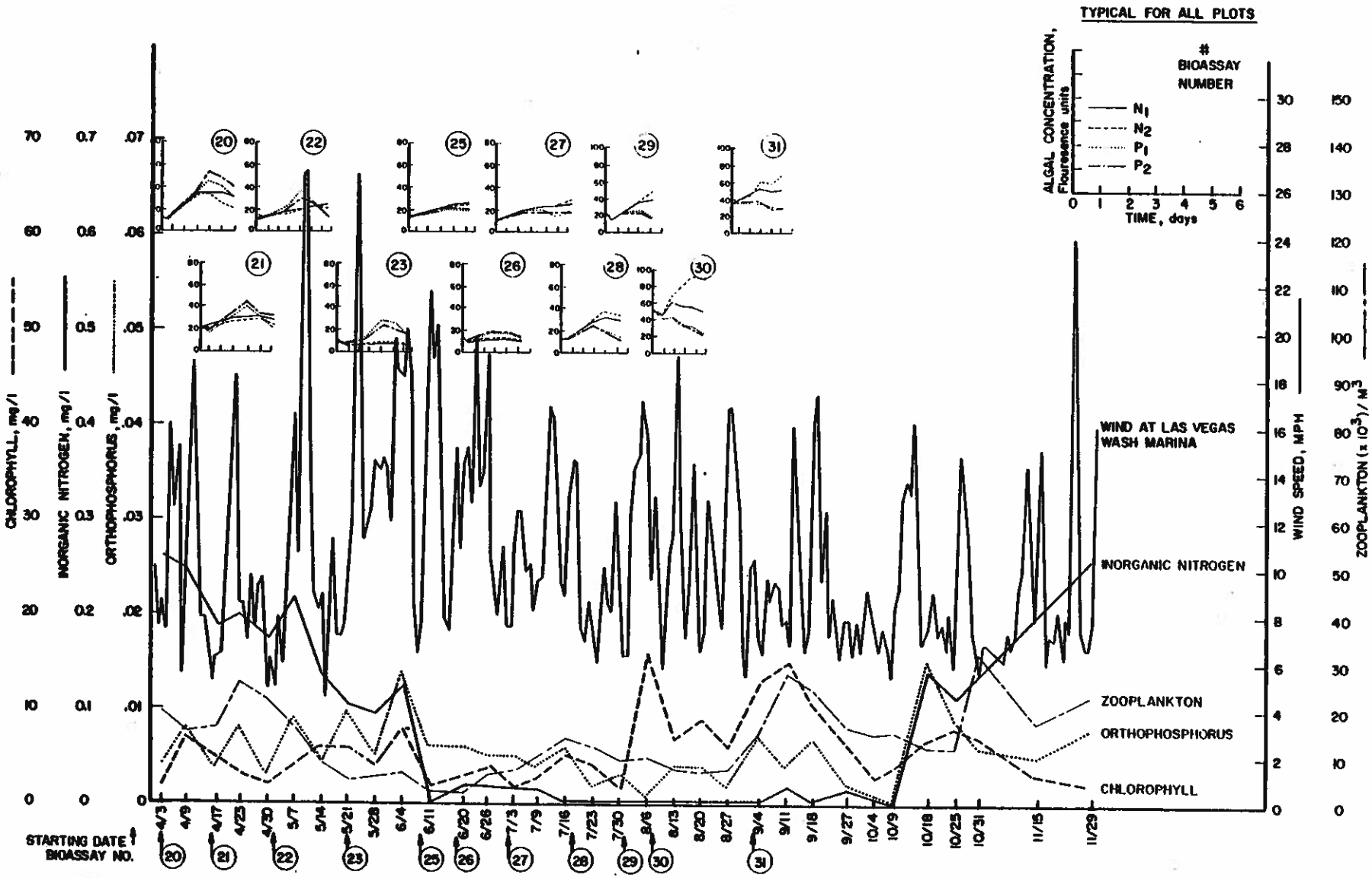


Figure 8-61 Water Quality and Bioassay Chronology, Station 5, 1980

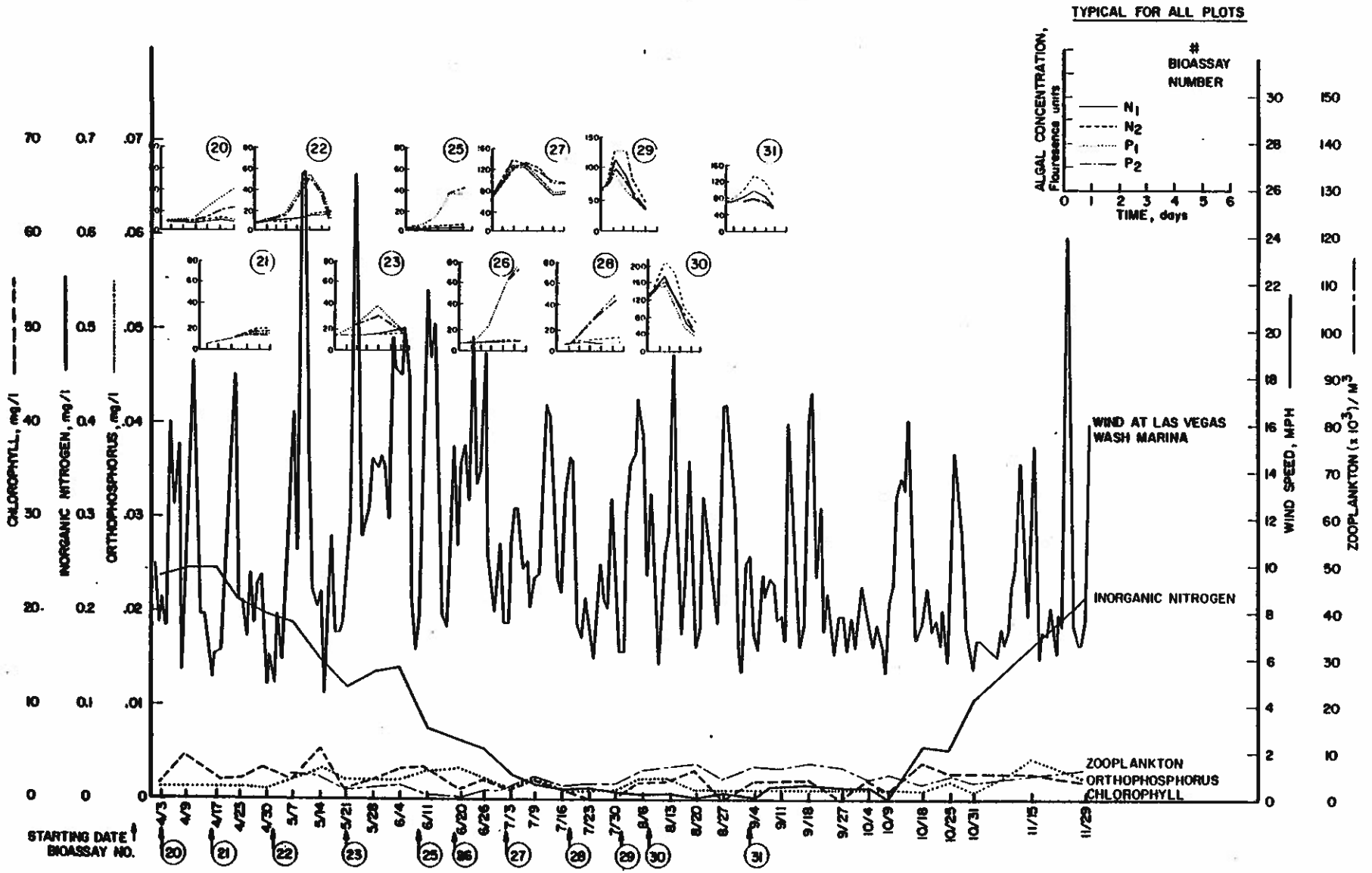


Figure 8-62 Water Quality and Bioassay Chronology, Station 8, 1980

summarized on Figures 8-63 and 8-64. The relationship between log chlorophyll and log TP was found to depend on the N/P ratio. Although the data do not correspond closely to the model proposed by Smith,[9] the nature of the general dependence of chlorophyll versus total P correlations on N/P ratios is significant to interpretation of WQSS data. Examination of relationships illustrated on Figure 8-63 shows that, with the exception of data segments for which r^2 values were low (<0.40), the slope of the TChl versus TP correlations increases with increasing N/P ratio. This implies that the transition from nitrogen limitation to phosphorus limitation in algae in the lake is gradual and not abrupt. However, a significant change in slope occurs between N/P=7 and N/P=17. Accordingly, it is reasonable to assume that phosphorus limitation predominates at ratios greater than 10. Further, such an assumption is somewhat conservative and adds significantly to the convenience of developing quantitative applications.

Physiological and Biological Data--Several physiological and biological indicators of nitrogen and phosphorus limitation were used in the WQSS. Indicators of nitrogen limitation produced limited useful results. Measurements of ammonia uptake by algae incubated in the dark were not able to distinguish between N and P limiting conditions. The specific tests conducted to measure nitrogen fixation (acetylene reduction) showed no nitrogen fixation. This indicated simply that while nitrogen may have been limiting at various times and locations, no population of algae capable of fixing nitrogen developed. Examination of algal samples showed the presence of some blue-green species but not nitrogen fixing ones.

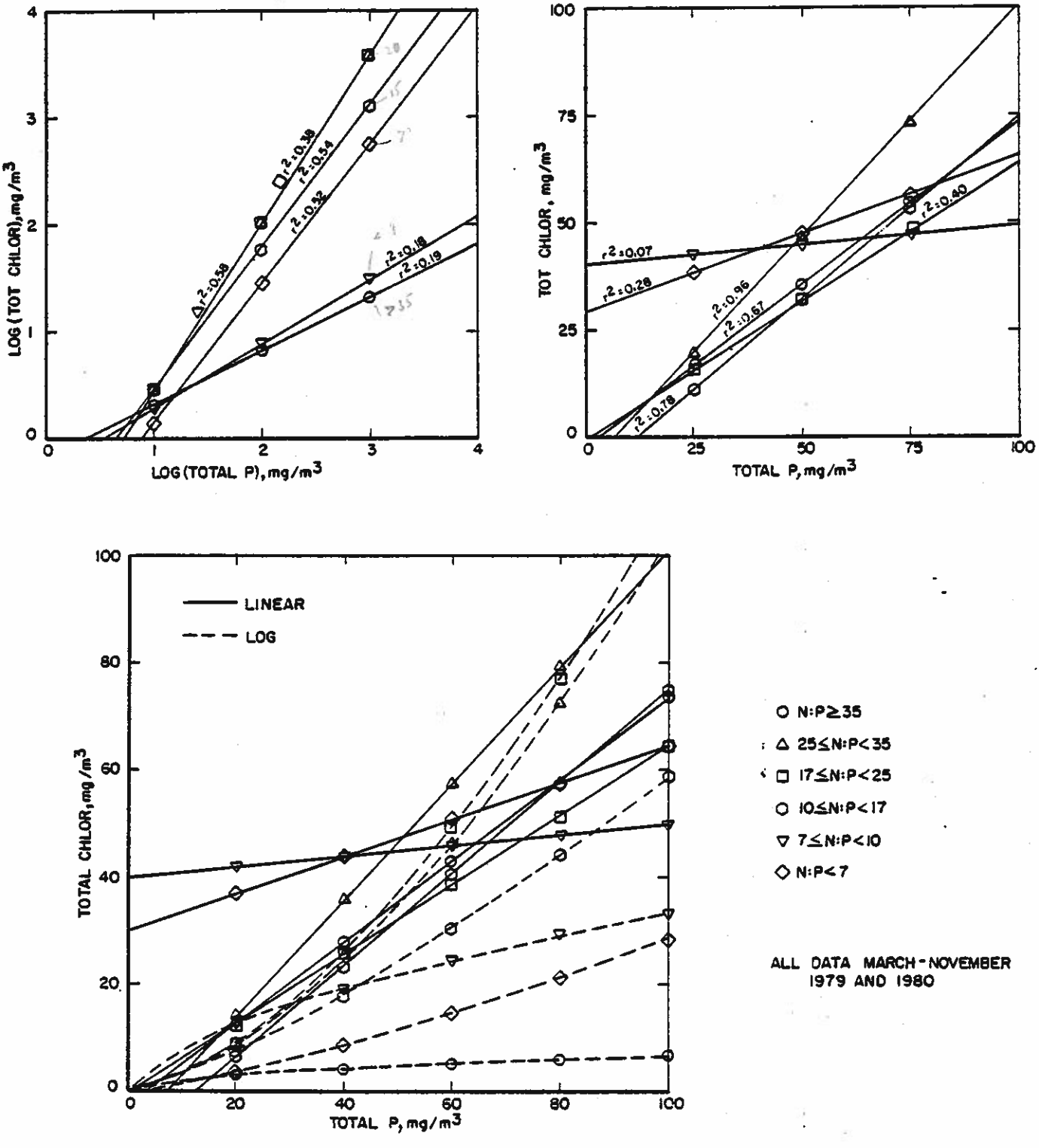
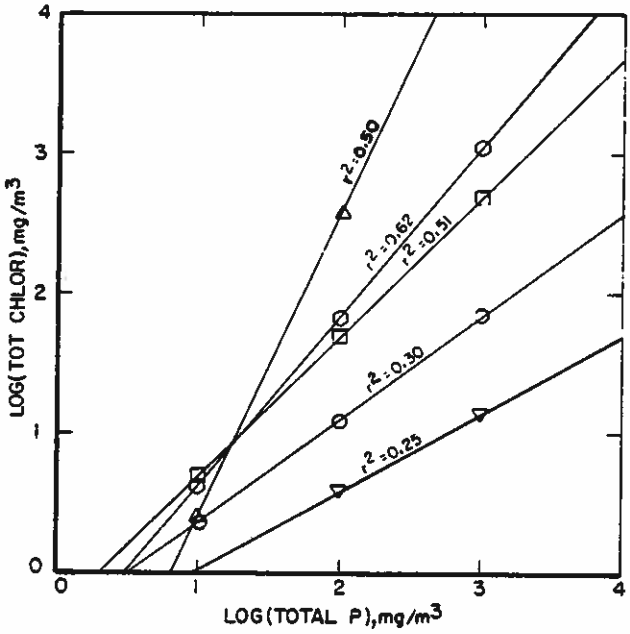
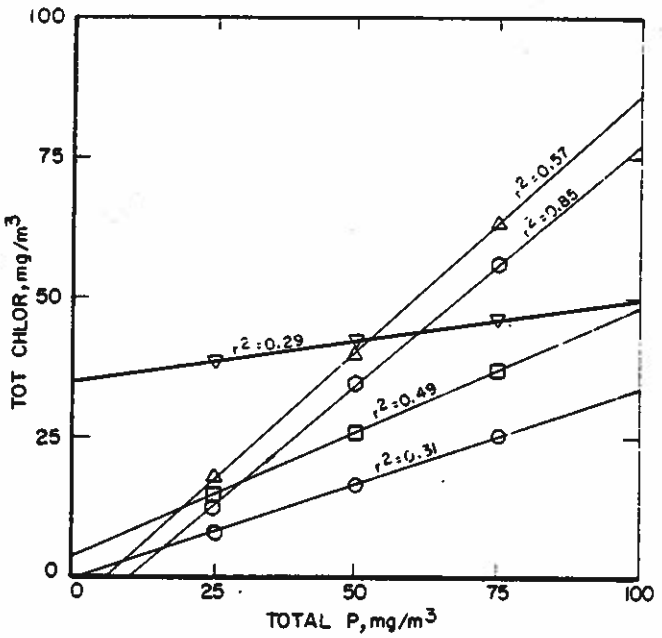


Figure 8-63 Chlorophyll Versus Total Phosphorus, V.H. Smith Model, All Data March to November, 1979 and 1980





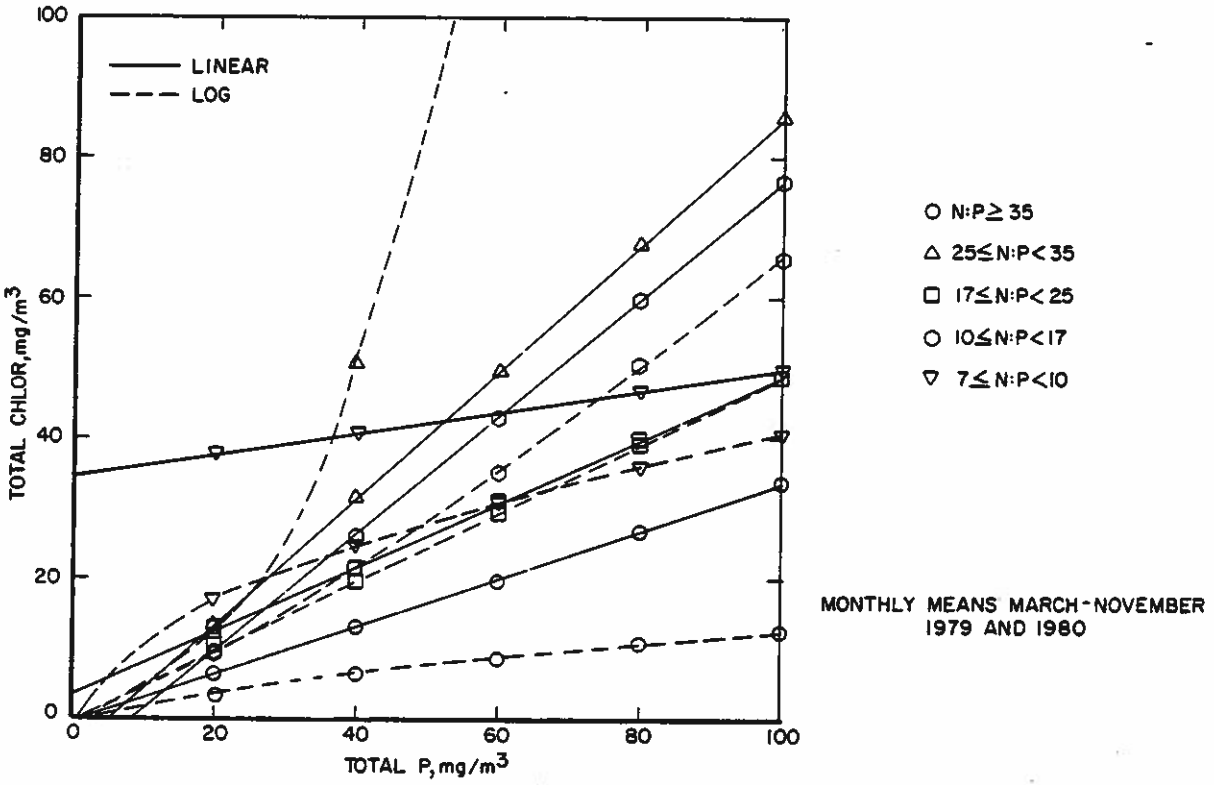


Figure 8-64 Chlorophyll Versus Total Phosphorus, V.H. Smith Model, Monthly Means March to November, 1979 and 1980

Indicators of phosphorus limitation include the particulate N/P ratio and APA. Particulate N/P ratios were calculated from particulate N and P measured in 1980, as shown in Table 8-15. As discussed previously, they generally corresponded to indications of the bioassays shown on Figure 8-65. The APA data were normalized for the size of the algal population by dividing by the total chlorophyll concentration. The resulting APA/chlorophyll values provide a relative measure of phosphorus availability in the algae. A summary of APA/chlorophyll (Figure 8-66) shows a progressive increase with increasing distance from the wash. Values at each station are lowest in winter and high during periods of high algal growth. These trends correspond generally to the pattern of nitrogen and phosphorus availability suggested by bioassay and water quality data.

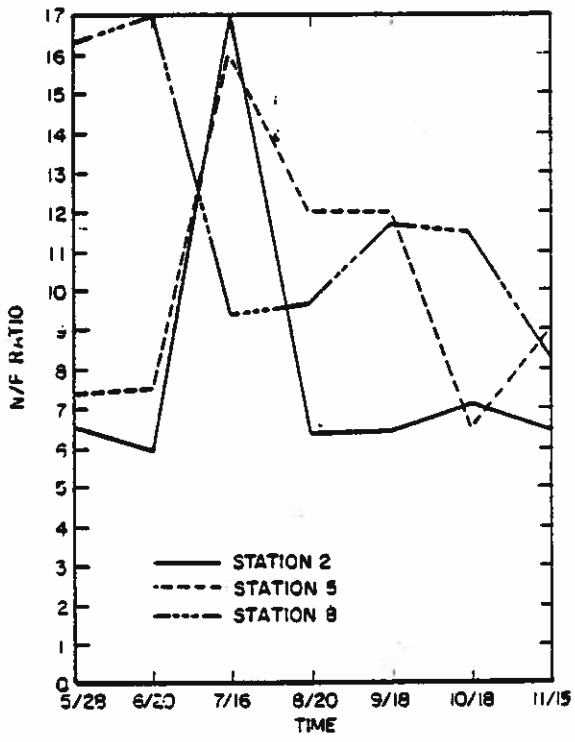


Figure 8-65 Particulate N/P Ratios Versus Time

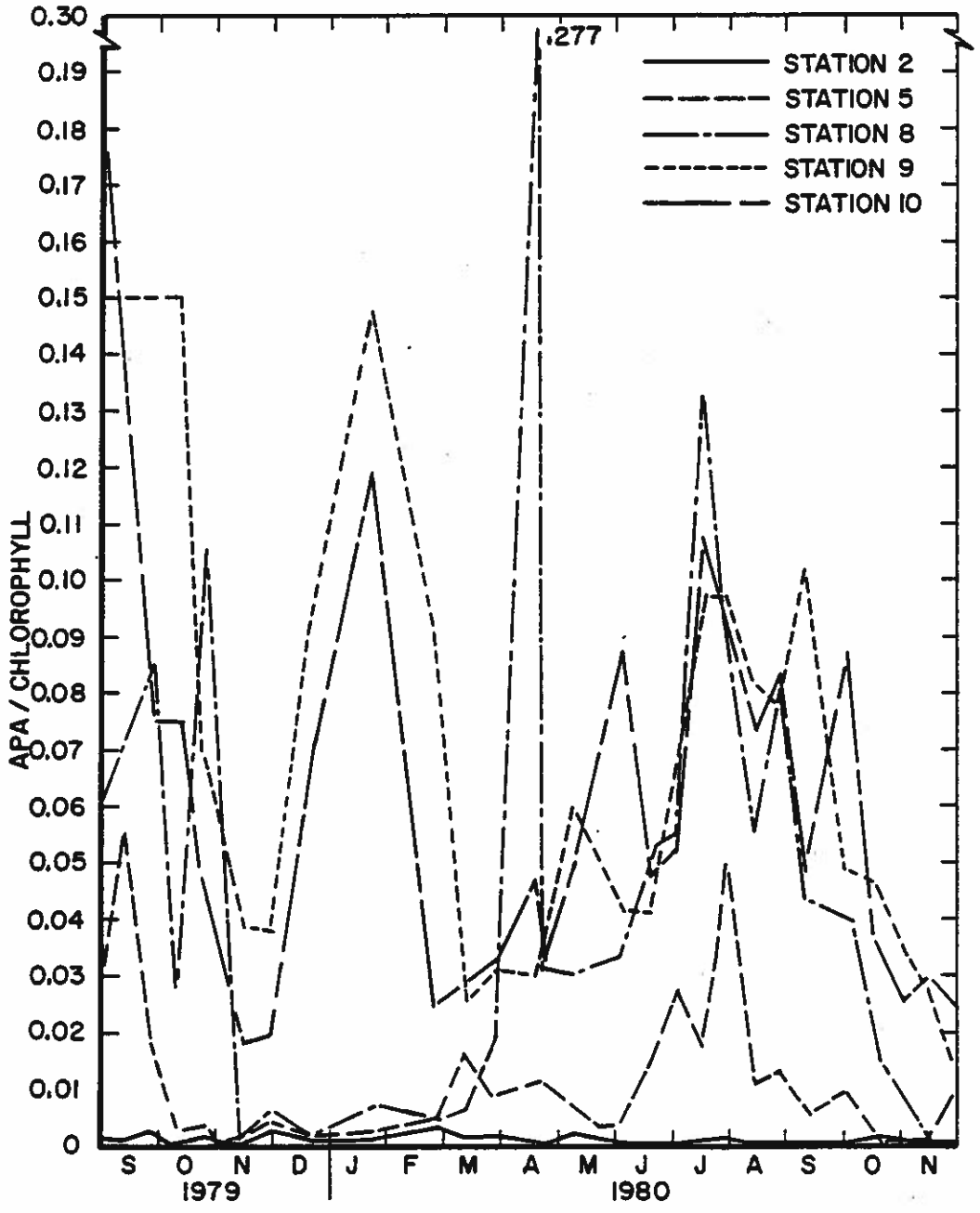


Figure 8-66 Alkaline Phosphatase Activity/Chlorophyll for the WQSS Study Period

Table 8-15. Particulate N/P Ratios

Station	Date	PRT P, mg/l	PRT N, mg/l	PRT N/PRT P
2	5/28/80	0.022	0.144	6.5
	6/20/80	0.050	0.296	5.9
	7/16/80	0.031	0.527	17.0
	8/20/80	0.108	0.678	6.3
	9/18/80	0.035	0.225	6.4
	10/18/80	0.019	0.134	7.1
	11/15/80	0.012	0.077	6.4
5	5/28/80	0.007	0.052	7.4
	6/20/80	0.008	0.060	7.5
	7/16/80	0.006	0.097	16.0
	8/20/80	0.008	0.096	12.0
	9/18/80	0.009	0.108	12.0
	10/18/80	0.010	0.065	6.5
	11/15/80	0.006	0.054	9.0
8	5/28/80	0.003	0.049	16.3
	6/20/80	0.002	0.034	17.0
	7/16/80	0.004	0.037	9.3
	8/20/80	0.003	0.029	9.7
	9/18/80	0.003	0.035	11.7
	10/18/80	0.004	0.046	11.5
	11/15/80	0.003	0.025	8.3

Nitrogen and Phosphorus Recycling--Material balances were conducted on total nitrogen and total phosphorus in the epilimnion at Stations 3 through 8. This was done in an effort to assess the significance of phosphorus recirculation in the epilimnion on transparency control. Calculations were performed according to the approach described previously. Results of the analysis are summarized in Table 8-16. Principal results are that effective mixing rates between the epilimnion and hypolimnion, expressed as a fractional turnover rate of the epilimnion, fell within a relatively narrow range from Station 3 to Station 9. Accordingly, an average mixing rate

of approximately 1 percent per day was assumed to apply uniformly throughout the lake during the recreation season. Sinking loss rates estimated for total nitrogen also fell within a relatively narrow range, with a minimum at Station 9 of slightly less than 1 percent, and maximum rate at Station 3 of approximately 2 percent per day.

Table 8-16. Epilimnion Material Balance TN and TP Loss Rates

Station	Time period	Nutrient form	Effective mixing rate day^{-1}	Sinking loss rate day^{-1}
3	5/1 to 10/1/80	TN	0.006	0.020
5	4/1 to 10/1/80	TN	0.010	0.017
8	4/1 to 10/1/80	TN	0.013	0.014
9	4/15 to 10/1/80	TN	0.009	0.009
5	4/1 to 10/1/80	TP	(0.010)	0.020
8	4/1 to 10/1/80	TP	(0.010)	0.002

Estimates were made of the sinking loss rate for total phosphorus at Stations 5 and 8. As shown in Table 8-16, the sinking loss rate estimated for Station 8 was one order of magnitude lower than that estimated for Station 5 with a loss rate of approximately 2 percent per day at Station 5 and 0.02 of 1 percent at Station 8. This suggests that at Station 8 where phosphorus concentrations are very low in the epilimnion, the biological system is apparently able to retain virtually all of the phosphorus within the system. On the other hand, at Station 5 where phosphorus is relatively abundant, the phosphorus loss rate is comparable to that estimated for total nitrogen. If changes in phosphorus loading are of a magnitude to produce surface concentrations at inner stations (Stations 2 and 3)

comparable to observed Station 5 levels, then phosphorus recycling would not be expected to be significant. However, if levels approach those of Station 8, then recycling should be taken into account. In any case, use of chlorophyll nutrient correlations in transparency control calculations would not be affected by the existence of differentials in loss rates because the correlations include such effects.

Limiting Factor Summary--Data and analysis in the preceding paragraphs indicate that light, iron, and silica were not limiting to algae during the WQSS. Results of the bioassays, pertinent water quality data, and physiological measurements pertaining to nitrogen and phosphorus limitation have been tabulated, as shown in Table 8-17. These compilations were used to derive an overall consensus for nitrogen and phosphorus limiting periods at various locations in the lake.

Algae-Nutrient Dependence. Algae-nutrient dependence was investigated in terms of chlorophyll-nutrient correlations following results of the limiting factor analysis which indicated that nitrogen and phosphorus were the principal limiting nutrients. Initially, multiple correlations were performed including iron and silica which confirmed other indications of their nonlimitation. Then, the correlations of chlorophyll with nitrogen and phosphorus were refined to generate quantitative relationships to be used in transparency control calculations. The significance of winter nutrient loading to the bay was also examined.

Multiple Correlations--Multiple correlations of chlorophyll with nitrogen, phosphorus, iron, and silica as shown in

Table 8-17a. Limiting Factor Analysis for Station 2

Date	Integrated surface data			Hypolimnion Data			Limiting nutrient from bioassays	APA, ug/l	Consensus
	N, mg/l	P, mg/l	N/P	N, mg/l	P, mg/l	N/P			
04/04/79		0.037							
04/18/79		0.045							
05/03/79	0.114	0.077	1.48	0.190	0.084	2.26			
05/16/79	0.132	0.018	7.33	0.162	0.020	8.10			
05/30/79	0.702	0.131	5.36	0.775	0.122	6.35			
06/13/79	0.018	0.024	0.75	0.015	0.009	1.66			
06/27/79	0.109	0.028	3.54	0.197	0.040	4.93			
07/05/79	0.019	0.002	9.50	0.013	0.006	2.17			
07/11/79	0.051	0.021	2.43	0.089	0.028	3.18			
07/19/79	0.010	0.008	1.25	0.010	0.014	0.71			
07/25/79	0.311	0.055	5.66	1.390	0.376	3.70			
07/31/79	0.048	0.016	3.00	0.467	0.051	9.16	N		N
08/07/79	0.410	0.058	7.07	2.490	0.339	7.35			
08/14/79	0.141	0.006	23.50	3.220	0.333	9.76			
08/21/79	0.308	0.019	16.21	1.260	0.154	8.18			
08/28/79	0.147	0.012	12.25	1.720	0.207	8.31		0.030	
09/05/79	0.365	0.016	22.81	0.571	0.064	8.92	N		
09/12/79	0.032	0.023	1.39	1.140	0.183	6.23	N	0.030	
09/20/79	0.006	0.004	1.50	0.366	0.031	11.81	N		
09/26/79	0.045	0.014	3.21	2.040	0.211	9.67	N	0.060	
10/03/79	0.012	0.013	0.92	0.615	0.039	15.77	N		
10/10/79	0.024	0.014	1.71	1.170	0.164	7.13	N	0.007	
10/16/79	0.034	0.010	3.40	2.830	0.267	10.60	N		
10/25/79	0.102	0.020	5.10	1.970	0.274	7.19	P	0.050	
10/31/79	0.184	0.026	7.08	2.540	0.239	10.63	P		
11/14/79	0.073	0.007	10.43	0.315	0.008	39.38	P	0.010	
11/29/79	0.101	0.011	9.18	0.602	0.080	7.53		0.056	P
12/19/79	0.162	0.005	32.40	0.350	0.027	12.96	P	0.010	
01/23/80	0.237	0.016	14.81	0.731	0.052	14.06		0.004	
02/26/80				3.830	0.435	8.80	N	0.003	
03/12/80	0.334	0.010	33.40	1.051	0.121	8.69	N+P	0.005	
03/26/80	0.280	0.008	35.00	1.270	0.087	14.60		0.017	
04/03/80	0.357	0.019	18.79	1.100	0.094	11.70	N+P		
04/09/80	0.458	0.051	8.98	2.010	0.336	5.98	N+P		
04/17/80				2.030	0.224	9.06	N+P	0.020	
04/23/80	0.395	0.042	9.41	1.660	0.421	3.94	N+P	0.017	
04/30/80	0.250	0.045	5.56	1.840	0.210	8.76			
05/07/80	0.413	0.099	4.17	4.910	0.623	7.88		0.008	
05/14/80	0.127	0.004	31.75	0.954	0.065	14.68			
05/21/80	0.859	0.108	7.95	4.640	0.622	7.46			
05/28/80	0.271	0.016	16.94	1.140	0.083	13.71			
06/04/80	0.613	0.660	9.29	2.380	0.230	10.35		0.003	
06/11/80	0.301	0.076	3.96	1.260	0.159	7.92			
06/20/80	0.193	0.041	4.71	3.460	0.519	6.67	N+P	0.007	
06/26/80	0.068	0.041	1.66	1.280	0.117	10.91			
07/03/80	0.029	0.021	1.38	1.760	0.218	8.07	P		N
07/09/80	0.024	0.020	1.20	2.850	0.368	7.74	P		
07/16/80	0.047	0.039	1.21	3.620	0.462	7.83	N		
07/23/80	0.034	0.028	1.21	3.550	0.403	8.81	N		
07/30/80	0.142	0.035	4.06	2.230	0.313	7.12	N		
08/06/80	0.219	0.020	10.95	1.940	0.337	5.76	N		
08/13/80	0.309	0.050	6.18	0.998	0.125	7.98	N		
08/20/80	0.116	0.046	2.52	0.737	0.079	9.33			
08/27/80	0.408	0.051	8.00	1.032	0.136	7.59	N+P		
09/04/80	0.018	0.042	0.43	1.040	0.113	9.20			
09/11/80	0.482	0.082	5.88	1.730	0.178	9.72			
09/18/80	0.014	0.016	0.87	0.758	0.106	7.15			
09/27/80	0.098	0.024	4.08	1.240	0.194	6.39			
10/04/80	0.115	0.024	4.79	1.640	0.270	6.07			
10/09/80	0.111	0.027	4.11	2.380	0.294	8.10			
10/18/80	0.300	0.044	6.82	1.640	0.256	6.41			
10/25/80	0.165	0.031	5.35	1.380	0.133	10.38			
10/31/80	0.367	0.039	6.85	1.530	0.190	8.05			
11/15/80	0.270	0.016	16.88	.943	0.148	6.37			P
11/29/80	0.250	0.017	14.71	2.610	0.414	6.30			

Table 8-17b. Limiting Factor Analysis for Station 4

Date	Integrated surface data			Hypolimnion Data			Limiting nutrient from bioassays	APA, ug/l	Consensus
	N, mg/l	P, mg/l	N/P	N, mg/l	P, mg/l	N/P			
04/04/79									
04/18/79									
05/03/79									
05/16/79									
05/30/79									
06/13/79									
06/27/79									
07/05/79									
07/11/79									
07/19/79									
07/25/79	0.017	0.006	2.83	0.609	0.101	6.03			
07/31/79				0.517	0.084	6.15	N		
08/07/79	0.038	0.012	3.17	0.419	0.100	4.19	N		
08/14/79	0.027	0.006	4.50	0.454	0.060	7.57			
08/21/79	0.026	0.010	2.60	0.742	0.147	5.05	N		
08/28/79	0.016	0.005	3.20	0.416	0.068	6.12	N		
09/05/79	0.006	0.006	1.00	0.526	0.101	5.21	N		
09/12/79	0.005	0.004	1.25	0.464	0.086	5.40	N		
09/20/79	0.003	0.002	1.50	0.129	0.128	1.01			N
09/26/79	0.006	0.004	1.50	0.530	0.117	4.53			
10/03/79									
10/10/79	0.005	0.007	0.71	0.631	0.120	5.26	N		
10/16/79							N+P		
10/25/79	0.076	0.011	6.91	0.076	0.051	1.49	N+P		
10/31/79									
11/14/79	0.048	0.006	8.00	0.046	0.005	9.20	N+P		
11/29/79	0.087	0.009	9.67	0.083	0.008	10.38			
12/19/79	0.132	0.009	14.67	0.124	0.007	17.71	P		
01/23/80	0.194	0.012	16.17	0.217	0.009	24.11	P		
02/26/80	0.232	0.009	25.78	0.397	0.019	20.89			
03/12/79	0.219	0.004	54.75	0.579	0.040	14.48	N+P		
03/26/79	0.253	0.004	63.25	0.327	0.011	29.73			
04/03/79									
04/09/79	0.227	0.004	56.75	1.050	0.118	8.90	P		P
04/17/79	0.205	0.005	41.00	0.896	0.121	7.40	P		
04/23/79	0.201	0.004	50.25	0.916	0.098	9.35	P		
04/30/79									
05/07/79	0.335	0.011	30.45	1.011	0.107	9.45	P		
05/14/79									
05/21/79	0.223	0.014	15.93	0.874	0.053	16.49	N+P		
05/28/79									
06/04/79	0.255	0.015	17.00	0.633	0.046	14.41			
06/11/79	0.003	0.008	0.38	1.310	0.173	7.57	N+P		
06/20/80	0.016	0.009	1.78	0.644	0.058	11.10	N+P		
06/26/80	0.025	0.007	3.57	0.950	0.091	10.44			
07/03/80	0.016	0.005	3.20	0.660	0.075	8.80	N+P		
07/09/80	0.014	0.005	2.80	0.811	0.059	13.75	N+P		
07/16/80	0.005	0.007	0.71	1.131	0.122	9.27	N		
07/23/80	0.014	0.005	2.80	0.502	0.057	8.81	N		
07/30/80	0.007	0.005	1.40	0.599	0.176	4.00	N		
08/06/80	0.018	0.002	9.00	0.419	0.052	8.06	N		
08/13/80	0.006	0.001	5.00	0.314	0.027	11.63	N		
08/20/80	0.002	0.005	0.40	0.304	0.128	2.38			N
08/27/80	0.010	0.005	2.00	1.255	0.173	7.25	N+P		
09/04/80	0.002	0.008	0.25	0.349	0.040	8.73			
09/11/80	0.017	0.007	2.42	1.940	0.255	7.60			
09/18/80	0.013	0.006	2.17	0.671	0.093	7.22			
09/27/80	0.003	0.003	1.00	0.561	0.106	5.29			
10/04/80	0.018	0.002	9.00	0.919	0.157	5.85			
10/09/80									
10/18/80	0.172	0.022	7.82	0.860	0.106	8.11			
10/25/80									
10/31/80	0.154	0.007	22.00	0.177	0.020	8.85			
11/15/80	0.220	0.017	19.94	1.320	0.139	9.47			P
11/29/80	0.212	0.009	23.56	0.212	0.010	21.20			

Table 8-17c. Limiting Factor Analysis for Station 5

Date	Integrated surface data			Hypolimnion Data			Limiting nutrient from bioassays	APA, ug/l	Consensus
	N, mg/l	P, mg/l	N/P	N, mg/l	P, mg/l	N/P			
04/04/79									
04/18/79									
05/03/79	0.042	0.003	14.00	0.065	0.004	16.25			
05/16/79	0.085	0.002	42.50						P
05/30/79	0 174	0.004	43.50						
06/13/79	0.010	0 003	3.33						
06/27/79	0.030	0.003	10.00						
07/05/79	0.017	0.003	5.67						
07/11/79	0.010	0.003	3.33						
07/19/79	0.010	0.002	5.00						
07/25/79	0.016	0.005	3.20	0.430	0.067	6.42			
07/31/79	0.009	0.004	2.25	0.260	0.055	4.73			
08/07/79	0.026	0.008	3.25						
08/14/79	0.050	0.007	7.14	0.402	0.038	10.58			
08/21/79	0.021	0.005	4.20	0 296	0.029	10.21	N		
08/28/79	0.016	0.004	4.00	0.389	0.049	7.94		0.040	
09/05/79	0.006	0.006	1.00	0.320	0.042	7.62	N		N
09/12/79	0.006	0.003	2.00	0.247	0.029	8.52	N	0.110	
09/20/79	0.002	0.002	1.00	0.404	0.043	9.40			
09/26/79	0.002	0.006	0.33	0.328	0.053	6.19	N	0.090	
10/03/79	0.005	0.003	1.67	0.309	0.054	5.72			
10/10/79	0.009	0.006	1.50	0.314	0.038	8.26	N+P	0.020	
10/16/79	0.010	0.003	3.33	0.164	0.033	4.91	N+P		
10/25/79	0.073	0.008	9.13	0.559	0.088	6.35	N+P	0.080	
10/31/79	0.074	0.008	9.25	0.285	0.037	7.70	N+P		
11/14/79	0.041	0.007	7.29	0.416	0.062	6.71	P	0.030	
11/29/79	0.101	0.019	5.32	0.125	0.007	17.86		0.065	
12/19/79	0.134	0.006	22.33	0.141	0.006	23.50		0.013	
01/23/80	0.190	0.011	17.27	0.210	0.008	26.25	N+P	0.009	
02/26/80	0.226	0.005	45.20	0.264	0.012	22.00		0.009	
03/12/79	0.232	0.005	46.40	0.320	0.013	24.62		0.033	
03/26/79	0.275	0.005	55.00	0.472	0.030	15.73		0.025	
04/03/79	0.261	0.004	65.25	0.843	0.079	10.67	P		
04/09/79	0.247	0.008	30.88	0.844	0.090	9.38	P		
04/17/79	0.189	0.004	47.25	0.609	0.060	10.15	N+P	0.039	
04/23/79	0.200	0.008	25.00	0.386	0.019	20.32	N+P	0.032	
04/30/79	0.176	0.003	58.33	0.519	0.040	12.98	P		
05/07/79	0.219	0.009	24.33	0.580	0.059	9.83	P		
05/14/79	0.139	0.005	27.80	0 381	0.020	19.05			
05/21/79	0.105	0.010	10.50	0.549	0.046	11.93	P	0.023	
05/28/79	0.095	0.005	19.00	0.621	0.056	11.09	P		
06/04/79	0.126	0.014	9.00	0.532	0.031	17.16		0.030	
06/11/79	0.003	0.006	0.50	0.386	0.017	22.71	N		
06/20/80	0.020	0.006	3.33	0.517	0.029	17.82	P	0.044	
06/26/80	0.019	0.005	3.80	0.437	0.026	16.81			P
07/03/80	0.017	0.005	3.40	0.869	0.133	6.53	N	0.054	
07/09/80	0.015	0.004	3.75	0.184	0.013	14.15	N	0.082	
07/16/80	0.002	0.006	0.33	0.857	0.066	12.98	N+P		
07/23/80	0.002	0.002	1.00	0.169	0.010	16.90	N+P		
07/30/80	0.004	0.003	1.33	0.434	0.038	11.42	N	0.102	
08/06/80	0.003	0.001	3.00	0.395	0.021	18.81	N+P		
08/13/80	0.003	0.004	0.75	0.335	0.017	19.71	N+P	0.072	
08/20/80	0.003	0.004	0.50	0.304	0.017	17.88			
08/27/80	0.002	0.002	1.00	0.263	0.011	23.91		0.077	
09/04/80	0.002	0.007	0.29	0.310	0.012	25.83	N		
09/11/80	0.019	0.004	4.75	0.308	0.028	11.00		0.073	
09/18/80	0.004	0.007	0.57	0.327	0.025	13.08			
09/27/80	0.016	0.002	8.00	0.219	0.021	10.43			
10/04/80	0.009	0.001	9.00	0.298	0.026	11.46		0.027	
10/09/80	0.002	0.001	2.00	0.311	0.020	15.55			
10/18/80	0.143	0.015	9.53	0.291	0.016	18.19		0.002	
10/25/80	0.113	0.009	12.56	0.595	0.054	11.02			
10/31/80	0.134	0.006	22.33	0.284	0.018	15.78		0.003	
11/15/80	0.200	0.005	40.00	0.698	0.059	11.83		0.001	
11/29/80	0.256	0.008	32.00	0.231	0.008	28.88		0.001	

Table 8-17d. Limiting Factor Analysis for Station 8

Date	Integrated surface data			Hypolimnion Data			Limiting nutrient from bioassays	APA, ug/l	Consensus
	N, mg/l	P, mg/l	N/P	N, mg/l	P, mg/l	N/P			
04/04/79									
04/18/79									
05/03/79	0.131	0.001	131.00						
05/16/79	0.111	0.001	111.00						
05/30/79	0 134	0.001	134.00						
06/13/79	0.019	0 002	9.50						
06/27/79	0.010	0.002	5.00						
07/05/79	0.016	0.002	8.00						
07/11/79	0.012	0.003	4.00						
07/19/79	0.011	0.002	5.50						
07/25/79	0.015	0.001	15.00						
07/31/79	0.011	0.006	1.83				N		
08/07/79	0.017	0.002	8.50	0.232	0.004	58.00			
08/14/79	0.012	0.002	6.00	0.236	0.004	59.00			
08/21/79	0.037	0.003	12.33						
08/28/79	0.016	0.002	8.00					0.060	
09/05/79	0.003	0.003	1.00				N		N
09/12/79							N		
09/20/79	0.002	0.001	2.00						
09/26/79	0.003	0.001	3.00	0.002	0.003	0.67	N	0.170	
10/03/79	0.010	0.003	3.33						
10/10/79	0.012	0.003	1.33				N+P	0.110	
10/16/79	0.012	0.002	6.00	0.302	0.003	100.70	P		
10/25/79	0.041	0.002	20.50	0.253	0.004	63.30	N	1.050	
10/31/79	0.057	0.001	57.00	0.059	0.002	29.50	N		
11/14/79	0.090	0.004	22.50	0.106	0.003	35.30	P	0.026	
11/29/79	0.128	0.004	32.00	0.116	0.006	19.30		0.066	
12/19/79	0.155	0.003	51.67	0.126	0.005	25.20		0.011	
01/23/80	0.193	0.004	48.25	0.200	0.006	33.33	P	0.027	
02/26/80	0.233	0.004	58.25	0.256	0.005	51.20		0.044	
03/12/79	0.232	0.006	38.67	0.252	0.013	19.40	P	0.018	
03/26/79	0.265	0.003	88.33					0.038	
04/03/79	0.235	0.001	235.00	0.231	0.005	46.20	P		
04/09/79	0.244	0.004	61.00	0.263	0.005	52.60	P		
04/17/79	0.244	0.002	122.00	0.231	0.003	77.00		0.277	
04/23/79	0.211	0.002	105.50	0.211	0.005	42.20		0.032	
04/30/79	0.194	0.003	64.67				P		
05/07/79	0.186	0.002	93.00	0.250	0.007	35.70	P	0.061	
05/14/79	0.150	0.003	50.00	0 248	0.005	49.60			P
05/21/79	0.118	0.002	59.00	0.243	0.005	48.60	P		
05/28/79	0.133	0.002	66.00						
06/04/79	0.138	0.002	69.00	0.240	0.005	48.00		0.098	
06/11/79	0.072	0.003	24.00	0.212	0.004	53.00	P		
06/20/80	0.061	0.003	20.33	0.250	0.012	20.80	N+P	0.052	
06/26/80	0.054	0.002	27.00	0.270	0.004	67.50			
07/03/80	0.026	0.001	26.00	0.231	0.004	57.80	P	0.055	
07/09/80	0.015	0.002	7.50	0.266	0.004	66.50	P		
07/16/80	0.009	0.001	9.00	0.256	0.005	51.20	P	0.132	
07/23/80	0.614	0.001	14.00	0.247	0.004	61.80	P		
07/30/80	0.009	0.001	9.00	0.290	0.005	58.00	P	0.092	
08/06/80	0.005	0.002	2.50	0.263	0.004	65.80	P		
08/13/80	0.007	0.002	3.50	0.260	0.002	130.00	P	0.112	
08/20/80	0.002	0.001	2.00	0.263	0.006	43.80			N
08/27/80	0.009	0.001	9.00					0.081	
09/04/80	0.002	0.001	2.00	0.254	0.002	127.00	N+P		
09/11/80	0.015	0.001	15.00	0.304	0.001	304.00		0.087	
09/18/80	0.016	0.001	16.00	0.294	0.008	36.80			
09/27/80	0.013	0.001	13.00	0.246	0.003	82.00			
10/04/80	0.011	0.001	11.00	0.312	0.002	156.00		0.080	
10/09/80	0.002	0.001	2.00	0.294	0.004	73.50			P
10/18/80	0.056	0.001	56.00	0.340	0.001	340.00		0.066	
10/25/80	0.055	0.002	27.50	0.330	0.004	82.50			
10/31/80	0.107	0.001	107.00	0.125	0.001	125.00		0.030	
11/15/80	0.161	0.004	40.25					0.003	
11/29/80	0.217	0.002	108.50					0.001	

Table 8-18, indicated that iron and silica contributed little to chlorophyll variance. This corresponds to the results of the bioassays which showed that iron and silica were not stimulating to the bioassay populations. Accordingly, quantitative relationships for nitrogen and phosphorus concentrations and chlorophyll were pursued.

Table 8-18. 1, 2, 3, and 4—Variable Models for Predicting Chlorophyll

Number in model	r^2	Variables in model
1	0.00	Iron
1	0.02	Diss N
1	0.12	Silica
1	0.62	Diss P
2	0.02	Diss N Iron
2	0.12	Silica Iron
2	0.14	Diss P Iron
2	0.62	Diss P Silica
2	0.62	Diss N Silica
2	0.66	Diss N Diss P
3	0.14	Diss N Silica Iron
3	0.62	Diss P Silica Iron
3	0.64	Diss N Diss P Silica
3	0.64	Diss N Diss P Iron
4	0.66	Diss N Diss P Silica Iron

Note: n=57

Single Correlations and Data Set Refinement--Correlations were developed and analysis of variance examined between total chlorophyll and both dissolved and total forms of nitrogen and phosphorus as tabulated in Table 8-19. As can be seen, ability to predict chlorophyll from nutrient concentrations gradually improved as the data set was refined by selecting progressively shorter time periods.

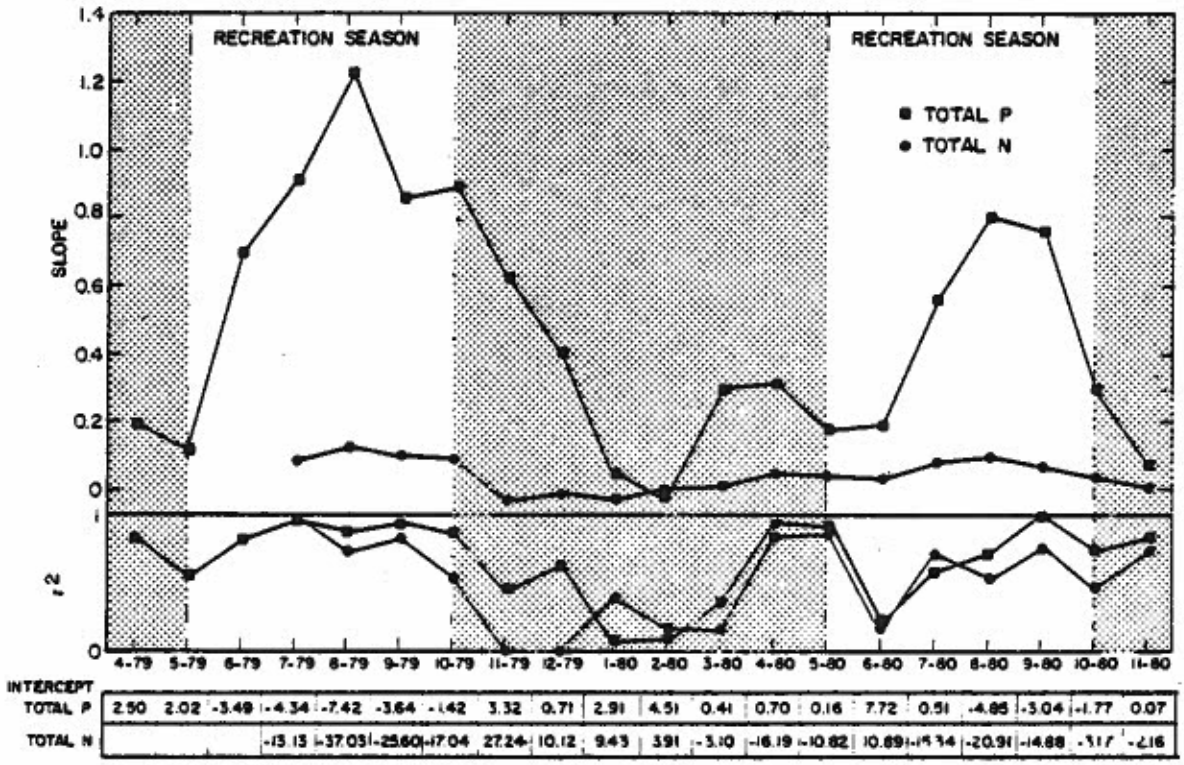
Table 8-19. Chlorophyll-Nutrient Correlations Summary

Analysis description	Results
Total chlorophyll versus nutrients; all data	
3/11/79 and 4/11/80	
Ortho P	r^2 = 0.32
Total P	r^2 = 0.44
Solution inorganic N (NH3 + NO2 + NO3)	r^2 = 0.04
Total N	r^2 = 0.05
Total chlorophyll versus nutrients	
3/79 to 11/7/79	
Ortho P	r^2 = 0.77
Total P	r^2 = 0.77
Inorganic N	r^2 = 0.03
Total N	r^2 = 0.90
4/80 to 10/15/80	
Ortho P	r^2 = 0.29
Total P	r^2 = 0.44
Inorganic N	r^2 = 0.06
Total N	r^2 = 0.34
Correlation of mean monthly total chlorophyll versus mean monthly nutrients	
3/79 to 11/79 and 4/11/80	
Ortho P	r^2 = 0.54
Total P	r^2 = 0.62
Inorganic N	r^2 = 0.20
Total N	r^2 = 0.65
Total chlorophyll versus nutrients for individual monthly data subsets	
3/79 to 11/80	Range of r^2
Ortho P	0.04 - 0.99
Total P	0.04 - 0.95
Inorganic N	0.01 - 0.80
Total N	0.03 - 0.98
Total chlorophyll versus nutrients for N and P limited periods in the growing season	
All data except 12/15/79 to 2/15/80 and 11/10 80	
Ortho P for N/P = 20	r^2 = 0.60
Total P for N/P >20	r^2 = 0.67
Inorganic N for N/P <20	r^2 = 0.05
Total N for N/P <20	r^2 = 0.03
1979 data only (3/79 to 12/15/79)	
Ortho P for N/P $\geq$20	r^2 = 0.78
Total P for N/P $\geq$20	r^2 = 0.82
Inorganic N for N/P <20	r^2 = 0.09
Total N for N/P <20	r^2 = 0.92
1980 data only (2/15/80 to 11/7/80)	
Ortho P for N/P $\geq$20	r^2 = 0.55
Total P for N/P $\geq$20	r^2 = 0.65
Inorganic N for N/P <20	r^2 = 0.05
Total N for N/P <20	r^2 = 0.01

Correlation coefficients tabulated for individual years of data were better than those for the total data set. Also, correlation coefficients were better for individual monthly data subsets than for entire seasonal periods. Dividing the data set according to nitrogen and phosphorus ratios on a month-by-month basis resulted in improved correlations in some months but poorer correlations in other months.

The correlations between monthly subsets of total chlorophyll (TChl) and TN and TP data showed a strong seasonal pattern of regression slopes and r^2 values, as shown on Figure 8-67. Monthly subsets of the data divided into nitrogen limiting (N/P ratio less than 10) and phosphorus limiting (N/P ratio greater than 10) groups showed a similar seasonal pattern of regression slopes and statistical characteristics (Figure 8-68). The slopes of the least squares regression lines indicate the amount of chlorophyll present per unit of TN or TP. For example, a low slope value for TChl-TP indicates relative production of chlorophyll per unit of TP. The intercept is a measure of the residual TN or TP if the TChl was zero, where intercept values are expected to be negative. Physically, the residual TN or TP would be interpreted as a fraction of the TN or TP not readily available for algal growth and chlorophyll production. It is probably a combination of dissolved and particulate organic material. The periods of interest on Figures 8-67 and 8-68 are April to October of 1979 and 1980 encompassing the recreation seasons.

The unsegregated monthly subsets, Figure 8-67, show the greatest seasonal variation in slopes of the TP regressions



	INTERCEPT																	
TOTAL P	2.50	2.02	-3.49	-4.34	-7.42	-3.64	-1.42	3.32	0.71	2.91	4.51	0.41	0.70	0.16	7.72	0.51	-4.85	-3.04	-1.77	0.07
TOTAL N				-13.13	-37.03	-25.60	-17.04	27.24	10.12	9.43	3.91	-3.10	-16.19	-10.82	10.89	-15.34	-20.91	-14.88	-3.17	-2.16

Figure 8-67 Monthly Variation of Total Chlorophyll Versus TN and TP Regression Characteristics, April 1979 to November 1980

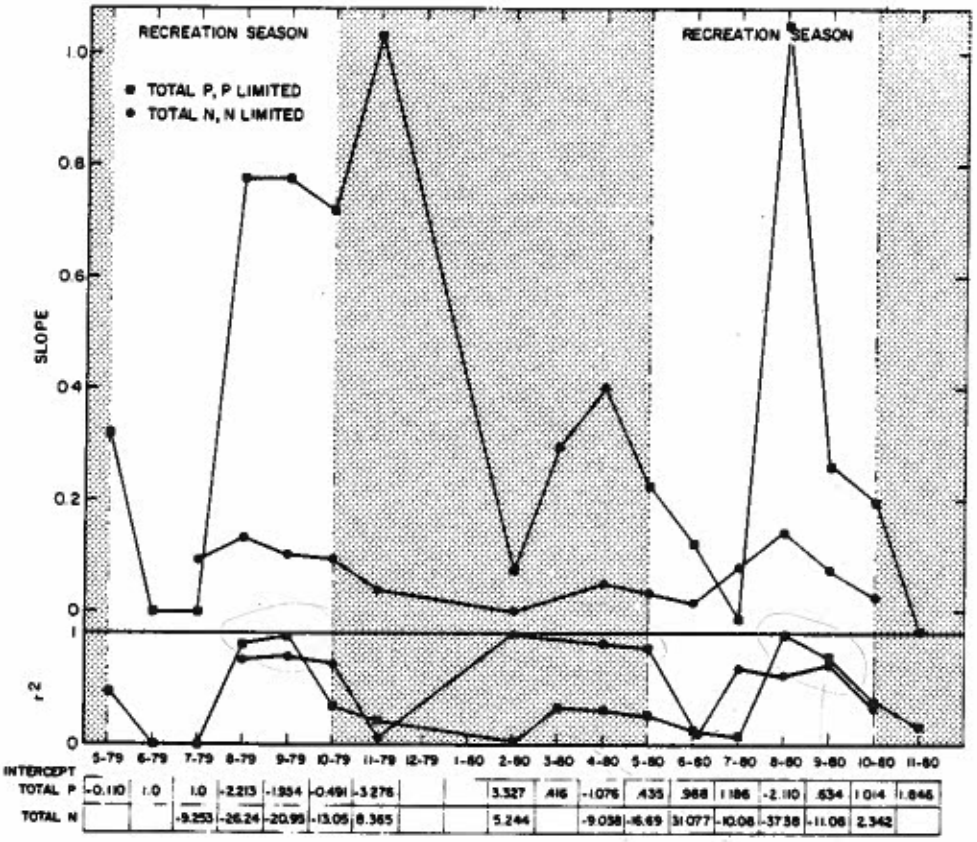


Figure 8-68 Monhtly Variation of N/P Ratio Segregated Total Chlorophyll Versus TN and TP Regression Characteristics, May 1979 to November 1980

ranging from less than 0.2 to greater than 1.2. Slopes were lowest in spring and winter and highest in summer. Intercepts and r^2 values varied over a similar cycle. The months of June and July in 1980 appear to be an exception to the general pattern. The slopes of the TN correlations vary over a similar seasonal cycle ranging from essentially zero in fall to 0.15 in mid-summer. The mixing of nitrogen rich hypolimnetic water in fall had a more dramatic effect on TN correlations than TP correlations. This is evident in the slopes, intercepts, and r^2 values. The June through July 1980 period was an exception to the general pattern for TN also. Overall, with the exception of the June through July 1980 period, TN and TP were highly correlated with TChl during the recreation season. Values of r^2 ranged from 0.6 to 0.95, corresponding to correlation coefficients of 0.77 to 0.97. The variations were consistent with those of the natural biological cycle. Low temperature, light, and deep mixing conditions in late fall to early spring would contribute to low chlorophyll production per unit TN and TP. Favorable light, temperature, and stratification conditions would contribute to efficient chlorophyll production in the summer.

Correlations of the N/P ratio segregated monthly data subsets varied over a seasonal pattern similar to that of the unsegregated monthly data. The major exception to the similarity was poorer correlations in general for TP. This is because of the much smaller number of data points in the phosphorus limiting group, particularly at inner bay stations. As a result, no correlations could be developed for June and July 1979 and for July of 1980. In addition, r^2 and PR>1T1 statistics for the TP correlations for March

to July of 1980 were uniformly poorer than for the same period using unsegregated data set, as shown in Table 8-20. For periods when the r^2 values were comparable between segregated and unsegregated data, the slopes and intercepts differed little between the two data sets (Figures 8-67 and 8-68).

Table 8-20. Statistical Parameters for Nitrogen/Phosphorus Ratio Segregated Monthly Data Subsets Nitrogen-Limited and Phosphorus-Limited Correlations of Chlorophyll with Total Nitrogen and Total Phosphorus

	Total P		Total N	
Month	r^2	PR>1T1	r^2	PR>1T1
05/79	0.58	0.00		
06/79	0.00	0.00		
07/79	0.00	0.00	0.98	0.00
08/79	0.90	0.00	0.76	0.01
09/79	0.99	0.00	0.79	0.00
10/79	0.35	0.03	0.72	0.00
11/79	0.21	0.21	0.07	0.53
12/79	—	—	—	—
01/80	—	—	—	—
02/80	0.04	0.61	1.00	0.00
03/80	0.34	0.00	0.88	
04/80	0.31	0.00	0.91	0.00
05/80	0.27	0.01	0.88	0.00
06/80	0.14	0.13	0.11	0 22
07/80	0.08	0.30	0.71	0.00
08/80	0.99	0.00	0.63	0.00
09/80	0.79	0.00	0.72	0.00
10/80	0.41	0.00	0.33	0.01
11/80	0.18	0.72		

Selecting the Final Data Set--The regression characteristics (slopes and intercepts) and statistics (r^2 and PR>1T1) provide a basis for selecting the final data groupings and quantitative relationships to be used in transparency control calculations. Comparison of regression characteristics for the principal annual data sets, as shown in Table 8-21, and the monthly data subsets (Figures 8-67 and 8-68) reveals several pertinent points. The range of regression slopes for both TN and TP correlations is relatively narrow. For annual data sets, TP regression slopes range from 0.32 to 0.76. Regression slopes for TN range from 0.039 to 0.098, neglecting the two data sets with negligible r^2 values. The slopes for annual data sets were higher with 1979 than 1980, consistent with the exceptional period of low monthly slopes in June and July of 1980.

Table 8-21. Total Chlorophyll versus Total N and Total P Regression Statistics

Correlation	Period	Parameter	Slope	r^2	PR>1T1 for r^2	Intercept	PR>1T1 intercept
Total chlorophyll versus nutrients	3/79 to 11/7/79	Total N Total P	0.098 0.757	0.90 0.77	0.0001 0.0001	-18.42 - 2.39	0.0001 0.047
Total chlorophyll versus nutrients	4/80 to 10/15/80	Total N Total P	0.039 0.322	0.34 0.44	0.0001 0.0001	-1.59 4.36	0.636 0.0193
[Mean monthly] Total chlorophyll versus nutrients	3/79 to 11/79 and 4/11/80	Total N Total P	0.054 0.397	0.65 0.62	0.0001 0.0001	-6.82 2.97	0.040 0.092
N/P limited Total chlorophyll versus nutrients	All except 12/15/80 and	Total N for N/P<20 Total P for N/P>20	0.005 0.695	0.03 0.67	0.0201 0.0001	31.43 - 3.05	0.0001 0.0001
N/P limited Total chlorophyll versus nutrients	1979 only 3/79 to 12/15/79	Total N for N/P<20 Total P for N/P≥20	0.096 0.750	0.92 0.82	0.0001 0.0001	-12.58 - 1.84	0.0002 0.0001
N/P limited Total chlorophyll versus nutrients	1980 only 2/15/80 to 11/7/80	Total N for N/P<20 Total P for N/P≥20	0.003 0.698	0.01 0.65	0.2350 0.0001	32.81 - 3.86	0.0001 0.0001
Total chlorophyll versus nutrients	All data 3/79 to 11/80	Total N Total P	0.007 0.358	0.05 0.44	0.0001 0.0001	15.42 3.158	0.0001 0.0039

Physically, the slopes indicate that between 0.32 and 0.76 ug of chlorophyll were present for every microgram of TP; and between 0.039 and 0.098 ug of chlorophyll were present for every microgram of TN. Statistically, r^2 values ranged from 0.44 to 0.82 for TP correlations, and from 0.34 to 0.92 for TN correlations, excepting the two negligible values. The slope significance, PR>|T| was uniformly high except for the two poor TN correlations. Values of the intercept significance, PR>|T|, also tended to be low where r^2 values were low.

Regression characteristics for the monthly data subsets were similar to those of the annual data sets. The range of slopes was slightly greater for both TN and TP correlations. The regression statistics for recreation season months, except June and July of 1980, were generally slightly better than for the annual data sets. As previously observed, the unsegregated monthly regression statistics were better than those of the N/P ratio segregated subsets.

The unsegregated monthly data subsets offer three advantages over the other data groupings:

1. Their regression statistics were generally superior.
2. They follow an annual pattern consistent with natural physical and biological cycles.
3. They provide an opportunity to match wash load discharge requirements to a seasonal pattern.

Based on these factors, the unsegregated monthly data subsets were re-examined to establish the final chlorophyll-nutrient quantitative relationships. Because of variations in individual months from year to year, probably related to annual variation in seasonal timing, and because of the limited data sets for individual months, development of quantitative relationships on a monthly basis cannot be justified. Accordingly, the recreation season was divided into spring and summer seasonal periods consisting of April to June, and July to September, respectively. Regression equations developed for these data subsets are summarized in Table 8-22.

Table 8-22. Chlorophyll-Nutrient Concentration Final Quantitative Relationships

Nutrient	Time period	Regression equation
TN	Spring months (April to June)	TChl = -12.4 + 0.043 TN
TN	Summer months (July to September)	TChl = -14.1 + 0.08 TN
TP	Spring months (April to June)	TChl = 0.001 + 0.27 TP
TP	Summer months (July to September)	TChl = 0.003 + 0.71 TP

Frequency distributions of TN and TP for the spring and summer periods of 1979 and 1980 are shown on Figure 8-69. Differences between both the levels and variability of TN and TP for the two seasonal periods are evident.

Effects of Winter Loads--Variations in chlorophyll-nutrient correlations over an annual cycle (Figure 8-67) and indeed annual variations in chlorophyll levels alone (Figure 8-11)

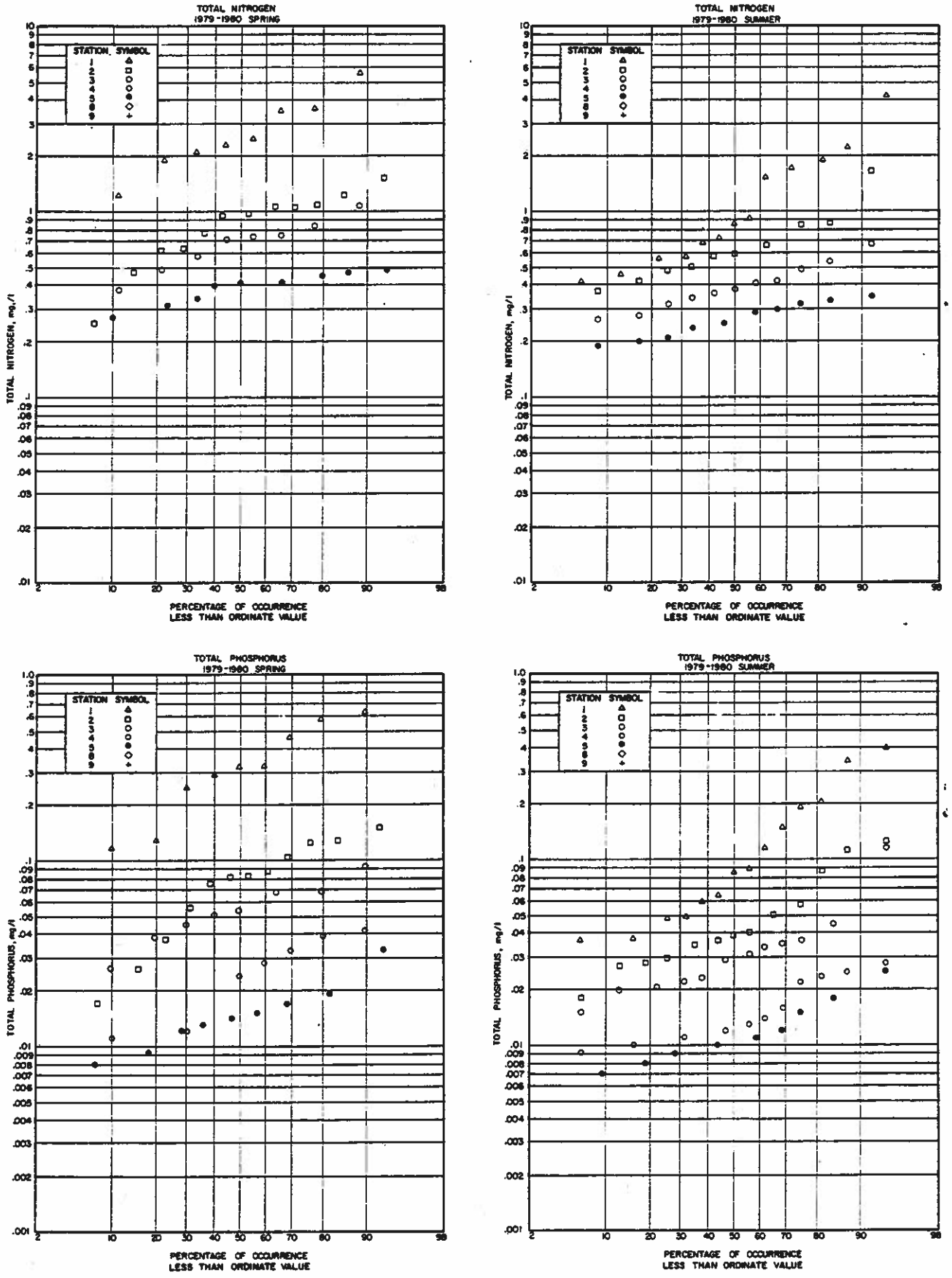


Figure 8-69 Total Nitrogen and Total Phosphorus Frequency Distributions, Springs and Summers of 1979 and 1980

raise the question of the effect of winter nutrient loading on chlorophyll levels during the recreation season. The data presented previously in this chapter provide a basis for assessment of this issue. Winter chlorophyll levels are negligible at all stations (Figure 8-11). Spring chlorophyll was highest at inner bay stations, decreasing continuously with increasing distance from the wash. Also, spring chlorophyll concentrations were proportional to spring concentrations of nitrogen and phosphorus in the lake. Thus, it appears that N and P concentrations during the winter-spring transition are significant to spring bloom chlorophyll levels. However, this does not necessarily imply that the winter-spring N and P levels result from winter N and P loading from the wash.

What factors, then, contribute to winter-spring levels of N and P in the bay and lake? Dissolved nitrogen levels increased significantly at all stations beginning in September-October with cooling surface temperatures and increased mixing (Figure 8-19). Total nitrogen levels increased correspondingly (Figure 8-20). Dissolved phosphorus levels increased slightly at Stations 1 to 6 with fall mixing, with a corresponding increase in total P levels. These fall increases all result from mixing of deeper water with higher nutrient concentrations into the surface layer. Some contributions from the plume are likely, particularly at the inner stations. However, once the surface concentrations of N and P increase in the fall, they remain approximately constant through the short December to February winter period. This is consistent with winter specific conductance data showing the plume isolated on the bottom to a depth of 70 meters or more (Figure 8-5).

Thus, it appears that fall mixing of nutrient-rich water from below the thermocline is the cause of the high winter N and P concentrations. Similarly, it appears that the winter loading of N and P from the wash largely passes through the bay to be dispersed in the deeper waters of the outer bay and Boulder Basin.

Wash Input Distribution. Analysis of wash input distribution is based on material balance and statistical methods described previously.

The simplified material balance (Figure 8-53) and the resulting dilution equation (7), suggest that a straight line relationship exists between wash input concentration and surface concentrations at stations in the bay. The slope of the line should be 1/(D+1) and the intercept should be approximately c_b, the background concentration. This relationship was tested by correlation of input concentrations (Wash Station 5) with bay surface concentrations at Stations 2, 3, and 4. Dilutions were computed from average monthly data for specific conductance, total phosphorus, and total nitrogen. Values of the r^2 statistic from linear regressions ranged from 0.04 to 0.65, as shown in Table 8-23. Lower values were found at the outer stations where physical conditions contribute to greater variability. Scatter diagrams of the data, including the average background concentration, illustrate the relationships found between influent and surface concentrations (Figures 8-70 to 8-72). Based on the correlation results, additional analysis was conducted using the simplified mass balance dilution relationship.

ASSUMES TRANSPORT IS SAME FOR P/L DATA

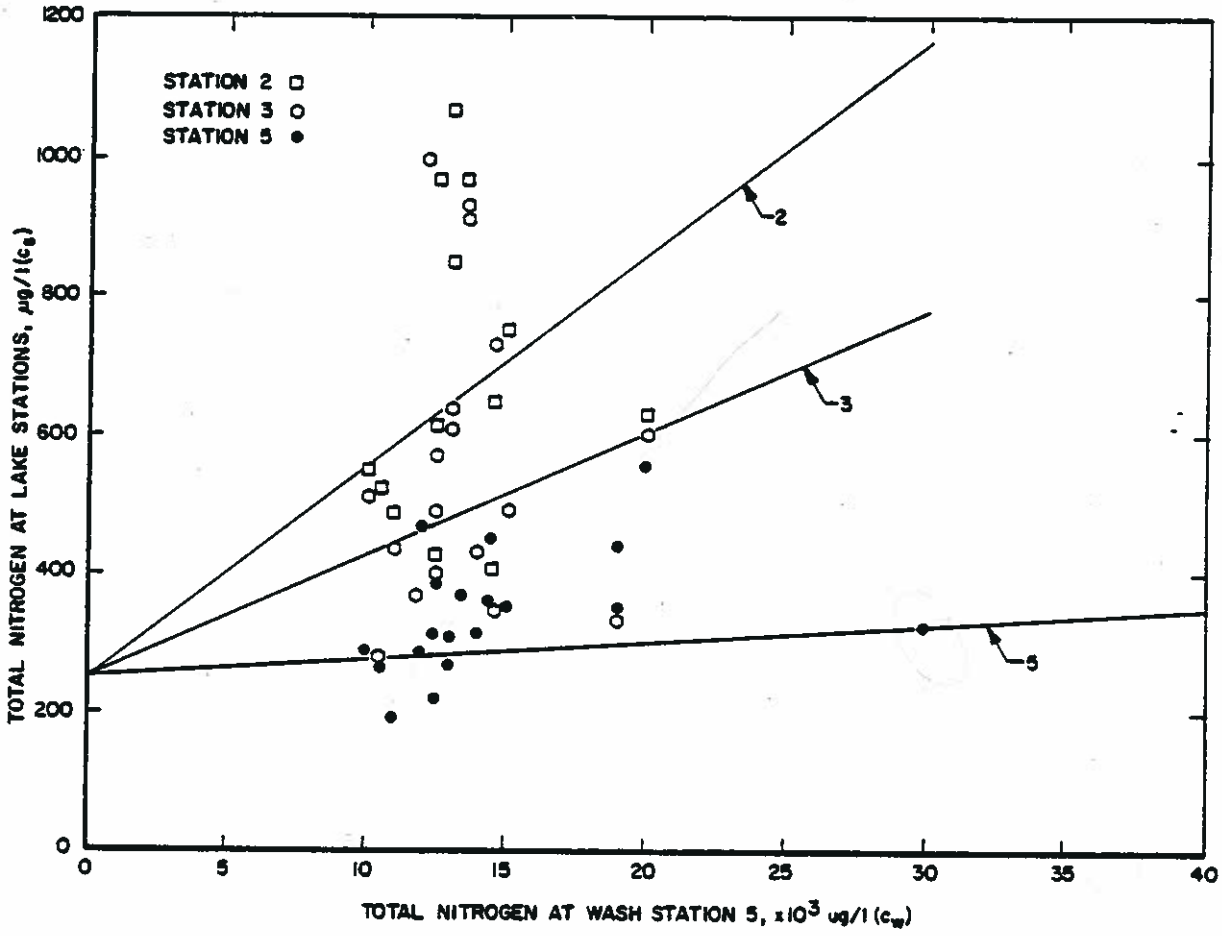


Figure 8-72 Total Nitrogen Surface Concentrations, Stations 2, 3, and 5, Versus Wash Input Concentrations

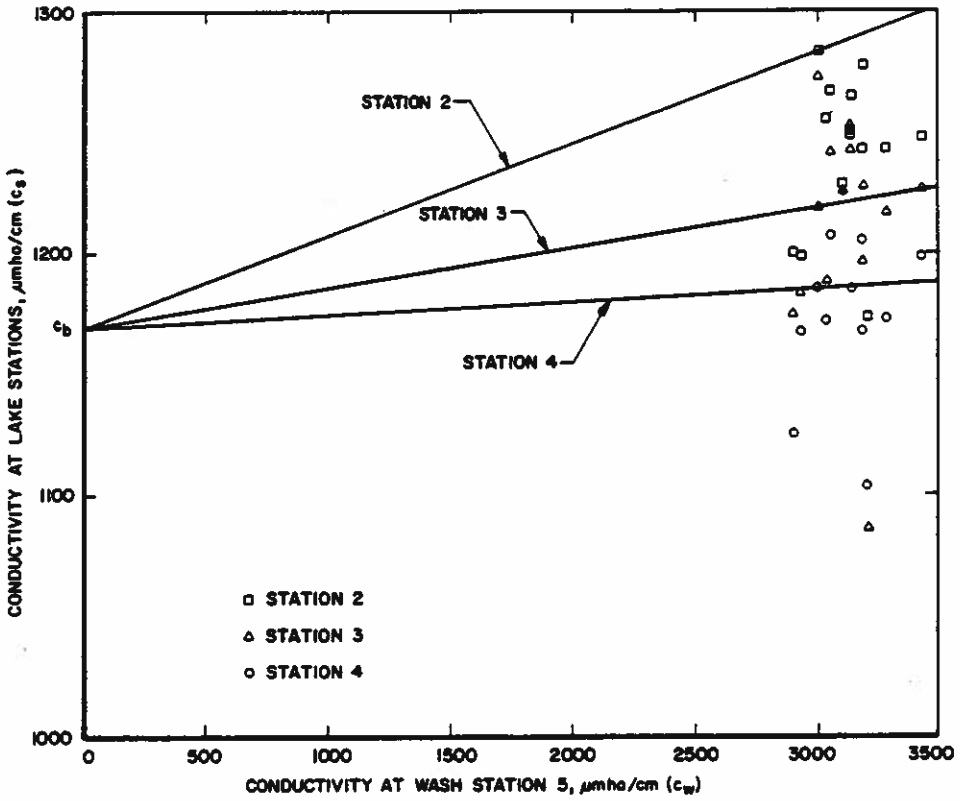


Figure 8-70 Bay Surface Concentrations, Stations 2, 3, and 4, Versus Wash Input Concentrations, Specific Conductance

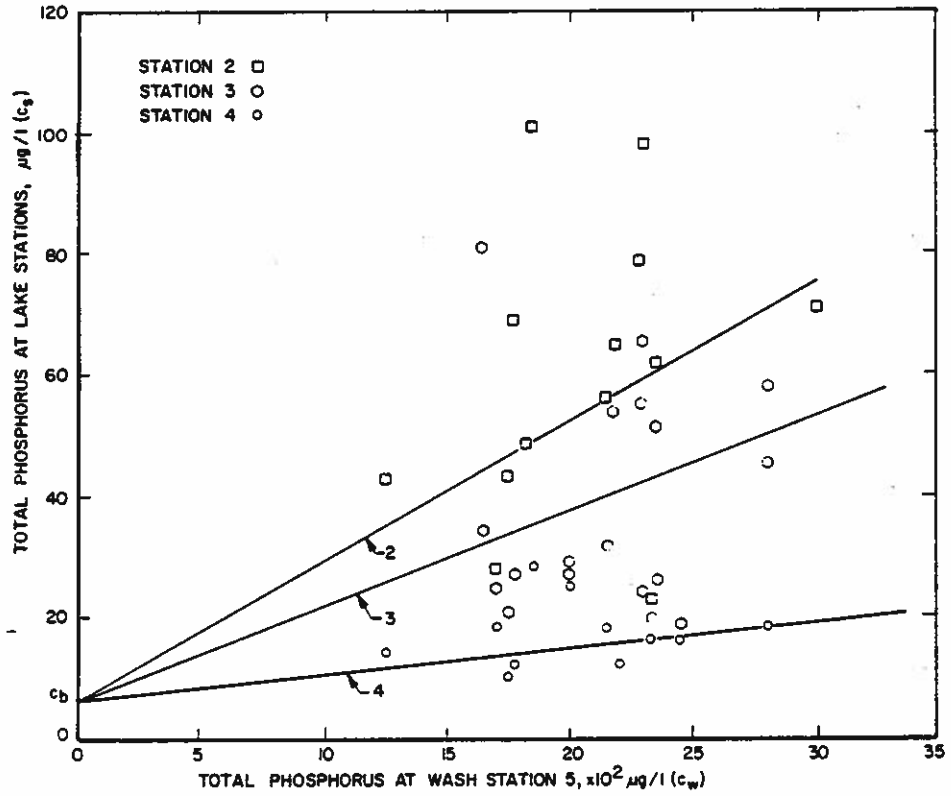


Figure 8-71 Bay Surface Concentrations Versus Wash Input Concentrations, Total Phosphorus

Table 8-23. Wash Input Distribution Correlation Statistics, May to September 1979 and 1980

Station	Specific conductance, r^2	Total P, r^2	Total N, r^2
2	0.65	0.37	0.38
3	0.64	0.30	0.30
4	0.16	0.23	—
5	—	—	0.05

Cumulative frequency distributions of dilutions computed from specific conductance data are summarized on Figure 8-73 for Stations 1 through 5. The means and ranges of dilution values observed at Stations 1 through 5 are summarized on Figure 8-74. The data show a uniformly increasing trend of dilution with increasing distance from the wash. The mean dilution was approximately 13/1 at Station 1, increasing to approximately 30/1 at Station 2, 40/1 at Station 3, nearly 70/1 at Station 4, and greater than 80/1 at Station 5. The large number of observations in the data sets contribute to relatively narrow confidence intervals for calculated dilutions. Mean dilutions at adjacent stations were significantly different at the 90 percent confidence level or better (Student's t test, 2-tailed) except for Stations 4 and 5, as shown in Table 8-24.

Table 8-24. Interstation Confidence Intervals for Geometric Mean Dilutions from Specific Conductance

Stations	n	$\bar{x}$	Confidence interval, percent
1	21	13	
			95
2	22	29	
			90
3	23	42	
			90
4	20	68	
			50
5	22	84	

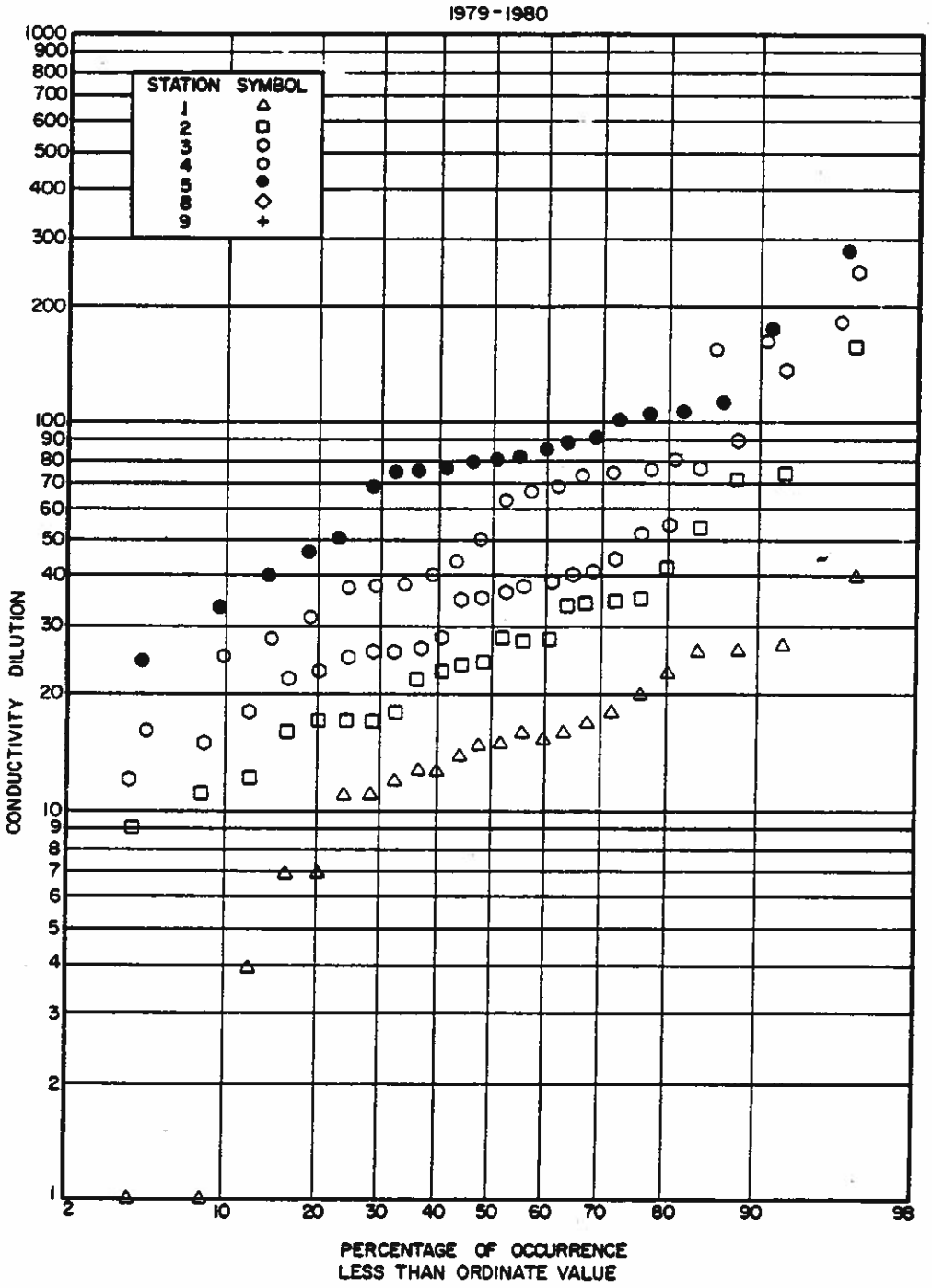


Figure 8-73 Conductivity Dilution Frequency Distribution, 1979 thru 1980

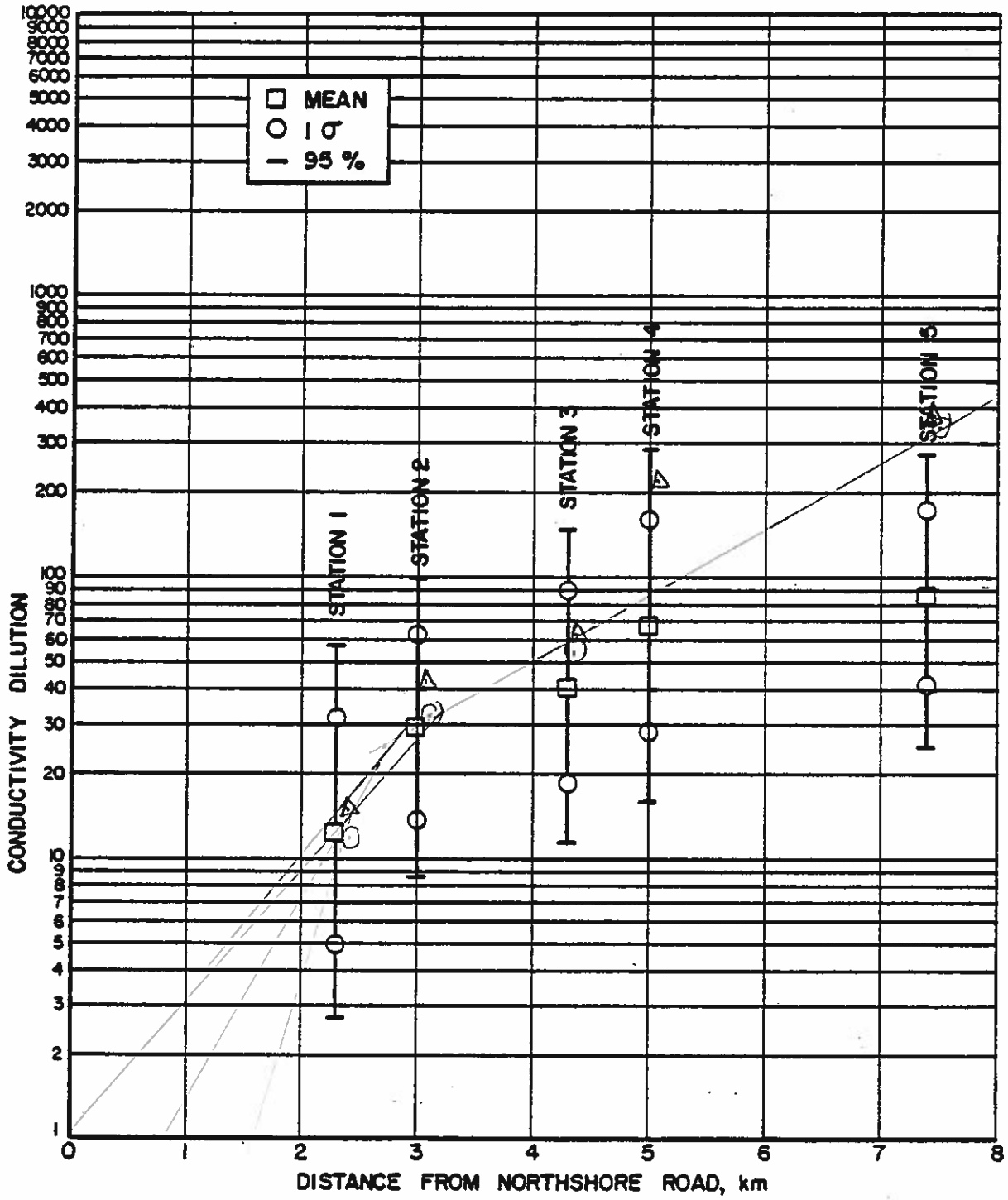


Figure 8-74 Conductivity Dilution Ranges for Las Vegas Bay Stations

Dilutions calculated from the nonconservative nitrogen and phosphorus concentrations are summarized on Figure 8-75. Dilutions calculated from the dissolved species are the highest. Dilutions calculated from total nitrogen and phosphorus were intermediate between those of specific conductance and the dissolved species. Dilutions computed from dye data taken during the hydraulic study are similar to those computed for specific conductance. Statistical characteristics of the frequency distributions for all of the parameters measured are summarized in Table 8-25.

The simplified dilution expression, equation (6), relates the wash nutrient concentration to concentrations at the bay surface at a given station. The expression does not include the wash flow rate. Thus, it cannot be used to predict effects of varying wash flow rate on concentrations in the bay. For purposes of this analysis the wash flow rate is assumed to be constant. This assumption is reasonable in light of the relatively constant wash flow rate observed through the course of the WQSS as described in Chapter 6 and the Hydraulic Study report. Also, wash flow is expected to increase at a rate of 2 to 3 percent per year in the near future as a result of increasing wastewater discharge rates. Flow increases of 10 to 15 percent are not expected to substantially change the plume mixing characteristics and the degree of dilution that occurs. Accordingly, assumption of constant wash flow will be reasonable for at least the next 3 to 5 years. Prediction of effects of wash flow rate can be achieved by use of the plume model in conjunction with additional material balance analysis.

NO FLOW DATA

Transparency Control Calculations. Transparency control calculations were conducted following the approach described previously. The objective is to determine the effect of changing wash input concentrations of N or P on Secchi depth

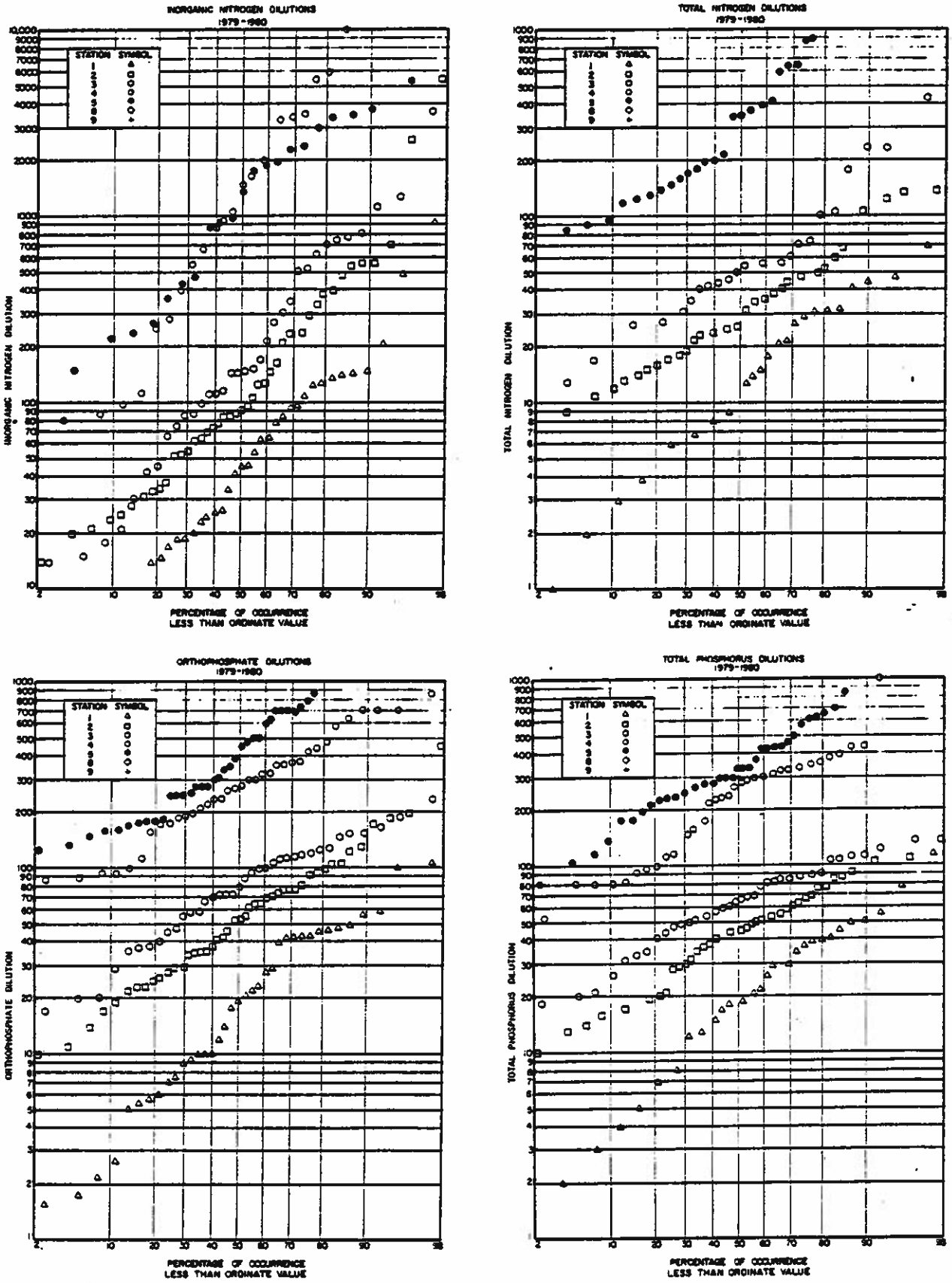


Figure 8-75 Nutrient Dilution Frequency Distributions, 1979 and 1980

Table 8-25. Statistical Characteristics of Frequency Distributions for Dilution Results

Distribution	Statistical parameters	Dilutions							
		Plunge point		WQSS Station 1		WQSS Station 2	WQSS Station 3	WQSS Station 4	WQSS Station 5
		2.1[a]		2.3[a]	2.7[a]	3.0[a]	4.3[a]	5.0[a]	7.0[a]
		Bottom	Surface	Surface	Surface	Surface	Surface	Surface	Surface
April to May dye study	Median	0.53			34	43	43	62	
	Mean	0.52			42	32	47	66	
	()[b]	(0.57)			(65)	(83)	(69)	(87)	
	Standard deviation	1.45			2.13	3.15	2.65	2.27	
	+1 st. dev.	0.75			132	101	125	150	
	−1 st. dev.	0.36			13	10	18	29	
August dye study	Median	0.78	13		25	29	49	77	
	Mean	0.77	14		22	22	53	90	
	()[b]	(1.3)	(21)		(35)	(43)	(64)	(101)	
	Standard deviation	2.74	2.66		2.25	2.40	2.09	2.09	
	+1 st. dev.	2.1	36		50	54	111	188	
	−1 st. dev.	0.28	5		10	9	25	43	
Conductivity	Median			15		25	35	56	80
	Mean			13		29	41	67	84
	()[b]			(23)		(33)	(47)	(82)	(126)
	Standard deviation			2.53		2.10	2.18	2.39	2.03
	+1 st. dev.			32		62	89	160	170
	−1 st. dev.			5		14	19	28	41
Dissolved P	Median			19		53	80	270	420
	Mean			16		55	77	290	489
	()[b]			(36)		(80)	(101)	(356)	(618)
	Standard deviation			3.11		2.49	1.97	2.10	2.41
	+1 st. dev.			51		136	152	609	1,179
	−1 st. dev.			5		22	39	138	203
Total P	Median			19		44	66	272	330
	Mean			17		42	61	230	367
	()[b]			(31)		(55)	(76)	(365)	(438)
	Standard deviation			2.72		1.93	1.70	2.15	2.12
	+1 st. dev.			45		81	104	495	779
	−1 st. dev.			6		22	36	107	173
Inorganic N	Median			45		92	148	1,475	1,350
	Mean			45		131	189	1,313	1,167
	()[b]			(139)		(249)	(477)	(5,543)	(2,607)
	Standard deviation			4.50		4.10	4.62	5.09	3.15
	+1 st. dev.			207		538	873	6,698	3,676
	−1 st. dev.			10		32	41	258	370
Total N	Median			11		28	53		343
	Mean			12		31	55		348
	()[b]			(19)		(37)	(74)		(536)
	Standard deviation			2.82		2.09	2.25		2.57
	+1 st. dev.			33		65	123		894
	−1 st. dev.			4		15	24		135

[a]Distance (km) from Northshore Road

[b]Mean calculated from median ⟷ Mean transformation equation: $M_e = M_d \exp(2.6509\sigma^2_{Log})$

M_d = Median from distribution

M_e = Mean

transparency at any location in the bay. Stations 2, 3, 4, and 5 were included in calculations to cover the range of anticipated Secchi depths. Principal factors included in the control calculations include:

1. Secchi depth dependence on total chlorophyll concentration.
2. Total chlorophyll dependence on nitrogen and phosphorus concentrations.
3. Variability of Secchi depth.
4. The relationship between wash input and bay surface concentrations of nitrogen and phosphorus.
5. Control requirements to force phosphorus limitation.
6. Nutrient budget components and background concentrations of nitrogen and phosphorus.

As described previously, two alternatives were used in dealing with the first two factors, Secchi depth dependence on chlorophyll and chlorophyll dependence on nutrient concentrations. The basic approach is described in the following section using the first alternative, two-step individual correlations for 1/SD versus TChl and TChl versus TN and TP. In the concluding part of this section, the control calculation procedures are compared using the one-step correlations for 1/SD versus TN and 1/SD versus TP.

The Secchi depth dependence on chlorophyll concentration was established for spring and summer periods (Table 8-12).

Chlorophyll dependence on TN and TP concentration was also established for spring and summer periods (Table 8-22). The variability of Secchi depths at Stations 1 to 5 was established for spring and summer conditions on Figure 8-56. The relationship between wash input load at the existing flow rate and bay surface concentrations was established as a directly proportional relationship, equation (6). This resulted in computed dilution distributions for TN and TP (Figure 8-75). Limiting nutrient analysis established that algae in the inner bay were limited principally by nitrogen during spring and summer periods (Table 8-17). Thus, for transparency control by phosphorus reduction to be effective, an initial amount of phosphorus removal would be required to bring about P-limiting conditions. The initial P-removal requirement is established by calculating the amount needed to increase the dissolved N/ortho P ratio in the hypolimnion to 10:1.

Background concentrations of nitrogen and phosphorus are important to consider. Concentrations at Station 8 were assumed to approximate what would exist in the absence of the current wash discharge, or background. The nutrient budget (Table 7-7) established that the Wash accounts for 95 percent of TN and 89 percent of orthophosphorus discharged to the bay. Thus, control calculations were based on the wash as the sole nutrient source.

Application of the transparency control calculation procedure is best described by means of examples. Examples used in this section are presented solely for purposes of illustration. They are in no way intended to suggest judgements, recommendation, or conclusions concerning existing or future water quality. Step-by-step application of the transparency control calculation procedure is illustrated by

the following example: What phosphorus loading to the bay would be permissible to maintain an average Secchi depth of 2 meters at Station 3 during the recreation season? The calculation procedure is divided into segments for three seasonal periods: spring, summer, and winter.

Calculation steps for spring conditions are as follows:

1. The allowable chlorophyll concentration is determined from the spring 1/SD-TChl correlation (Table 8-12) 1/SD = 0.077 + 0.014 TChl. A Secchi depth of 2 meters corresponds to 30.2 ug/l TChl.

2. Using this TChl concentration, the allowable TP concentration in the epilimnion is determined from the spring TChl-TP correlation (Table 8-22) TChl=0.001 + 0.27TP. The TChl of 30.2 ug/l corresponds to 112 ug/l TP.

3. The existing mean spring TP at Station 3 is 54 ug/l (Figure 8-69). Since the concentration corresponding to the desired Secchi depth is higher, the phosphorus load to the bay could increase.

4. To determine how much the TP load could increase within the 112 ug/l limit, first the N/P ratio in the hypolimnion must be checked to determine if phosphorus is limiting (Table 8-26). The ratio is less than 10. Therefore, the N/P ratio of the wash influent would have to be adjusted to at least 10 so that increasing phosphorus loading would affect the Secchi depth.

Assuming that the nitrogen load was allowed to increase more rapidly to produce phosphorus-limiting conditions, an allowable phosphorus increase can be calculated. For the existing mean April to October wash input TP of 1.93 mg/l and the mean background TP at Station 8 of 8 ug/l, the mean TP dilution for Station 3 can be calculated from equation (6):

$$D = \frac{C_w - C_s}{Cs - Cb} = \frac{1930 - 54}{54 - 8} = 41 \qquad (6)$$

5. Using the mean dilution calculated for spring conditions, D=41, the allowable wash TP concentration corresponding to a Station 3 TP concentration of 112 ug/l can be calculated from equation (6).

$$41 = \frac{C_w - 112}{112-8}$$

or $C_w = 4.35$ mg/l

6. For a current wash flow rate of 63 mgd, the total maximum daily load (TMDL) would be 1,050 kg (2,300 pounds) per day.

Table 8-26. Mean Hypolimnetic TN and TP in Spring and Summer Periods, Stations 2 to 5

Period	Station	TN, mg/l	TP, mg/l	N/P
Spring	2	1.67	0.221	7.56
	3	1.62	0.221	7.33
	4[a]	0.924	0.096	9.63
	5[a]	0.554	0.044	12.59
Summer	2	1.41	0.189	7.46
	3	1.52	0.240	6.33
	4	0.623	0.102	6.11
	5	0.374	0.039	9.59

[a] 1980 data only.

Calculation steps for summer conditions are as follows:

1. The allowable chlorophyll concentration is determined from the summer 1/SD-TChl correlation, 1/SD = 0.179 + 0.013 TChl (Table 8-12). A Secchi depth of 2 meters corresponds to 24.7 ug/l.

2. Using this TChl concentration, the allowable TP concentration in the epilimnion is determined from the summer TChl-TP correlation, TChl = 0.003 + 0.71 TP (Table 8-22). The TChl of 24.7 ug/l corresponds to 34.8 ug/l TP.

3. The existing mean summer TP at Station 3 is approximately 38 ug/l (Figure 8-69). The same procedure used for spring conditions would be used to determine the allowable TP load for summer conditions to reach the allowable Station 3 TP concentration of 34.8 ug/l. The allowable summer load would be about 385 kg (850 pounds) per day.

As described previously, no load limitation would be required for the November through March winter period.

To facilitate calculation of transparency control requirements for different conditions, the basic control relationships were converted to graphical form (Figures 8-76 to 8-81). Separate figures were prepared for each limiting nutrient, location, and seasonal period (Table 8-27). Each figure has an abscissa, left and right ordinate scales, plots of the Secchi depth versus limiting nutrient relationship with 70 and 90 percent confidence intervals, and horizontal lines indicating pertinent limiting nutrient levels. The figures were constructed as follows:

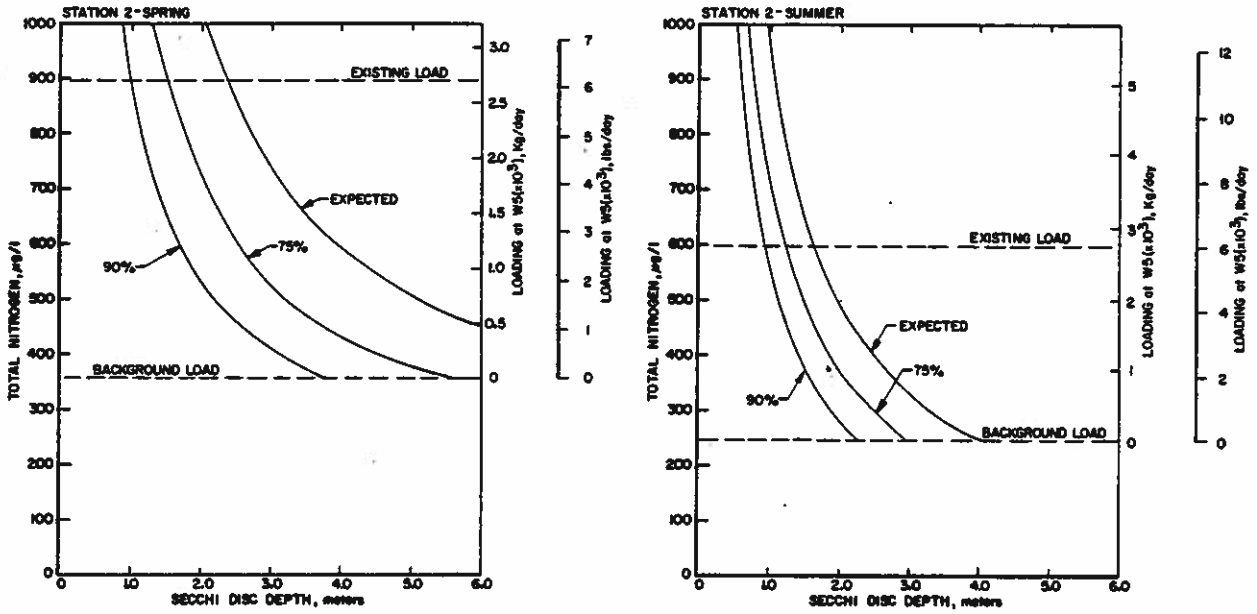


Figure 8-76 Transparency Control for Nitogen Limited Conditions, Station 2

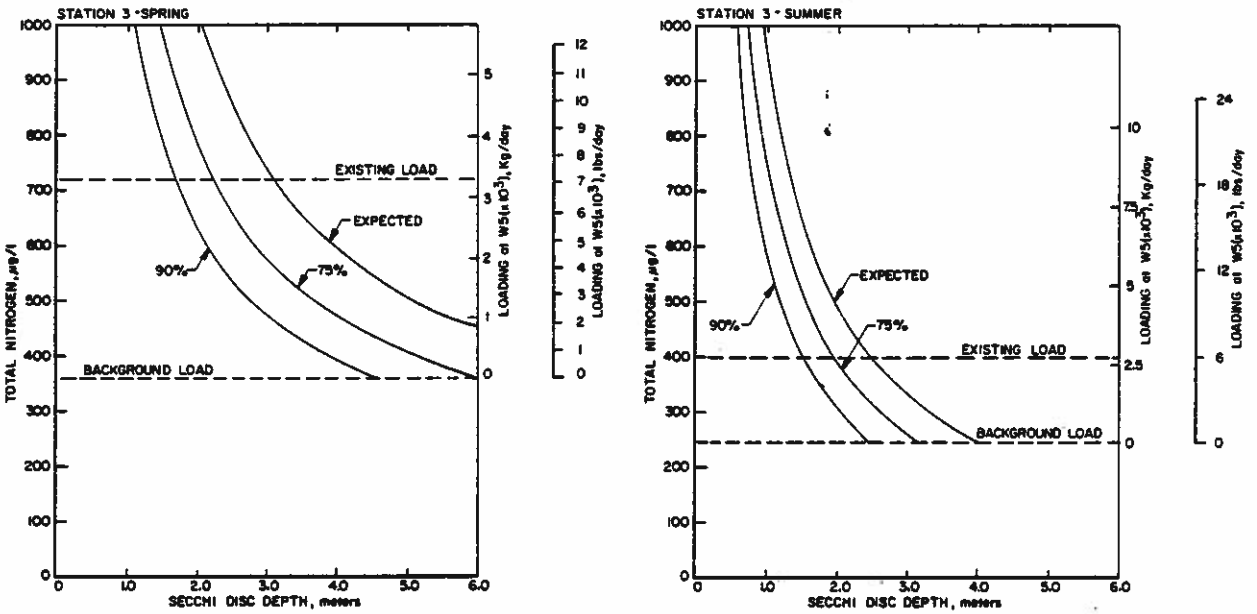


Figure 8-77 Transparency Control for Nitrogen Limited Conditions, Station 3

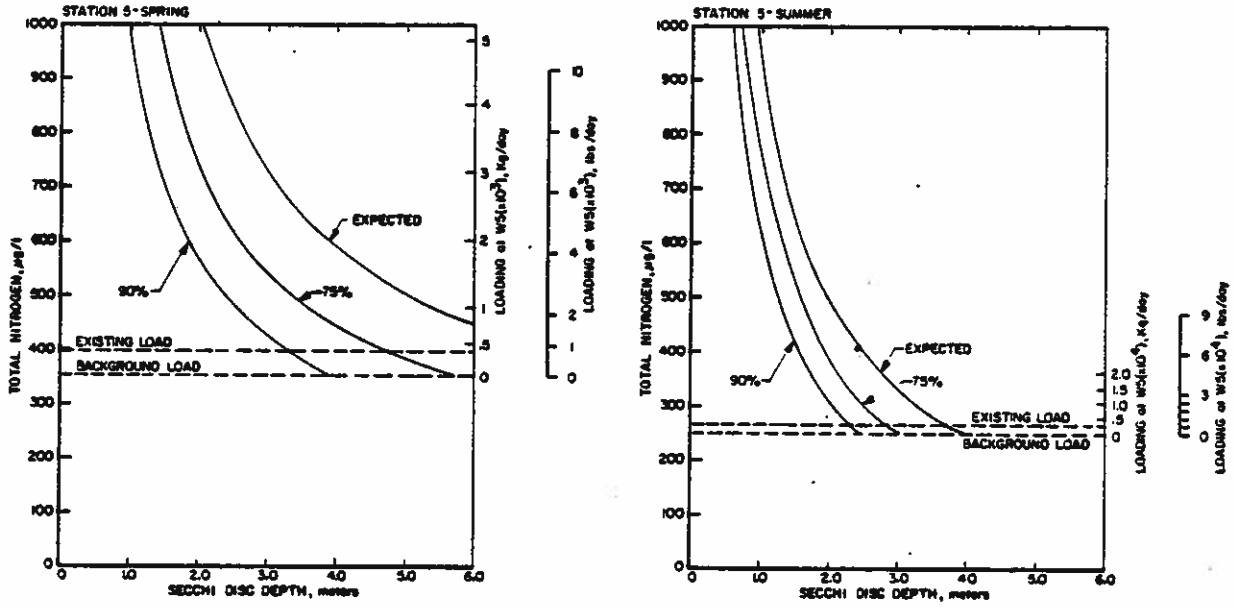


Figure 8-78 Transparency Control for Nitrogen Limited Conditions, Station 5

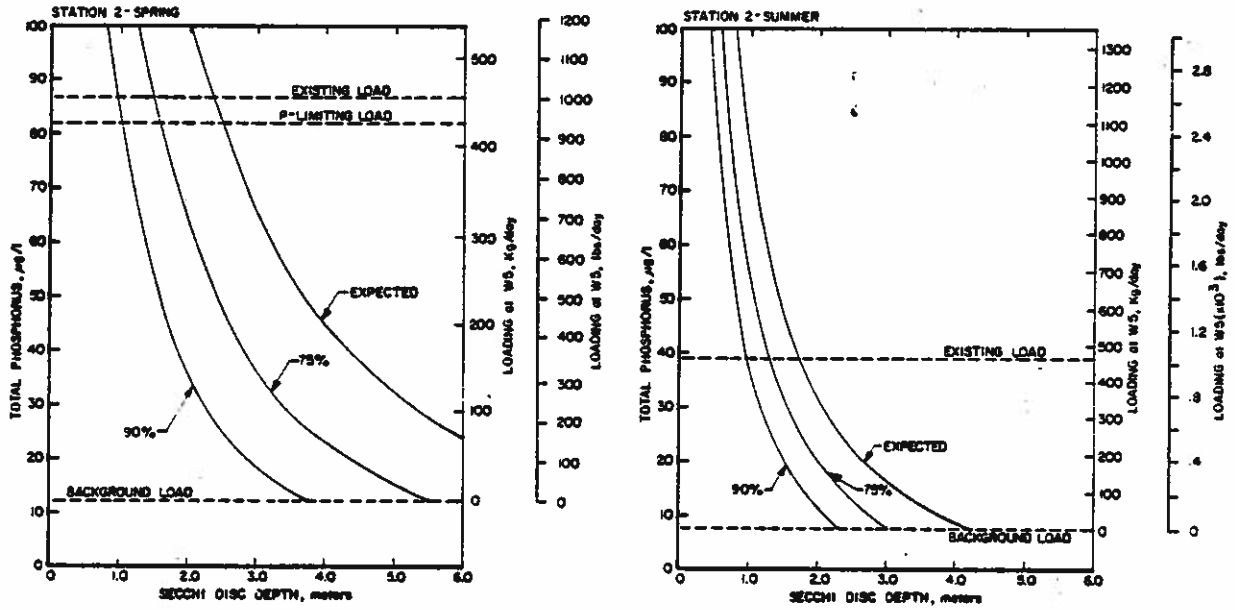


Figure 8-79 Transparency Control for Phosphorus Limited Conditions, Station 2

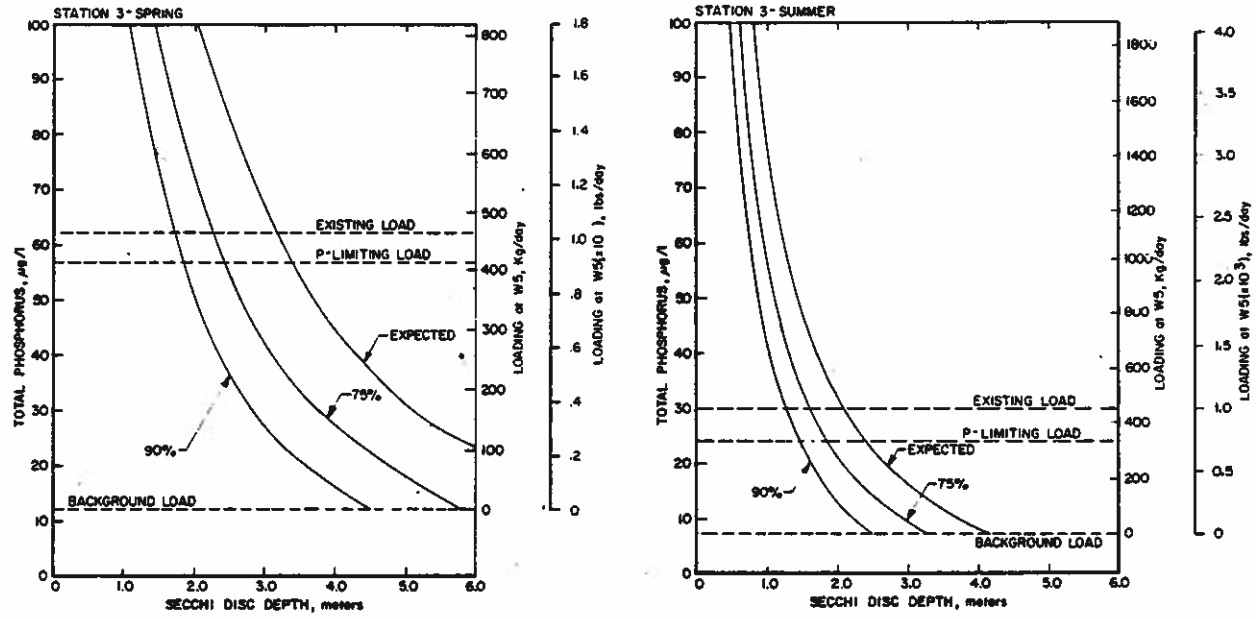


Figure 8-80 Transparency Control for Phosphorus Limited Conditions, Station 3

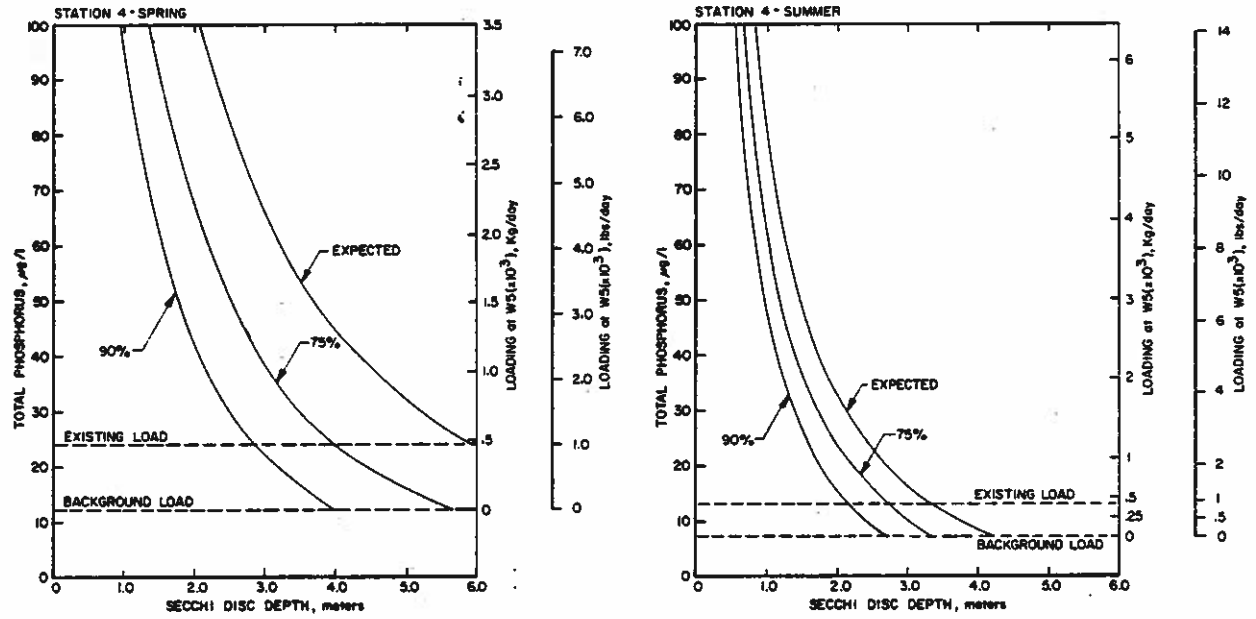


Figure 8-81 Transparency Control for Phosphorus Limited Conditions, Station 4

Table 8-27. Transparency Control Calculation Figure Key

Figure	Limiting nutrient	Station	Season
8-76	N	2	Spring, summer
8-77	N	3	Spring, summer
8-78	N	5	Spring, summer
8-79	P	2	Spring, summer
8-80	P	3	Spring, summer
8-81	P	4	Spring, summer

1. The Secchi depth-limiting nutrient relationship was calculated from the final spring and summer correlations. The curve was plotted using the left ordinate for the limiting nutrient concentration in ug/l and the abscissa for Secchi depth in meters.

2. Recurrence intervals were established from the frequency distributions of observed Secchi depths. For example, for Station 2, TN, spring (Figure 8-76), the 90 percent and 75 percent recurrence intervals were established by the slope of the frequency distribution of Secchi depths for Station 2 from Figure 8-56 (spring). The intervals at existing conditions were read directly from Figure 8-56: for existing spring nutrient loading conditions, the median Secchi depth (50 percentile) was about 2.6 meters; 75 percent of the time, the Secchi depth was about 1.6 meters or greater; 90 percent of the time, the Secchi depth was about 1.1 meters or greater. Intervals for Secchi depths corresponding to other conditions were generated from a series of lines parallel to the Station 2 distribution on Figure 8-56).

3. Horizontal lines indicating existing and background concentrations of the limiting nutrient are added to the figures for convenience.

4. The right ordinate is used to include the wash load of the limiting nutrient at existing flow conditions. The scale was established by matching load = 0 to the background concentration and the mean existing load to the mean existing bay surface concentrations. The load scale established in this manner effectively relates wash concentration to bay surface concentration by direct proportion exactly as the dilution expression, equation (6). In the phosphorus figures, 8-79 to 8-81, construction of the left ordinate scale also included (as required) the initial reduction in P-load required to raise the hypolimnetic (plume) N/P ratio to 10:1.

Application of the figures can be made for a variety of problems. They can be used to estimate nutrient control requirements to achieve or maintain a specified transparency. They can be used to estimate how transparency would be expected to change with nutrient loading. They should be applicable to assessing effects of both higher and lower loading conditions within a reasonable range. Examples of applications are as follows:

Example 1--If it is desired to maintain a Secchi depth of 2 meters at Station 3 on the average by control of phosphorus, what phosphorus loading to the bay would be required?

Load requirements for phosphorus control at Station 3 Secchi depth are found in Figure 8-80.

1. For spring conditions an increase in phosphorus load could occur and the 2-meter transparency limit would be maintained. To maintain phosphorus control, the N/P ratio would have to be raised to 10. Assuming P limiting conditions, a P-load limit of about 910 kg (2,000 pounds) per day would be required.

2. For summer conditions a reduction in load to an average of 400 kg (900 pounds) per day would be required.

Example 2--If existing nitrogen loadings are increased by 13 percent, from 3,200 to 3,600 kg (7,000 to 8,000 pounds) per day, what transparency conditions would result?

Transparency conditions for nitrogen loads and concentrations at Station 3 are found on Figure 8-77.

1. The N/P ratio (Table 8-26) is less than 10, so conditions are nitrogen limiting.

2. For spring conditions, the average Secchi depth would be about 2.8 meters, 75 percent of the time the Secchi depth would be greater than 2.0 meters, and 90 percent of the time the Secchi depth would be greater than 1.5 meters.

3. For summer conditions, the average, 75 percent, and 90 percent Secchi depth levels would be 2.2 meters, 1.7 meters, and 1.3 meters, respectively.

An annual program of nutrient reduction for transparency control can be developed following the procedures illustrated above. Two additional examples are included to further illustrate use of the control figures. Hypothetical situations were used in the examples specifically to include a range of control requirements from stringent to lenient. Example 3 assumes that providing conditions suitable for swimming in the vicinity of the Las Vegas Wash Campground (Station 2) would require a minimum Secchi depth of 1.2 meters. The 90 percent recurrence interval is used to approximate this need. Example 4 assumes that the inner bay, from the wash to Station 2, is considered as a mixing zone. Control would not be applied to that area and beneficial uses such as swimming would be limited. Controls would be applied at Station 3 to maintain conditions desired for all beneficial uses. Accordingly, a 2-meter Secchi depth is assumed for Station 3 with 90 percent of the time. Transparency control by phosphorus control was assumed for both examples.

Example 3--What annual program of wash phosphorus load discharge would be required to maintain a Secchi depth of 1.2 meters at Station 2 90 percent of the time?

1. The N/P ratio is less than 10 for both spring and summer conditions so it must be adjusted to 10 for phosphorus control to be effective. This is accounted for on Figure 8-79.

2. Spring (April to June) conditions (Figure 8-79) would require limitation of TP loading to an average of about 345 kg (760 pounds) per day.

3. Summer (July to September) conditions (Figure 8-79) would require limiting wash discharge of TP to an average of about 300 kg (670 pounds) per day.

Example 4--What annual program of wash phosphorus load discharge would be required to maintain a Secchi depth of 2 meters at Station 3 90 percent of the time?

1. Spring (April to June) conditions (Figure 8-81) would require the average TP load to be limited to approximately 350 kg (770 pounds) per day.

2. Summer (July to September) conditions (Figure 8-81) would require the average TP load to be limited to about 73 kg (160 pounds) per day.

3. Winter (October to March) conditions would require no control as described in Example 1.

Example 5--To illustrate comparison of nitrogen and phosphorus control requirements to meet the same transparency objective, Example 4 is repeated for nitrogen. What annual program of wash nitrogen load discharge would be required to maintain a Secchi depth of 2 meters at Station 3 90 percent of the time?

1. Spring (April to June) conditions (Figure 8-77) would require the average TN load to be limited to approximately 2,400 kg (5,300 pounds) per day.

2. Summer (July to September) conditions (Figure 8-77) would require the average TN load to be limited to less than 1,000 kg (2,200 pounds) per day.

3. Winter conditions would require no control.

Comparison of examples 4 and 5 shows that control of transparency for the specified condition would require about the same percentage reduction in either nitrogen or phosphorus. Accordingly, decisions on control strategy would logically be based on the practicality and economics of nitrogen and phosphorus removal.

Application of Single-Step Correlations--To determine the validity of using single step correlations between 1/SD and TN or TP, r^2 values of single and multiple linear regressions of 1979 and 1980 recreation season data were compared (Table 8-28). Taken individually, TChl, TN, and TP accounted for between 54 and 71 percent of the variance in 1/SD. In multiple correlations of TChl with TN and with TP, the TChl accounted for only an additional 9.4 and 6.6 percent, respectively, of the variance in 1/SD. Thus, use of direct, single-step correlations between 1/SD and TN or TP should result in reasonably comparable estimates to those using the two-step correlations.

Table 8-28. One- and Two-Variable Models for Predicting 1/SD (RECIPSEC), Recreation Seasons 1979 and 1980

'n'	Variables	r^2	Δr^2 due to adding TChl
298	TChl	0.54	
298	TN	0.69	
298	TP	0.71	
298	TN+TChl	0.76	0.065
298	TP+TChl	0.76	0.047

Regression equations following the single-step approach were developed from the data on Secchi depth, total nitrogen, and total phosphorus following a similar process to that used for the two-step correlations. Based on the previous indications of seasonal variation in regression equations, month-by-month regressions were examined for 1/SD versus TN and for 1/SD versus TP (Figure 8-82). Slopes of the regression equations for both TN and TP varied over an apparent annual cycle. However, the differences between spring and summer levels were not distinct as in the previous two-step correlations. In addition, the slopes for 1979 and 1980 data differed significantly. Thus, single regression equations were developed for the May to September recreation season for both TN and TP:

$$1/SD = 0.053 + 0.707\ TN,\ r^2=0.69$$
$$1/SD = 0.167 + 5.42\ TP,\ r^2=0.71$$

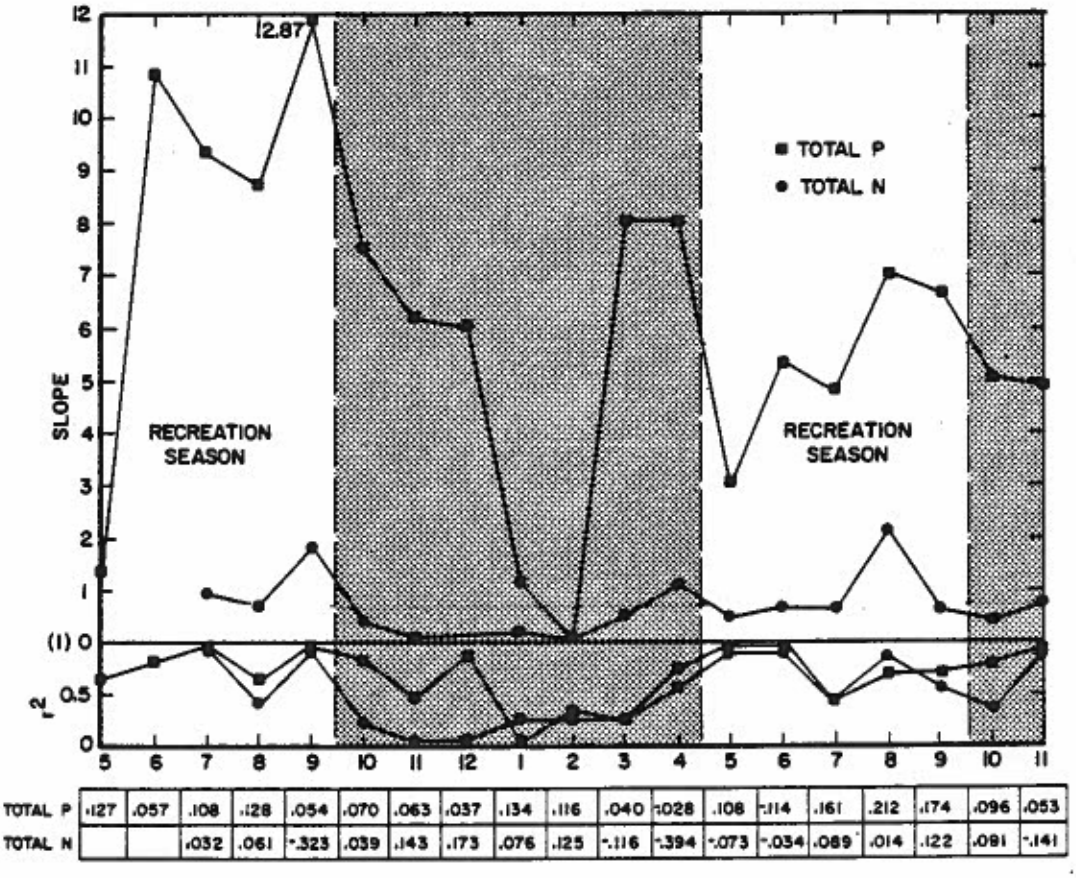
Graphical presentation of the Secchi depth relation to total nitrogen concentrations and wash loads and to total phosphorus concentrations and wash loads were then developed by the same procedures as for Figures 8-76 to 8-81 using the single-step correlations.

Application of the single-step correlations was tested using the examples of the previous section. The difference in percent reductions in nutrient loadings and Secchi depths calculated by similar procedures for Examples 1 to 5 generally differed by approximately 10 to 20 percent (Table 8-29). Large differences between results of the two methods are not expected because of their derivation from the same data following similar procedures. The differences found, for example in Table 8-29, are attributable to two principal sources: (1) the use of data from the entire

Table 8-29. Comparison of Computed Loading and Secchi Depths for Examples 1 to 5 by One- and Two-Step Correlations--Recreation Season Only

Example No.	Two-Step Correlation		One-Step Correlation		Difference between two methods, percent
	Load, lbs/day	Reduction, percent	Load, lbs/day	Reduction, percent	
1	1,300	+27	1,200	+18	9
2	720	-29	900	-12	17
4	460	-55	370	-64	11
5	3,700	-48	1,960	-67	19

Example No.	Two-Step Correlation			One-Step Correlation		
	Secchi depth, meters			Secchi depth, meters		
	50 percent	75 percent	90 percent	50 percent	75 percent	90 percent
2 (spring)	2.8	2.0	1.5	2.7	2.0	1.6
2 (summer)	2.2	1.7	1.3	1.6	1.2	0.9



TOTAL P	.127	.057	.108	.128	.054	.070	.063	.037	.134	.116	.040	-.028	.108	-.114	.161	.212	.174	.096	.053
TOTAL N			.032	.061	-.323	.039	.143	.173	.076	.125	-.116	-.394	-.073	-.034	.089	.014	.122	.091	-.141

Figure 8-82 Monthly Variation of Regression Characteristics for Single-step Correlations Between 1/SD and TN, TP, May 1979 to November 1980

recreation season to develop the single-step correlations as opposed to the spring and summer subsets used to develop the two-step correlations, and (2) the contribution of chlorophyll data to Secchi depth prediction in the two-step correlations not present in the single-step correlations. The two-step correlations are recommended for general use because of the additional refinement provided by including chlorophyll effects and additional seasonal factors.

Other Transparency Control Considerations. The transparency control calculation procedure is designed to take the fullest advantage possible of system characteristics defined in the WQSS. The calculations are completely dependent on the correlation and dilution relationships derived from WQSS observations of Secchi depths, chlorophyll levels and nutrient concentrations. The control calculation procedure as described in the preceeding examples provides a reasonable basis for estimating allowable loads. The procedure is based on existing plume conditions. Significant changes in wash temperature and/or salinity would alter distribution of wash input and would change the dilution of the plume into the surface layer. A series of plume model computer runs were made as part of the Hydraulic Study, Appendix F, to determine the sensitivity of plume depth to changes in wash salinity and temperature. That analysis showed that, for a given change in wash salinity or temperature, the effect on plume depth will vary depending on the time of year and on daily wind and temperature fluctuations. On the average, decreases in salinity of 10 to 20 percent will not substantially change plume depth if plume temperature is unchanged. Plume depth is more sensitive to temperature changes. A 1° to 2°C increase in temperature would substantially raise plume depth particularly in the spring months.

As discussed earlier in this chapter, a significant increase in the wash flow could also alter mixing characteristics and the resulting plume dilution. Flow increases of up to 10 to 20 percent (6 to 13 mgd) are not expected to substantially affect plume dilution. The sensitivity of plume dilution to flow changes could be further assessed by making additional plume computer model runs in conjunction with additional material balance analysis.

Effects of changes in lake level are difficult to predict. Two principal types of effects would be expected. One type would be related to volume changes and differences in dilution that would result at a fixed point in the lake. For example, if the lake level dropped by 8 meters, or about 25 feet, from the level during the WQSS (about 1,200 feet elevation), the water depths at Stations 2 and 3 would be 3 meters and 11 meters, respectively. These correspond to the current water depths at Stations 1 and 2, respectively. Station 1 would no longer be in the lake. The other effect of lake level change is related to differences in bottom characteristics and resulting differences in mixing and plume dispersion. A major change in lake level would move the primary plume dilution area, where the plume flows on the bottom. Differences in bottom slope and roughness would contribute to mixing and dispersion differences. Based on the bathymetric survey of the Hydraulic Study, Appendix F, lake level changes of up to 5 to 7 meters are not likely to cause major differences in dilution characteristics.

The calculation procedure has an additional limitation related to its strictly empirical formulation. The predictive capability of an empirically based method is limited by the data used for its formulation. The applicability of the method to

future conditions depends on the representativeness of data from the period sampled and similarity to future conditions. Certainly, the methods and quantitative relationships can be applied only to the Las Vegas Bay-Lake Mead system.

Thus, the transparency control calculation procedure is applicable for wash and lake conditions expected to occur over the next several years. However, when future wastewater management plans are developed in TFS-II, control calculation procedures will have to be adjusted to reflect long-term forecasts of lake level and wash flow, salinity, and temperature.

EFFECTS ON BENEFICIAL USES

Chapter 4 identified water transparency as a factor affecting more than one beneficial use of Lake Mead. Transparency affects some uses directly and others indirectly. Uses directly dependent on transparency include swimming and aesthetics. Uses affected indirectly by transparency conditions include ones dependent on algal productivity, such as fishing and possibly water supply. This section focuses on transparency as it affects swimming and briefly describes the potential effect that reduced productivity may have on the fishery. Other indirect effects that transparency and associated nutrient loadings may have on water supply and other beneficial uses affected through periphyton growth or dissolved oxygen changes are described in separate chapters covering those subjects.

The objective of this beneficial use discussion are:

1. Review water quality criteria related to transparency.

2. Compare actual conditions measured during WQSS to appropriate criteria.

3. Describe effects of present conditions on beneficial uses, based on the area and time that existing conditions exceed criteria, taking relevant site-specific and seasonal factors into consideration.

Criteria Review

As discussed in Chapter 4, user surveys were not included in the WQSS. During the initial portion of WQSS, consideration was given to including some type of survey to determine the perception of users to a range of transparency levels. However, that approach was not approved. Instead, the beneficial use/criteria assessment consisted of a review of available literature and criteria documents to identify possible quantitative or qualitative criteria for transparency.

Transparency of the recreational waters is important from the point of view of safety as well as aesthetics. Swimmers should be able to see a certain distance below the surface of the water so they can avoid hazardous submerged objects and other swimmers. Clear waters are more appealing to swimmers and divers, thus enhancing the recreational benefits derived from the water.

WHY NOT BUILD APPROVED SWIMMING AREAS.

The literature review conducted by the PMC indicates that there are very few transparency-related criteria that have been developed. Table 8-30 lists several sources which have identified a numerical criterion for Secchi depth. A minimum

Secchi depth of 1.2 meters (4 feet) appears to be the criterion most commonly recommended. Stricter criteria ranging from 2 to 3 meters[11] are required by safety standards where diving is permitted or expected. This factor should be considered because of the rocky shoreline of Las Vegas Bay adjacent to the Las Vegas Wash campground. If swimming is permitted in the area, diving would be likely to occur and low transparency in the area would present substantial injury hazard.

Table 8-30. Secchi Depth Criteria

Source	Secchi depth criterion, meters	Comment
EPA, Proposed Criteria for Water Quality, October 1973[12]	1.2	Minimum for bathing and swimming waters.
Water Quality Criteria: Report of the Nutrient Technical Advisory Committee to the Secretary, April 1968[13]	1.2	Desirable for primary contact waters. In diving areas, clarity shall equal the minimum required for safety standards.
Water Quality Standards for Puerto Rico and the Virgin Islands[14]	1.0	
Commonwealth of Massachusetts, Article VII of the State Sanitary Code[15]	1.2	Minimum allowable transparency at bathing beaches.

The PMC draft Beneficial Use Report included an assessment of the use of chlorophyll as a water quality standard. Available literature was reviewed and a number of state water quality officials were contacted. A concentration of 50 ug/l of chlorophyll was generally cited as the upper acceptable

limit. Based on the Secchi depth/ chlorophyll relationship developed for Lake Mead, a 50 ug/l chlorophyll concentration is approximately equivalent to a Secchi depth of 1.2 meters.

The various references on transparency criteria that have been reviewed and the communications with various state officials and scientists have consistently made one key point. The determination of an appropriate transparency-related standard cannot be made on a completely objective, rigorous basis. Nor can it be established strictly by what has been done for other waterbodies. Some judgement is required and local opinion should play a significant role in establishing such a standard.

Another factor that enters into the establishment of a water quality standard is the application of a numerical criterion. There are two primary issues:

1. The time basis associated with the criterion--Should the standard be based on average occurrence or on a maximum basis such as 90 percent of the time?

2. The portion of the waterbody for which the criterion will apply--Is there some portion of Las Vegas Bay which should not be designated for swimming use?

The time basis is closely associated with the numerical criterion. For example, if a numerical criterion is identified as a minimal acceptable transparency level, it should logically have a high frequency of occurrence associated with it. Also, it is reasonable to restrict application of the standard to the

portion of the year during which the primary beneficial use occurs. In this case, for example, swimming is restricted by seasonal conditions almost exclusively to the period between May and September.

It is common practice in water quality planning, and consistent with Nevada Water Pollution Control Regulations[16] to allow some zone of mixing for discharges from point sources. It is possible to exclude an additional portion of the bay (beyond the mixing zone) if it is determined that achievement of water quality necessary for swimming in this particular area is not attainable. One of the purposes of the work proposed in TFS-II is to address the issue of attainability.

We recommend the following with regard to a water quality criterion for transparency necessary to support swimming in Lake Mead:

1. Secchi depth be used as the basis for the criterion, since it is an all inclusive indicator of transparency registered by the human observer including effects of chlorophyll, color, turbidity, and suspended solids.

2. A Secchi depth of 1.2 meters (4 feet) be adopted as the minimal acceptable transparency level for areas of Lake Mead designated for swimming. The 1.2 meter criterion should be imposed from May 1 through September 30 and should be met 90 percent of the time during that period.

3. The issue of whether Secchi depths greater than 1.2 meters should be required must be decided by

local decision makers and should include consideration of the likelihood of diving in areas of restricted transparency. The work proposed under TFS-II is intended to provide data on costs, energy, and treatment facilities associated with achieving minimum Secchi depths greater than 1.2 meters.

4. A mixing zone, within which the proposed criterion would not apply, should be allowed extending from the point at which Las Vegas Wash enters Las Vegas Bay downstream to WQSS Station 2. This is the most confined shallow portion of the inner bay where the plume is most concentrated. The shallow depth does not permit thermal stratification and the plume flowing along the bottom is most easily mixed into the surface layer in windy or unstable temperature periods. Station 2, at a water depth of about 11 meters, is approximately where the plume separates from the bottom and thermal stratification begins to isolate the plume from the surface layer during the recreation season. This station is also near the inner boundary of the Las Vegas Wash campground; thus, the region of most likely swimming use would be protected. During the recreation season, it is expected that this downstream point would be approximately 700 meters from the point where the wash enters the bay.

5. The question of whether the area of inner Las Vegas Bay not designated for swimming should be extended beyond the mixing zone must be decided by the local decision makers. The work proposed under TFS-II should provide data pertinent to making such a decision.

Comparison of Criteria to Existing Conditions

A transparency control program needs to take into account the seasonal and spatial variations of transparency conditions in Lake Mead, as well as the seasonal and spatial variations of transparency-related uses. Although available use data for Lake Mead have not been spatially divided, some general observations made during the WQSS are included in this discussion.

A comparison of actual WQSS transparency conditions during the swimming season (May through September) to the proposed 1.2-meter Secchi depth criterion is provided on Figure 8-83. The frequency distribution of Secchi depth values indicates that Secchi depth was never less than the 1.2 meters from Station 4 outwards. Transparency at Station 2 averaged approximately 2 meters during the recreation seasons of 1979 and 1980. However, transparency at Station 2 exceeded only about 0.7 meter 94 percent of the time in the 1979 and 1980 recreation seasons. Recurrence intervals from Figure 8-83, expressed in terms of percentage of time that transparencies are greater than levels of 1.2 meters, are summarized in Table 8-31.

Table 8-31. Secchi Depth Recurrence Intervals for 1.2 Meters

Station	Percent of time 1.2 meters or greater
1	31
2	79
3	94
4	98
5	>98
8	>98

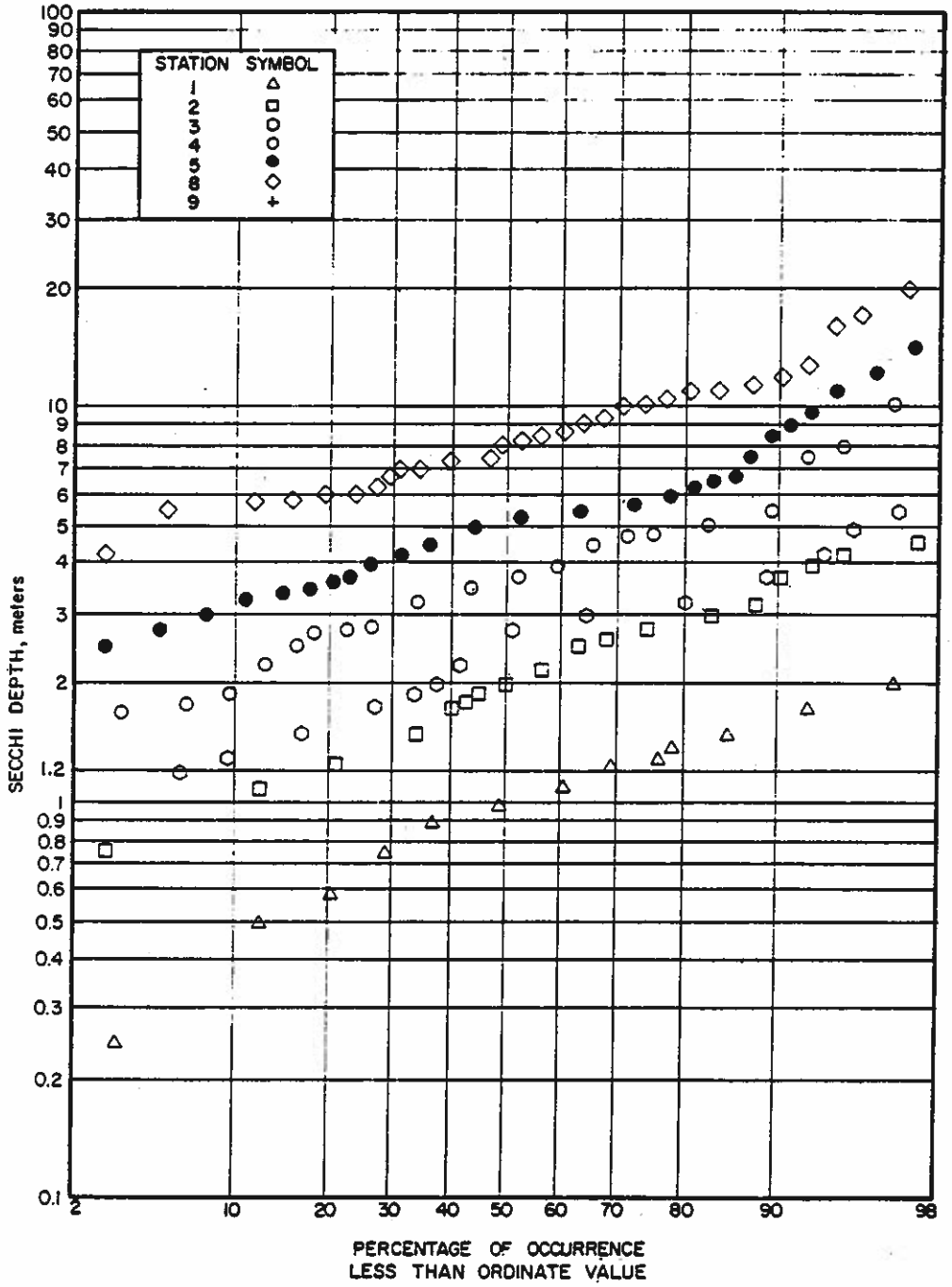
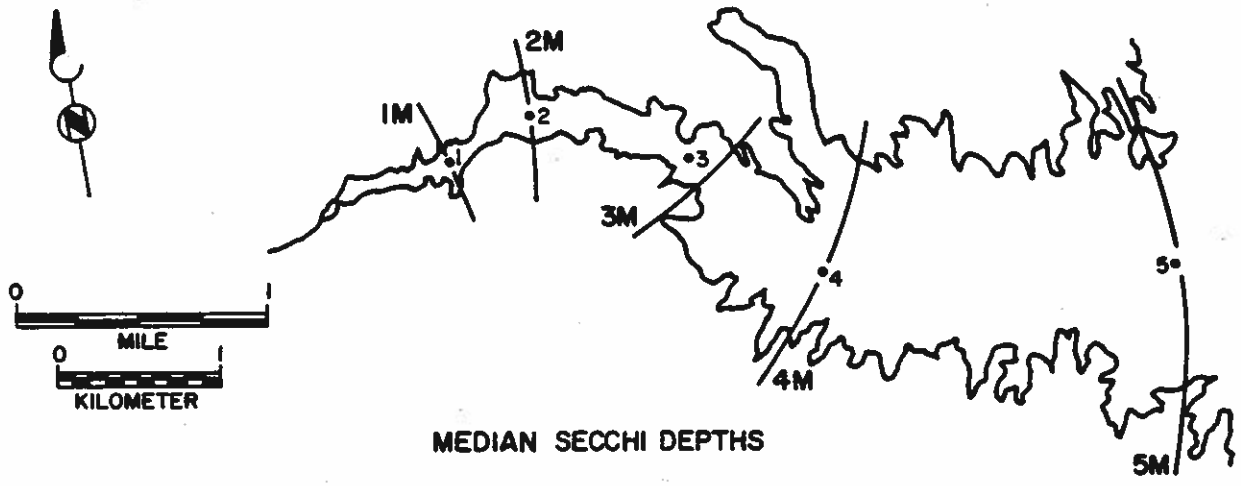


Figure 8-83 Secchi Depth Frequency Distribution, 1979 and 1980

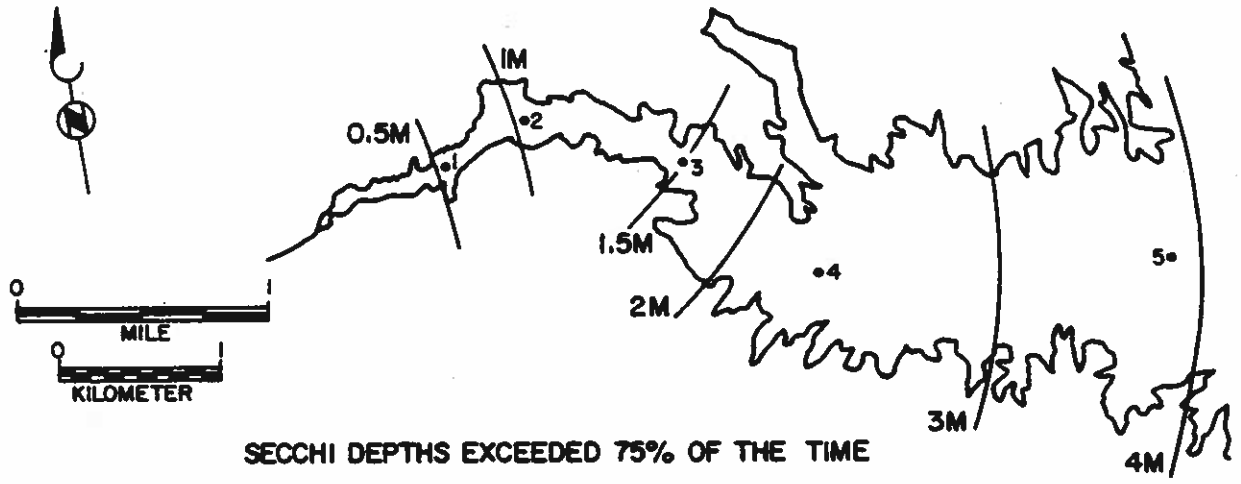
Secchi depth results for the recreation season are displayed graphically on Figure 8-84 for recurrence intervals of 50, 75, and 90 percent. From these maps, it is apparent that the area of Las Vegas Bay having Secchi depths less than the 1.2 meters is confined to inner Las Vegas Bay. Outwards of the Las Vegas Wash Marina, Secchi depths are well in excess of 2 meters on the average.

Effects on Swimming and Aesthetics

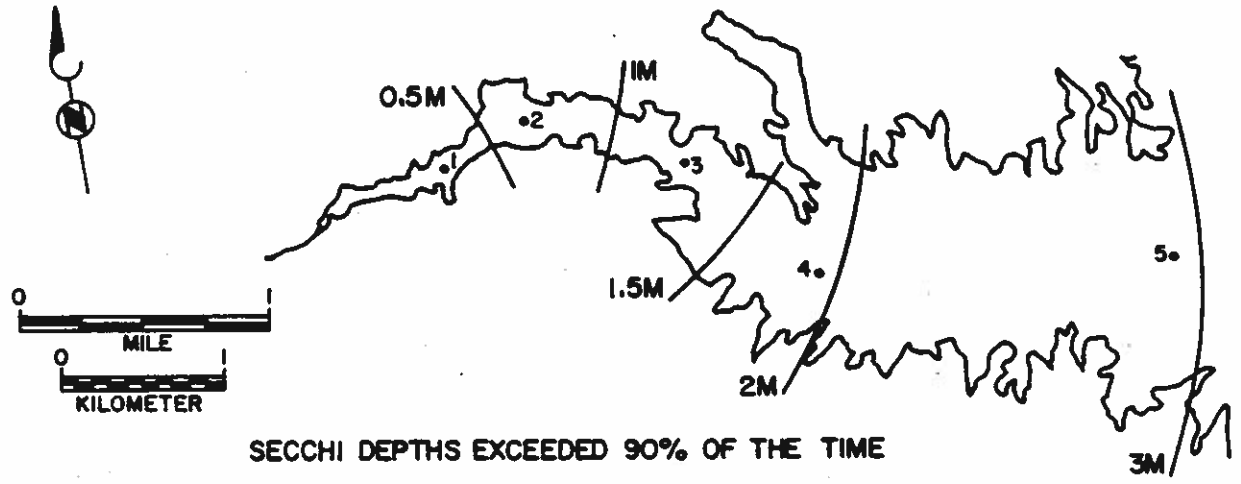
Inner Las Vegas Bay represents a relatively small portion of the area of Las Vegas Bay (11 percent) and a very small portion of the total area of Lake Mead (less than 1 percent). However, the distribution of water transparency in the inner bay region from the confluence with Las Vegas Wash to Station 5 is important because of the relatively intense use of this portion of the bay for purposes affected by transparency. The location of the U.S. National Park Service campground along the southern shoreline from Stations 1 to 3, and the location of Las Vegas Wash Marina between Stations 3 and 4 contribute heavily to these uses. Swimming and fishing along the shoreline from Stations 1 to 3 were commonly observed during the WQSS. As identified in Chapter 4, the Las Vegas Wash Marina receives the most intensive use of any location in the Boulder Basin area. Recreational activities in Las Vegas Bay and the lower basin of Lake Mead commonly begin and end at Las Vegas Marina, and a significant amount of local activity occurs in the marina itself. Visual observations of water quality in the inner portion of the system correspond well with the distribution of Secchi depths shown on Figure 8-83. Water in the vicinity of Las Vegas Wash Marina and inward toward Stations 1, 2, and 3 commonly had a green turbid appearance as opposed to a clearer blue appearance of



MEDIAN SECCHI DEPTHS



SECCHI DEPTHS EXCEEDED 75% OF THE TIME



SECCHI DEPTHS EXCEEDED 90% OF THE TIME

Figure 8-84 Secchi Depth, Meters, Through Inner Las Vegas Bay

water outward toward Station 5. Swimming and diving for sample collection associated with the WQSS at locations inward of Station 3 were difficult because of reduced transparency. The relatively steep and rocky character of the shoreline adjacent to the campground with numerous submerged obstacles combined with the restricted transparency present significant hazards to swimmers and divers attracted to the water from the campground by its proximity and the desert heat.

Effects on Fishing

While limited transparency in inner Las Vegas Bay may adversely affect swimming and aesthetics, it may benefit fishing. Algal growth resulting in the reduced transparency is the foundation of the food chain on which the fish population exists. In general, the higher the productivity of algae at the bottom of the food chain, the greater the fish population that can be supported. Very little is known about the quantitative relationship between algal and fish productivity in Lake Mead. Studies are presently being conducted by the Nevada Department of Wildlife and UNLV's Lake Mead Limnological Research Center which may, in the future, provide a basis for predicting the relationship between algal and fish productivity. At the present time, only some general comments can be made.

As described in Chapter 7, the nutrient budget of Las Vegas Bay depends heavily on the loadings of both nitrogen and phosphorus from the wash. Nitrogen loading from the wash contributes less significantly to the overall budget for Boulder Basin because of the high nitrogen concentrations in the Colorado River inflow. Phosphorus loading to the bay and Boulder Basin is, however, a major factor in the overall

Boulder Basin budget. Effects of nitrogen and phosphorus loadings from the wash on the overall Colorado River budget have a corresponding effect on the nutrient budget of Lake Mojave downstream of Hoover Dam.

Reductions in nitrogen or phosphorus loading to Las Vegas Bay, Boulder Basin, and downstream reservoirs, may be expected to have different effects on the fisheries in those locations. Nitrogen and phosphorus loading to Las Vegas Bay have been shown in this chapter to be quantitatively related to the level of phytoplankton population. Reductions in algal productivity resulting from a nutrient load reduction would be expected to have a proportionate effect on reduction in fish productivity.

Chlorophyll levels in Boulder Basin, in comparison to chlorophyll levels in Bonelli Bay and Virgin Basin, appear to be affected by nutrient loading from Las Vegas Wash. The higher algal productivity in Boulder Basin appears to be phosphorus-limited and only slightly higher than that of Virgin Basin. Accordingly, reductions in phosphorus loading to Boulder Basin from Las Vegas Bay would be expected to reduce algal productivity by a small but proportionate amount. A corresponding decrease in fish productivity would be expected, but of a magnitude proportional to the difference in productivity between Boulder Basin and Virgin Basin. This difference is currently small.

Reductions in nutrient loading from Las Vegas Wash to Lake Mead may be expected to have a proportionately greater effect on fish productivity in downstream reservoirs than on fish productivity in either Las Vegas Bay or Boulder Basin. This is

because only a small fraction of the total nutrients entering Las Vegas Bay from the wash contribute to algal productivity in the surface layer of the bay. As described previously, the plume and the thermocline segregate a majority of the influent nutrients distributing in the deeper water of the outer bay and Boulder Basin. However, the total effect of nutrient reduction would be propagated to downstream portions of the system.

Although increasing algal productivity may beneficially affect the fishery by increasing fish food, excessive levels of algal productivity can contribute to conditions unsuitable for fish propagation and for fishing. Algal productivity in the inner portion of Las Vegas Bay appears to contribute significantly to dissolved oxygen depletion through microbial respiration as described in Chapter 9.

CONCLUSIONS

The analysis presented in this chapter provides the basis for certain conclusions on the issue of transparency, algae, and nutrients. The conclusions are grouped into the four key areas of the analysis: (1) transparency dependence, (2) algae dependence, (3) transparency control procedures, and (4) beneficial uses and water quality criteria.

Transparency Dependence

1. The chlorophyll concentration is the most significant water quality factor affecting transparency in Las Vegas Bay. Other water quality parameters contribute only marginally to controlling transparency.
2. Quantitative relationships between 1/SD and total chlorophyll in Las Vegas Bay vary seasonally and are

best described by dividing the WQSS data into two groupings, spring (April to June) and summer (July to September):

a. April to June, 1/SD = 0.077 + 0.014 TChl
b. July to September, 1/SD = 0.179 + 0.013 TChl

3. Transparency varies significantly depending on location in the bay, decreasing with increasing proximity to the wash. But, the seasonal quantitative relationships describe the relationship between transparency and chlorophyll levels at all locations for that period of the year.

4. Transparency in Las Vegas Bay during the recreation season is controlled by the discharge of nutrients from the wash during that period. Winter discharge of nutrients appears to have little effect on transparency during the recreation season.

Algae Dependence

1. Algal chlorophyll concentrations in Las Vegas Bay are controlled by either nitrogen or phosphorus availability depending on location in the bay and season.

2. Quantitative relationships between total chlorophyll and total nitrogen or total phosphorus in Las Vegas Bay are best described by dividing the WQSS data into two groupings, spring (April to June) and summer (July to September):

a. April to June, TChl = -12.4 + 0.042 TN
b. July to September, TChl = -14.1 + 0.08 TN
c. April to June, TChl = 0.001 + 0.27 TP
d. July to September, TChl = 0.003 + 0.71 TP

3. Chlorophyll levels vary significantly depending on location in the bay. But, the seasonal quantitative relationships describe the relationship between chlorophyll and nutrient levels at all locations for that period of the year.

Transparency Control Procedures

1. Transparency of inner Las Vegas Bay is expected to increase in proportion to reduction in nitrogen loading from Las Vegas Wash if the dissolved N/P ratio of the wash entering the bay is less than 10 according to:

   a. The quantitative relationship between Secchi depth and total chlorophyll for the appropriate time of the recreation season.

   b. The quantitative relation between total chlorophyll and total nitrogen for the appropriate time of the recreation season.

   c. The reduction in the total nitrogen level in the epilimnion based on dilution levels between the wash and the bay as limited by background nitrogen levels in the bay.

2. Transparency of inner Las Vegas Bay is expected to increase in proportion to reduction in phosphorus loading from Las Vegas Wash if the dissolved N/P ratio of the wash entering the bay is greater than 10 according to:

   a. The quantitative relationship between transparency and total chlorophyll for the appropriate time of the recreation season.

   b. The amount of phosphorus limitation required to make phosphorus limiting, i.e., N/P = 10.

   c. The quantitative relationship between total chlorophyll and total phosphorus for the appropriate time of the recreation season.

   d. The reduction in the total phosphorus level in the epilimnion based on dilution levels between the wash and the bay.

Beneficial Uses and Water Quality Criteria

1. Secchi depth should be used as the basis for transparency measurement and for water quality criteria in the bay.

2. A minimum Secchi depth of 1.2 meters should be maintained in all areas of Lake Mead designated for swimming. This criteria should be met 90 percent of the time from May 1 through September 30.

3. The issue of whether Secchi depths greater than 1.2 meters should be required in any areas of the lake must be resolved by local decision makers and should include consideration of the liklihood of diving in areas of restricted transparency.

4. A mixing zone, within which the proposed criteria would not apply, should be allowed extending from the mouth of Las Vegas Wash downstream to WQSS Station 2.

5. For nitrogen and phosphorus loading conditions during the 1979 and 1980 recreation seasons, Secchi depths inwards of WQSS Station 3 did not meet the proposed criterion, i.e. Secchi depths were less than 1.2 meters more than 10 percent of the time.

6. Improved transparency would have beneficial effects on swimming, aesthetic, and fishing uses in the inner bay; but nutrient reductions to improve transparency may have some adverse effects on the fishery, particularly downstream of Lake Mead, due to reduced algal productivity.

CHAPTER 9

DISSOLVED OXYGEN ANALYSIS

Oxygen concentrations in the metalimnion of Lake Mead are reduced to less than 5 mg/l during the summer months. The factors responsible for this reduction and the impact of the low oxygen concentrations on beneficial uses are discussed in this chapter.

INTRODUCTION

The metalimnion is the area of the lake that has a steep thermal gradient. Metalimnetic oxygen depletion was described by Shapiro in his study of Lake Washington.[1] Metalimnetic oxygen depletion has been reported for several other lakes, but it is not a common condition. A number of mechanisms have been proposed to explain this phenomenon. Since waters of the metalimnion are denser than the surface waters (epilimnion), organic materials pass more slowly through this layer than through the epilimnion, increasing time available for decomposition. Metabolic rates are slower in the colder bottom waters of the hypolimnion. In some cases, large populations of zooplankton and phytoplankton are found in the metalimnion and their respiration will deplete oxygen. Low oxygen concentrations in the metalimnion occur throughout Lake Mead; however, the concentrations are lowest in Las Vegas Bay.

Dissolved oxygen (DO) concentrations were routinely measured throughout the water column during the limnological monitoring program. A special dissolved oxygen study was conducted in September 1980 to determine the cause of the oxygen depletion in Las Vegas Bay, and to attempt to determine the impact of the Las Vegas Wash load on the DO depletion.

Background

The metalimnetic depletion of DO was first reported in 1944 and has probably occurred since Lake Mead was formed in 1935.[2] The U.S. Bureau of Reclamation (USBR) conducted a study in the spring of 1964 and concluded that there were no problems with DO depletion in Lake Mead.[3] Since the DO depletion does not typically begin until the thermocline is established in June, the USBR missed the period of DO depletion. Hoffman et al., found a negative heterograde DO profile throughout the lake during the period of thermal stratification in 1965 and 1966.[4] DO measurements were taken in Las Vegas Bay, Boulder Basin, and other locations throughout Lake Mead. The minimum oxygen concentrations were in the thermocline, usually near 30m. The minimum oxygen concentrations in Las Vegas Bay were lower than those in other areas of the lake. Hoffman et al., reported that similar conditions existed in 1968.[5] The existence of the metalimnetic depletion of DO was well documented in these reports but no attempts were made to explain its existence.

Everett hypothesized that decomposition of organic matter in the thermocline was responsible for the DO depletion.[6] No data were reported that supported this hypothesis. Deacon and Tew conducted the first extensive study of the DO depletion in 1972.[7] They found that the negative heterograde DO profile

developed during May and June with the lowest DO concentrations in the 20 to 30 meter region. The DO depletion was most pronounced from July through October and was eliminated in November when the thermocline disappeared. The depletion occurred throughout Lake Mead but was most severe in Las Vegas Bay. Deacon concluded that the DO depletion was due to the oxidation of organic matter in the thermocline and respiration of shad congregating in the thermocline to feed. Deacon concluded that the basic or background depletion occurring in Virgin Basin was due to zooplankton and shad respiration in the area of the thermocline.[8] The additional depletion occurring in Las Vegas Bay was due to the inflow of nutrients from Las Vegas Wash.

An extensive study of zooplankton respiration in the thermocline was conducted by Burke.[9] Zooplankton samples were were collected at a station in Boulder Basin near Saddle Island every two to four weeks from June 1975 through April 1976. Respiration rates were obtained from the literature and the total zooplankton respiration was calculated by multiplying zooplankton numbers by the respiration rates. To determine the total amount of oxygen lost in a given period of time, Burke used the following equations:

$$\text{Total DO lost} = \text{DO visibly lost} + \text{DO gained by reaeration}$$

$$\text{DO visibly lost} = \frac{\text{mean loss of DO in a time period}}{\text{number of days in time period}}$$

Burke concluded that zooplankton respiration accounted for 33 to 69 percent of the total DO lost in the 10 to 25 meter zone.

Baker et al., used an approach similar to that of Burke.[10] They concluded that zooplankton accounted for 31 percent and phytoplankton accounted for 43 percent of the oxygen lost. They stated that shad respiration could account for the remainder of the depletion.

In May 1980, the Program Management Consultant (PMC) conducted a preliminary analysis of the DO depletion condition and assessed the adequacy of the limnological monitoring program to provide the data needed to fully analyze the causes, effects, and significance of oxygen depletion in Lake Mead. The following conclusions resulted from this preliminary review:

1. During the months of June through October, DO depletion occurs in the metalimnion in Las Vegas Bay, Boulder Basin, and Bonelli Bay.

2. Dissolved oxygen depletion is generally between 1 and 3 mg/l greater in Las Vegas Bay and Boulder Basin than in Bonelli Bay.

3. Microbial respiration by phytoplankton and zooplankton appears to be the major factor contributing to dissolved oxygen depletion in Las Vegas Bay, although the oxidation of nitrogenous biochemical oxygen demand (BOD) and sediment uptake of oxygen may also contribute to the depletion.

4. Under present conditions, most carbonaceous BOD discharged from the treatment plants is removed in Las Vegas Wash.

5. Even if all carbonaceous and nitrogenous BOD demands were eliminated from the treatment plant discharges, the current DO standard in Las Vegas Bay would still not be met.

6. Reducing the phosphorus discharged from the wash will reduce respiration by algae and zooplankton, and should improve DO levels in the metalimnion in Las Vegas Bay. However, a DO concentration of 5 mg/l would still not be achieved in all areas.

7. Based on preliminary discussions with fisheries experts, there appear to be no obvious indications that the oxygen deficit is lowering fish productivity or stressing fish populations in the lake.

8. Additional field measurements are needed to better define the magnitude of the factors affecting DO depletion and to complete work on waste load determinations.

9. Additional work is required to confirm whether there are any effects of current metalimnetic DO levels on the fishery. Possible modifications to the current standard should be investigated.

A special metalimnetic DO depletion study was conducted in September 1980 to confirm the preliminary analysis and to develop qualitative estimates of the relative contribution of carbonaceous and nitrogenous oxygen demand, benthic uptake, and phytoplankton and zooplankton respiration to the oxygen depletion in Las Vegas Bay.

Objectives

The following major objectives of the metalimnetic oxygen depletion study were identified in the August 22, 1980 Proposed Program to Evaluate Metalimnetic Dissolved Oxygen Depletion:

1. Determine the cause of the metalimnetic oxygen depletion in Las Vegas Bay and Bonelli Bay.
2. Determine why the depletion is more severe in Las Vegas Bay.
3. Determine the relationships between oxygen depletion and chlorophyll concentrations and oxygen depletion and BOD from Las Vegas Wash.
4. Determine the impact of the metalimnetic oxygen depletion on the beneficial uses, particularly the fishery, of Las Vegas Bay.

Chapter Organization

This chapter has been divided into seven sections:

1. Introduction.
2. Methodology--The field program and analytical procedures are discussed.
3. Results--The DO data from the WQSS sampling program and the special metalimnetic DO study are presented.

4. Data Comparisons--The historical data on Lake Mead and data from other lakes that have metalimnetic oxygen minima are discussed.

5. Analysis--This section contains a discussion of the factors affecting the DO minimum and the relationships between chlorophyll and BOD and the DO minimum.

6. Effect on Beneficial Uses--Dissolved oxygen criteria and the impact of low DO concentrations on beneficial uses are discussed.

7. Conclusions.

METHODOLOGY

Many parameters possibly related to the metalimnetic DO depletion condition in Lake Mead were measured as part of the routine limnological monitoring program. Profiles of DO, temperature, conductivity, and pH were taken during every sampling trip. Chlorophyll and phytoplankton numbers and types were determined in the integrated samples. A zooplankton tow was made on each trip. Nutrient concentrations were determined in the epilimnion, metalimnion, and hypolimnion.

The special metalimnetic DO depletion study was conducted at Stations 1 through 6 from September 24 to 27, 1980, by the University of Nevada at Las Vegas (UNLV) with assistance from Brown and Caldwell (BC) and Dr. Joseph Shapiro. Physical measurements were made at 1 meter intervals through the DO depletion zone and at 1 to 5 meter intervals throughout the remainder of the water column at Stations 1 through 6. Total, carbonaceous, and nitrogenous BOD concentrations were determined in the DO depletion zone at Stations 3 through 6 and in the

vicinity of the plume at Stations 1 and 2 where DO depletion was not evident. Total nitrogen, ammonia, nitrate, and nitrite concentrations were measured at the same depths as the BOD concentrations. Algal numbers and types, chlorophyll, and pheophytin were determined at the same depths as the BOD concentrations. Zooplankton numbers and types were determined at these same depths at Stations 3 through 6. Total, algal, and zooplankton respiration rates were determined in the zone of depletion at Stations 3 through 6. Water samples were collected at various depths in the zone of depletion with a Van Dorn sampler. Duplicate dark BOD bottles and a light BOD bottle were filled with water from the Van Dorn sampler. The two dark bottles were incubated for 45 to 49 hours at the depth from which the samples were collected. The DO concentration of the light bottle was determined by the Winkler procedure.[11] At the end of the incubation period, the DO concentrations in the dark bottles were determined by the Winkler procedure. The total respiration in ug/l/day was calculated as follows:

$$\frac{\text{initial DO} - \bar{x}\ \text{DO of dark bottles}}{\text{incubation period}} = \text{respiration rate}$$

The algal respiration was determined in the same manner except the water from the Van dorn sampler was filtered through a plankton net to remove all zooplankton prior to filling the light and dark BOD bottles. The zooplankton respiration was calculated by subtracting the algal respiration from the total respiration. A list of the parameters analyzed and the purpose of each analysis are presented in Table 9-1. A detailed description of the analysis techniques is presented in Appendices A and E.

As part of the analysis, the total volume, the volume of the epilimnion, and the volume below the thermocline of both Las Vegas Bay and Bonelli Bay were determined. Las Vegas Bay

Table 9-1. Parameters Related to Dissolved Oxygen Issue

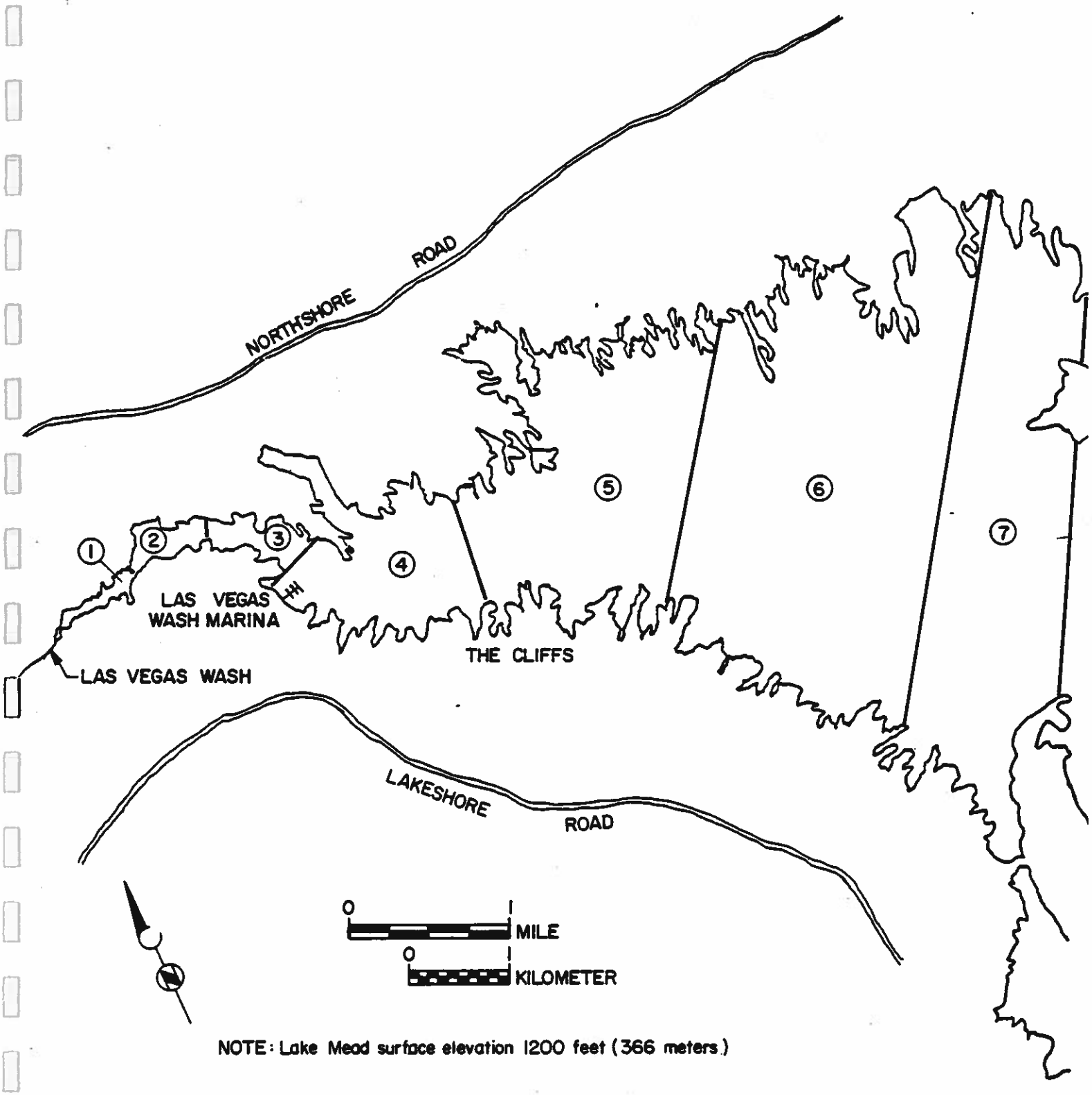
Analysis	Purpose of Analysis
Dissolved oxygen	Determine oxygen concentrations
Temperature	Indicates thermal structure and relates to decomposition rates
Conductance	Indicates position of plume
pH	Indicates primary productivity
Total BOD	Indicates oxygen demand
Carbonaceous BOD	Indicates oxygen demand due to organic decomposition
Nitrogenous BOD	Indicates oxygen demand due to nutrification
Ammonia Nitrate Nitrite	The relative concentrations of ammonia nitrate, and nitrite are indicative of whether nitrification is occurring
Algal numbers	Indicates relative abundance of algae
Zooplankton numbers	Indicates relative abundance of zooplankton
Total respiration	Indicates amount of demand due to respiration
Algal respiration	Indicates amount of demand due to algal respiration
Zooplankton respiration	Indicates amount of demand due to zooplankton respiration
Chlorophyll *a*	Indicates relative abundance of algae
Pheophytin *a*	Indicates general physiological state of algae
Primary productivity	Indicates if oxygen is being produced in depleted zone

was divided into seven sections as illustrated on Figure 9-1. The volume of each section at each U.S. Geological Survey (USGS) contour interval was determined by planimetering the contour to determine the area, and then multiplying the area by the height from the bottom of the section. During the summer of 1980, the lake elevation was fairly constant at 1,204 feet. The volumes of the individual sections were summed to determine the total volume of Las Vegas Bay. The depleted zone was defined as the volume below the thermocline. The thermocline was about 10 meters deep during the early summer and generally near 14 to 15 meters deep at the end of the summer. For the purposes of this analysis, it was assumed that the thermocline was constantly at a depth of 12 meters throughout the depleted period. The volume of the epilimnion was calculated as the volume above the 12-meter depth. The volume below the thermocline was calculated as the volume below the 12 meters depth.

The Bonelli Bay volume was determined in the same manner as Las Vegas Bay except that the bay was only divided into two sections as shown on Figure 9-2. The 12-meter depth divided the epilimnion from the volume below the thermocline.

RESULTS

The metalimnetic minimum of DO occurs throughout Lake Mead during the summer period of thermal stratification. The depletion in Las Vegas Bay is more severe than in Bonelli Bay and Virgin Basin. In Las Vegas Bay, DO concentrations drop below the current standard of 5 mg/l between depths of 15 meters and 50 meters throughout most of the summer.



NOTE: Lake Mead surface elevation 1200 feet (366 meters.)

Figure 9-1 Las Vegas Bay Zones

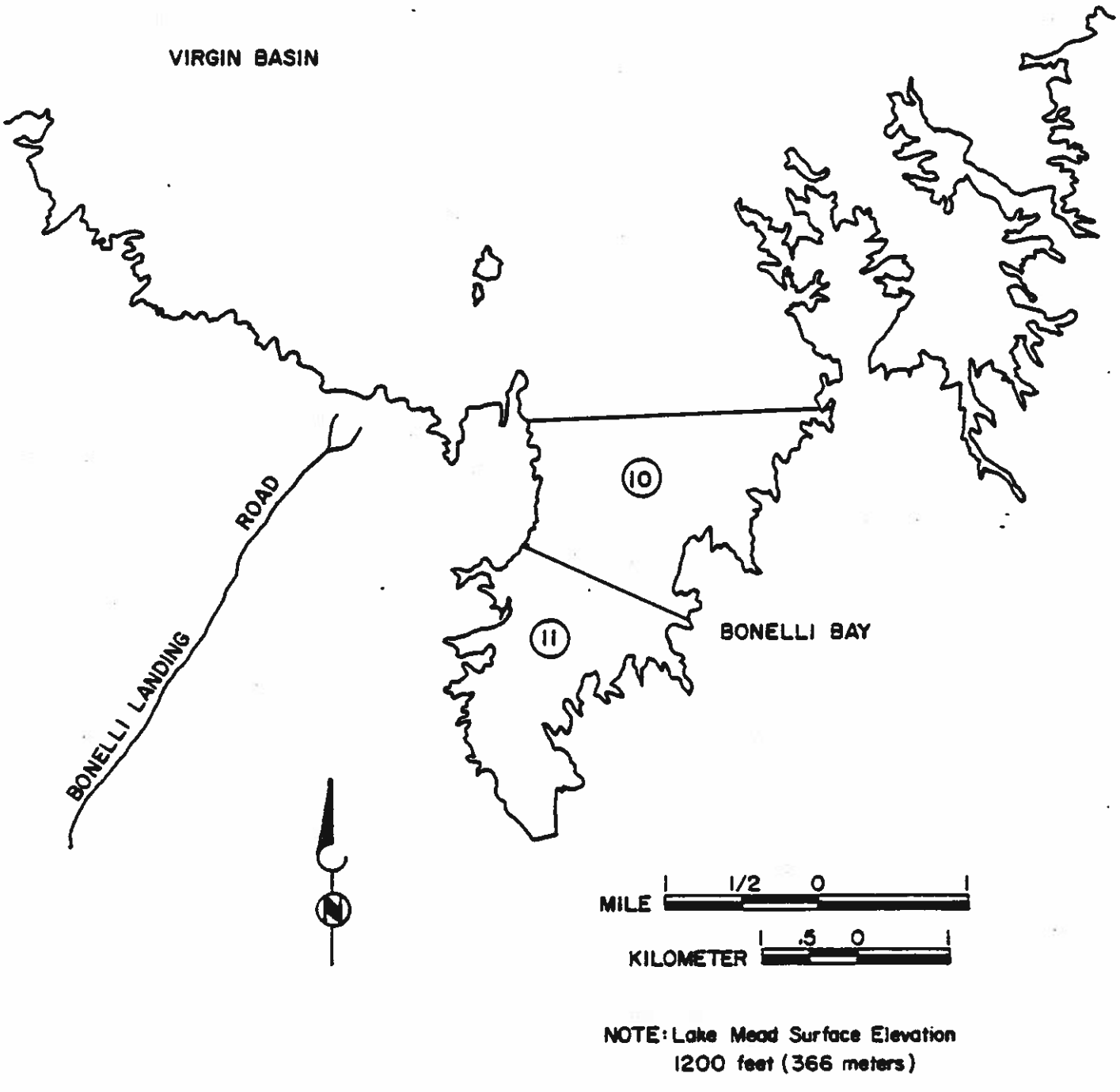


Figure 9-2 Bonelli Bay Zones

Seasonal Distribution

The depletion begins in late April in Las Vegas Bay and gets more extensive and more severe as the summer progresses. It begins to dissipate with the lowering of the thermocline in October. From December until about mid-April, the entire water column is well oxygenated.

Figures 9-3 and 9-4 present profiles of temperature, DO, and conductivity at Stations 2 and 5 in Las Vegas Bay for representative seasonal periods during 1980. The 1979 profiles were similar to the 1980 profiles and are included in Appendix E. Station 2 is shallow (10m deep) and was generally well mixed as shown by the temperature profiles. The DO concentrations were usually quite high throughout the water column. The Station 2 profiles are typical of the inner portion of Las Vegas Bay from the mouth of the wash out to Station 2. The profiles at Station 5 during 1980 are typical of the area from Station 3 out to Station 8 during both 1979 and 1980.

The depleted zone starts as a small volume of water immediately below the plume in late April. As the thermocline becomes established in the summer, the zone of depletion and the plume are confined by the thermocline. Typically, the DO concentrations drop by several mg/l just below the point of highest conductivity. There was always a distinct minimum in the area of the thermocline, and as shown on the September 1980 profile, there was often a secondary minimum at a depth of about 30 meters at the deeper stations. The DO depletion zone decreases as the thermocline drops during the fall and the water above the thermocline becomes reaerated. The volume of depletion becomes progressively smaller until it is dissipated by the mixing of the oxygen-rich epilimnetic waters with the

metalimnetic and hypolimnetic waters. The entire volume of the bay is well aerated and DO concentrations are typically near the saturation level from December through March.

Spatial Distribution

The metalimnetic DO depletion zone extends from near Station 3 in Las Vegas Bay out to Station 8. The longitudinal profiles of DO shown on Figure 9-5 indicate that the most severe depletion occurs near Station 3 early in the summer when the thermocline is near 10m. As the thermocline drops to about 15 meters during the late summer, most of the water column near Station 3 is aerated and the most severe depletion is near Station 4. The minimum DO concentrations increased with increasing distance from Las Vegas Wash. The DO concentrations drop to less than 1 mg/l at Stations 3 and 4, less than 3 mg/l at Station 5, and less than 4 mg/l at Stations 7 and 8. The concentrations occasionally dropped to lower values at the outer stations, but they were generally near 4 to 5 mg/l in the depleted zone.

Comparison of Las Vegas Bay to Bonelli Bay

The metalimnetic DO depletion in Bonelli Bay and Virgin Basin is not nearly as extensive as it is in Las Vegas Bay. The depletion starts later in the season in Bonelli Bay and never becomes as severe as it does in Las Vegas Bay. As shown on Figure 9-5, the minimum DO concentrations at Station 8 in Boulder Basin were generally 1 to 2 mg/l lower than the minimum concentrations at Station 9 in Virgin Basin. In Bonelli Bay, the lowest DO concentrations were usually found at the bottom at Station 11 and in the metalimnion at Station 10. The minimum DO concentration in Bonelli Bay was generally near 3 to 4 mg/l whereas the minimum concentration in Las Vegas Bay was less than 1 mg/l.

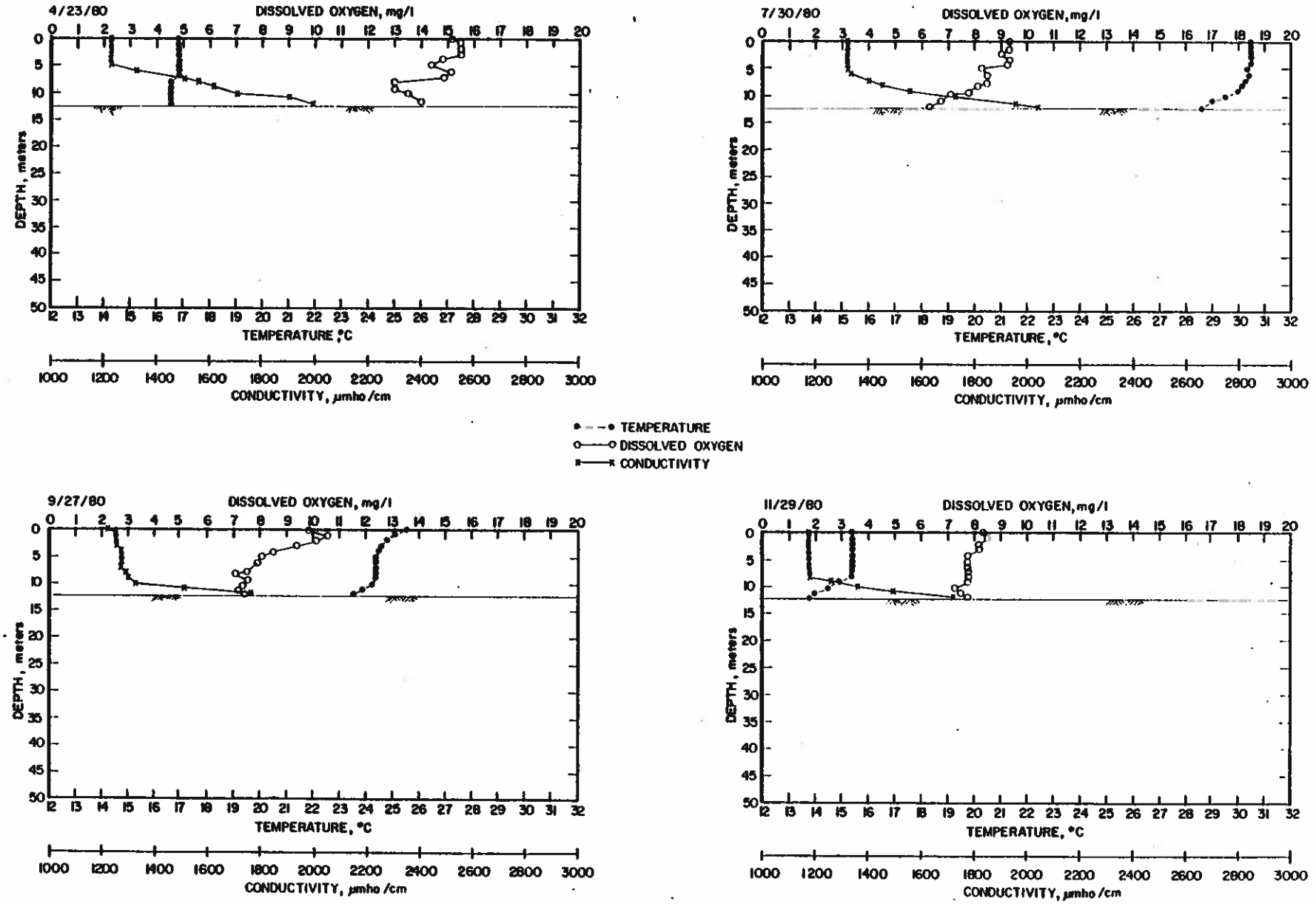


Figure 9-3 Dissolved Oxygen and Temperature Profiles at Station 2

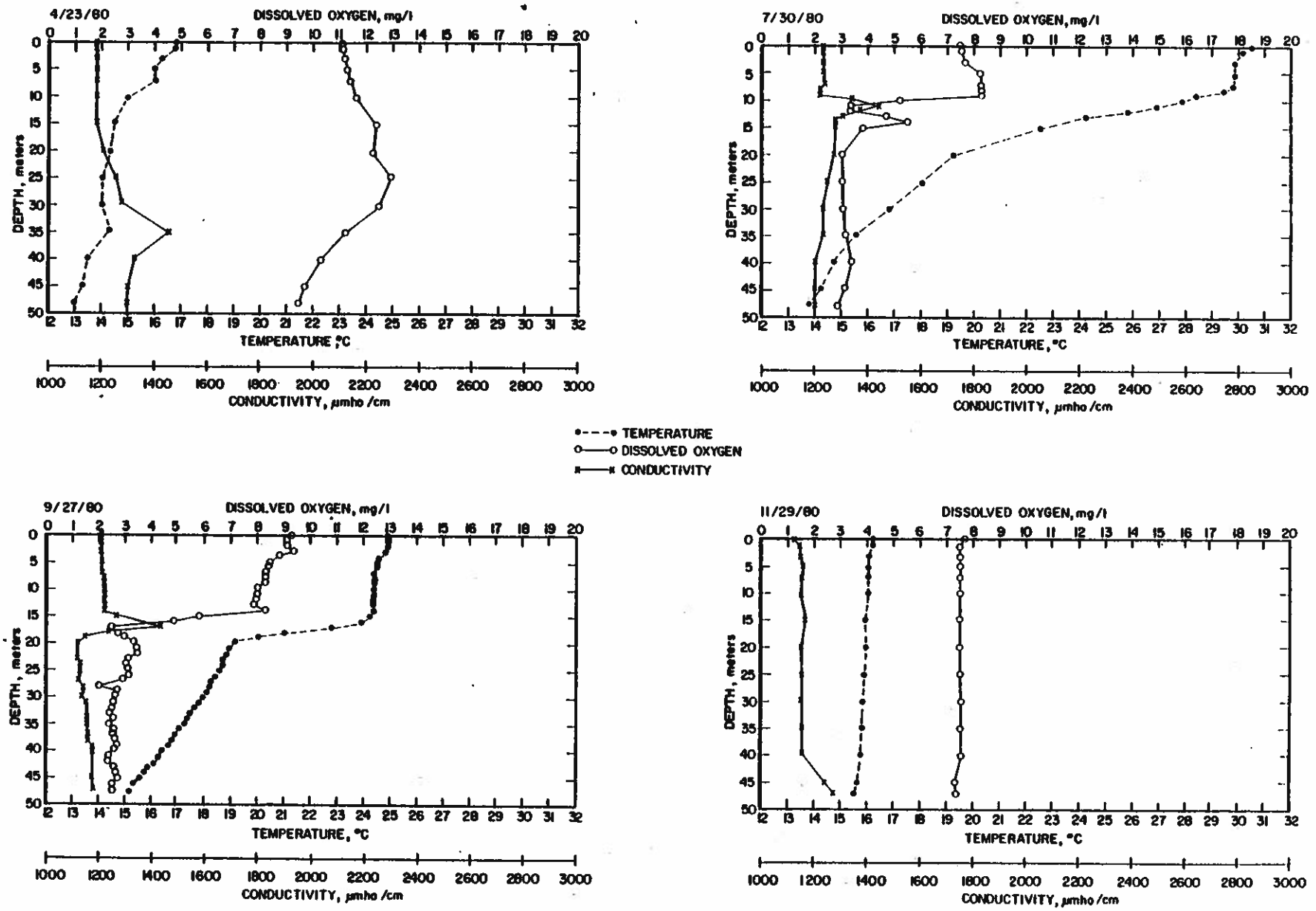


Figure 9-4 Dissolved Oxygen and Temperature Profiles at Station 5

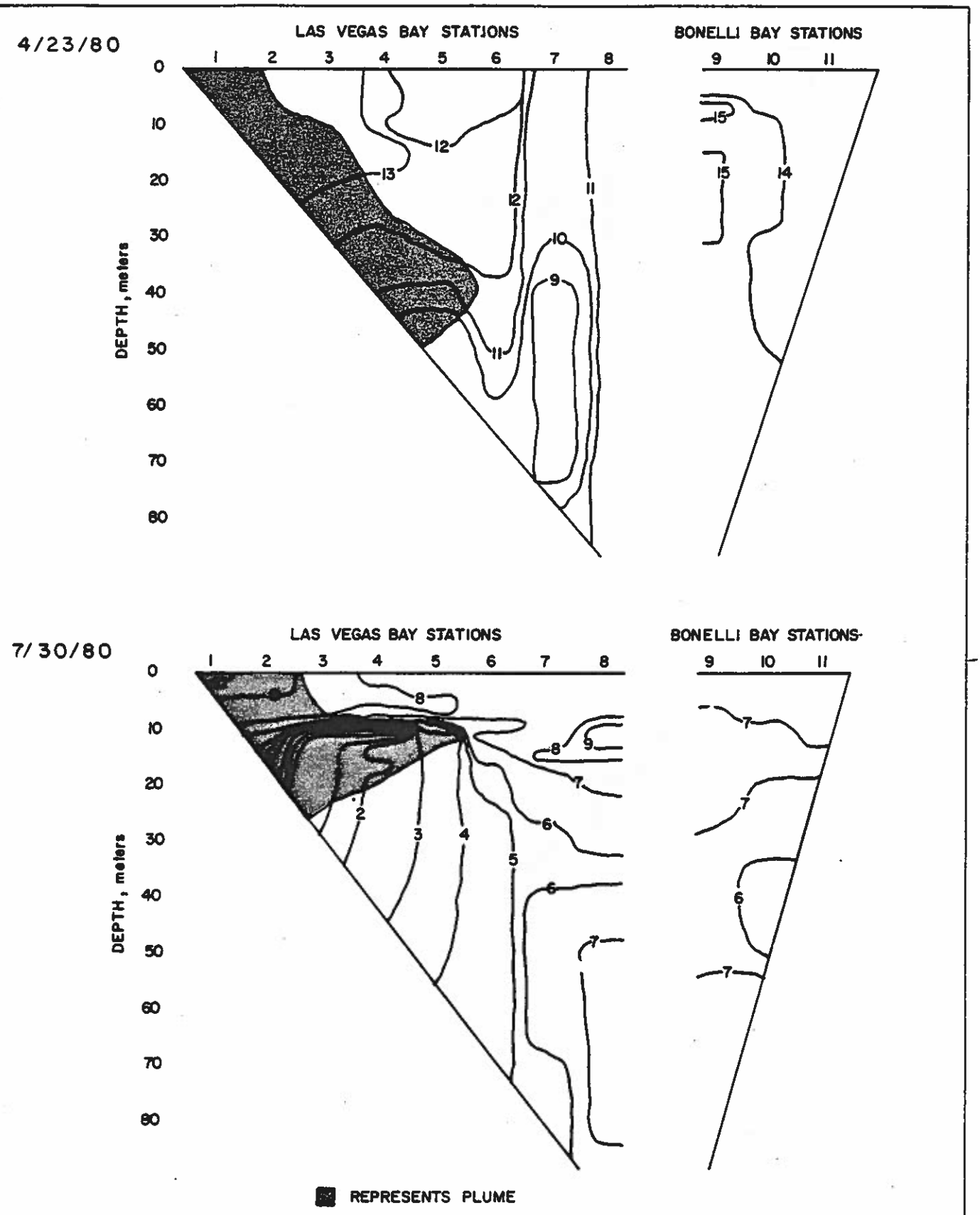


Figure 9-5 Dissolved Oxygen Contours in Las Vegas Bay and Bonelli Bay

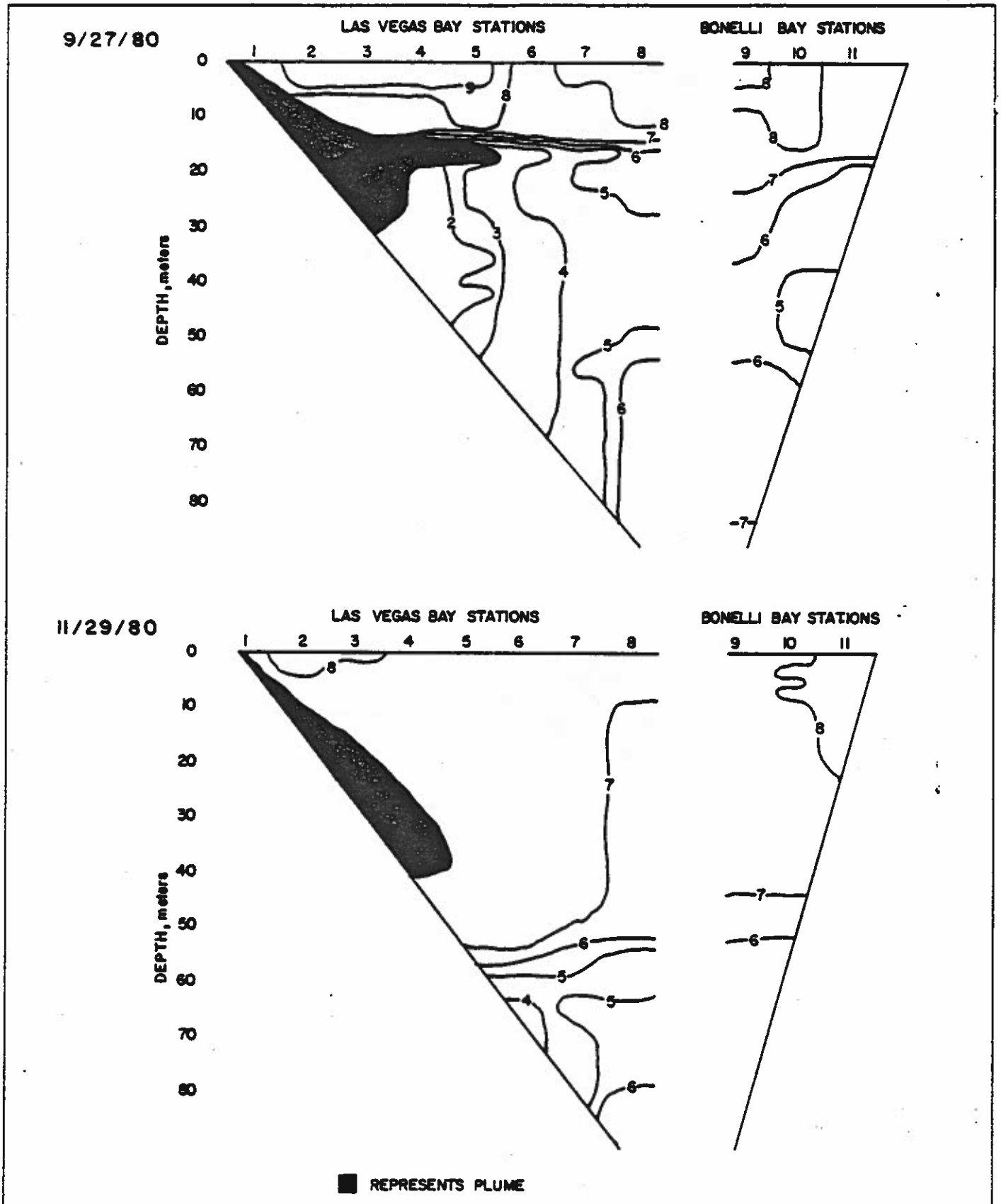


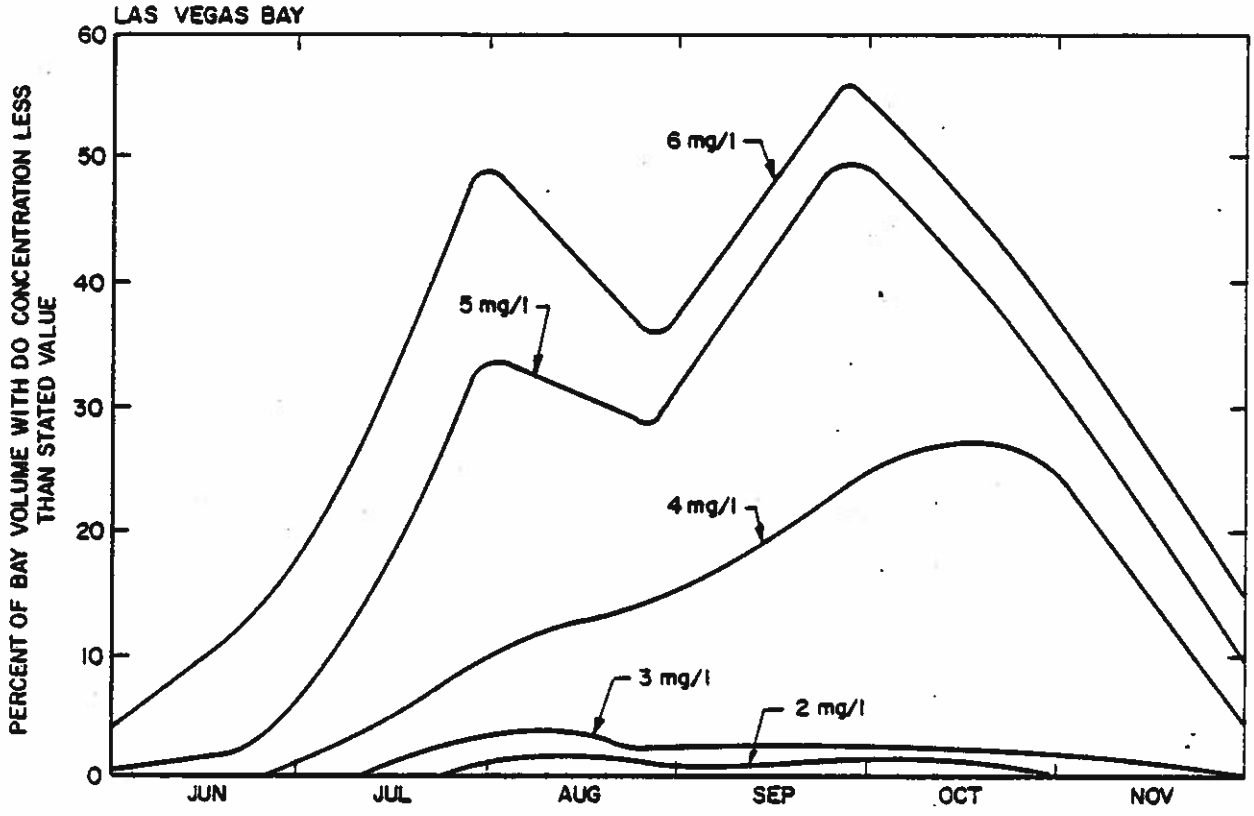
Figure 9-5 (Continued) Dissolved Oxygen Contours in Las Vegas Bay and Bonelli Bay

The oxygen depleted zone occupied a much greater volume of water in Las Vegas Bay than in Bonelli Bay. As shown on Figure 9-6, about 10 percent of the volume of Las Vegas Bay had DO concentrations less than 6 mg/l in June 1980. The depleted volume increased during the summer months until 55 percent of the bay volume had DO concentrations less than 6 mg/l in late September. At this time, about 25 percent of the bay volume had DO concentrations less than 4 mg/l and about 2 percent of the bay volume had concentrations lower than 2 mg/l. The entire volume of Bonelli Bay had DO concentrations greater than 6 mg/l in June 1980. By the end of July, about 10 percent of the volume had DO concentrations less than 6 mg/l. At the end of September about 20 percent of the volume had DO concentrations less than 6 mg/l and about 5 percent of the volume had DO concentrations less than 5 mg/l.

The natural or background depletion in Lake Mead, as represented by Bonelli Bay, can be defined as a relatively small volume of the water column (about 5 percent) having DO concentrations less than 5 mg/l. Minimum DO concentrations in this small volume are generally near 3 to 4 mg/l with concentrations occasionally dropping to 2 mg/l.

DATA COMPARISONS

The data collected during the WQSS were compared to historical data to determine if the WQSS data represented typical conditions in the lake. Since metalimnetic oxygen depletion is not a common phenomenon, the WQSS data were also compared to data collected on other lakes that currently have, or historically had, oxygen depletion in the metalimnion to put Lake Mead into perspective.



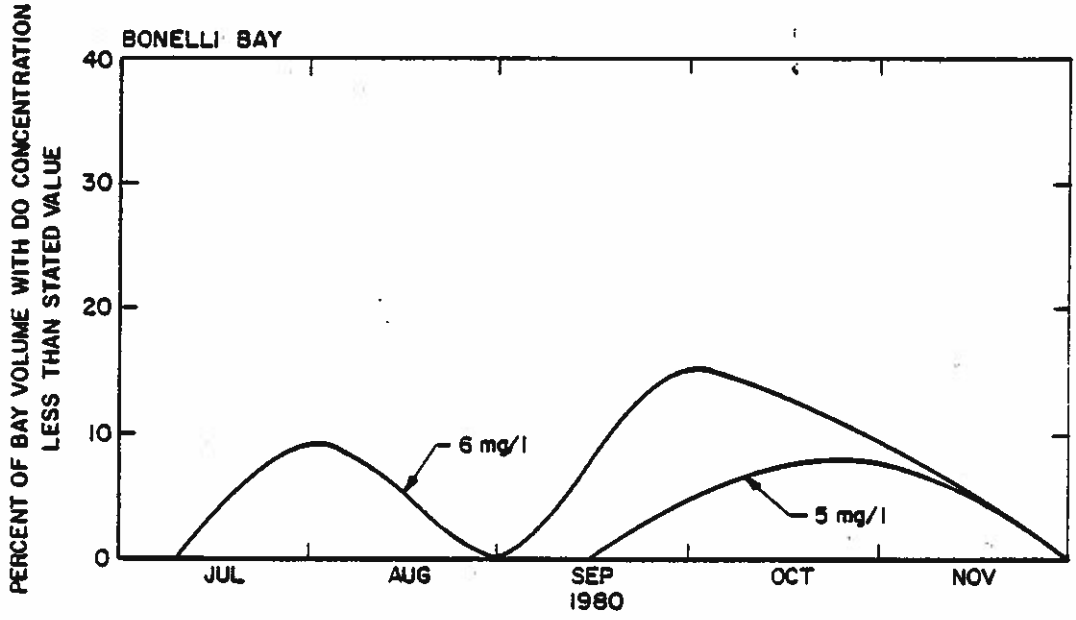


Figure 9-6 Oxygen Depletion in Las Vegas Bay and Bonelli Bay

Historical Data

As discussed in the introduction to this chapter, the metalimnion of Lake Mead has been depleted of oxygen during the summer months since the lake was formed. The oxygen depletion has always been more severe in Las Vegas Bay than in other areas of the lake. Dissolved oxygen and temperature profiles collected at Station 5 during 1977 and 1978 are shown on Figure 9-7. They are almost identical to the profiles for 1980 shown on Figure 9-4. This indicates that the DO depletion condition has not changed during the last four years.

All of the available historical data collected at Station 5 were compiled and the progression of the DO depletion in the metalimnion during the summer months of each year was plotted on Figure 9-8. This figure shows the minimum DO concentrations for each sampling date during the summer months of six years from 1968 through 1980. The same general pattern occurred during each year. The DO concentrations dropped below 5 mg/l at the end of June during each year and then declined steadily throughout the summer. The concentrations increased quickly during the fall. The pattern during 1980 was slightly different than the previous years. The minimum DO concentration occurred earlier (mid-August) and then the concentration increased by over 2 mg/l in late August. Then the concentrations decreased until fall overturn occurred. The sharp decrease in mid-August may be related to the high chlorophyll concentrations that occurred at this time. The increase in the DO concentration in late August appears to be related to the inflow of oxygen-rich Colorado River water. The background conductivity in Las Vegas Bay was typically near 1,100 umhos/cm. The Colorado River water was much lower in conductivity. During August 1980, a plume of

900 to 1,000 umhos/cm water was detected flowing into Las Vegas Bay. This inflow of the Colorado River water improved water quality conditions in outer Las Vegas Bay during the summer of 1980.

Comparison of Lake Mead to Other Lakes

Metalimnetic oxygen depletion in several other lakes is briefly discussed in this section. Lake Mead is compared to these other lakes.

Lake Washington. The depletion of metalimnetic oxygen in Lake Washington was first described by Shapiro.[11] For data collected from 1933 through 1958, he found that oxygen depletion which began in June and grew progressivly stronger during the summer months grew stronger year by year. The depletion disappeared at fall overturn in October. The minimum DO concentration in Lake Washington was 2.2 mg/l. Shapiro concluded that the oxygen minimum was due to respiration of copepods in the metalimnion. The amount of wastewater effluent entering the lake was decreased from 1963 to 1968 due to a diversion project.[12] By 1969 all wastewater was diverted from Lake Washington. Following the wastewater diversion, the minimum DO concentrations in the metalimnion increased to 6 mg/l in 1969. The metalimnetic DO concentrations consistently remained above 5 mg/l from 1969 to 1980.[13]

Lake Powell. A metalimnetic minimum of DO develops in Lake Powell in late summer each year.[14] It extends the full length of the reservoir. The oxygen concentration in the center of the lake is usually 2 to 4 mg/l. The bays are normally anaerobic. The depleted zone disappears when the thermocline deepens in the fall and metalimnetic waters mix with epilimnetic

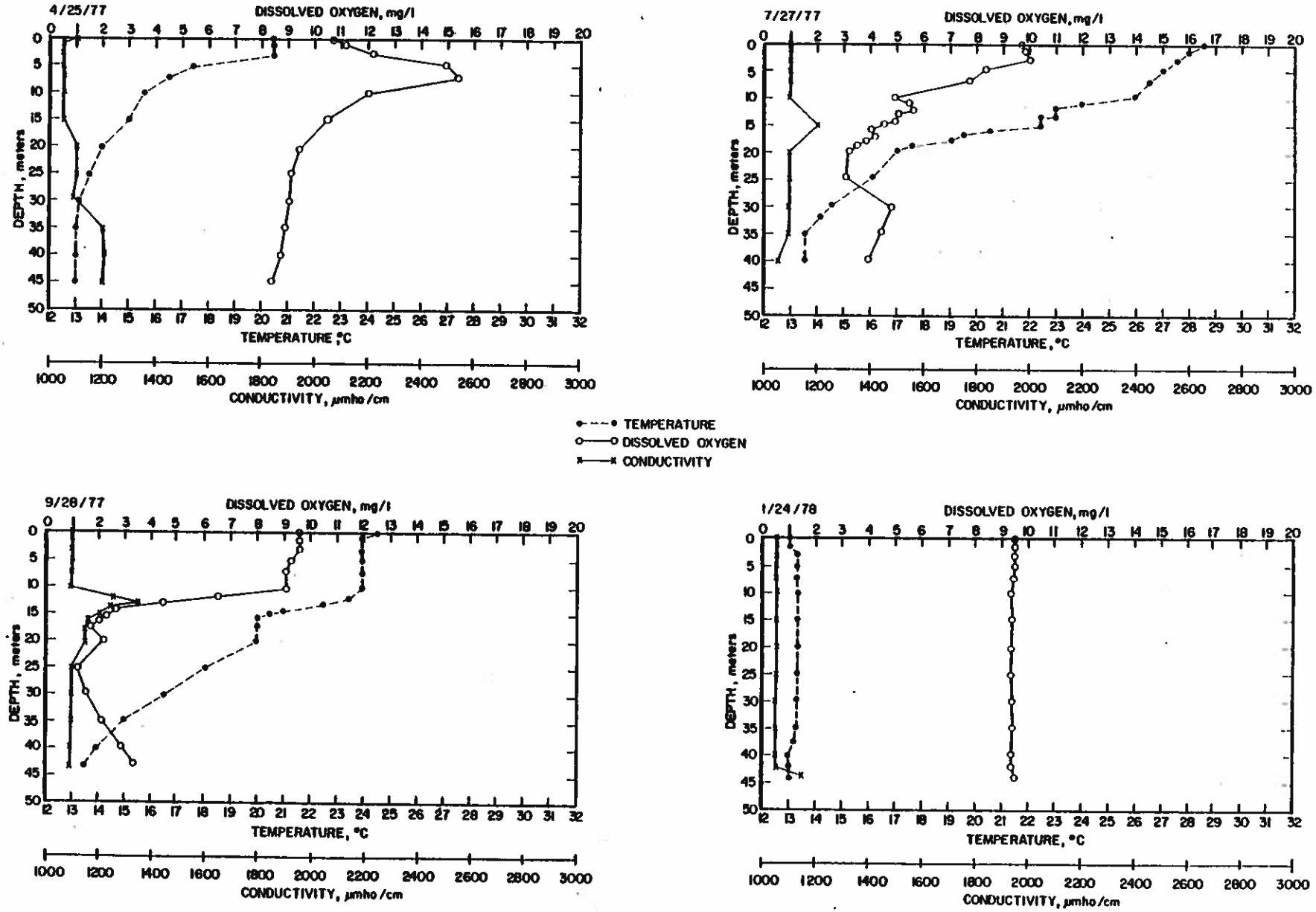


Figure 9-7 Historic Temperature and Dissolved Oxygen Profiles at Station 5

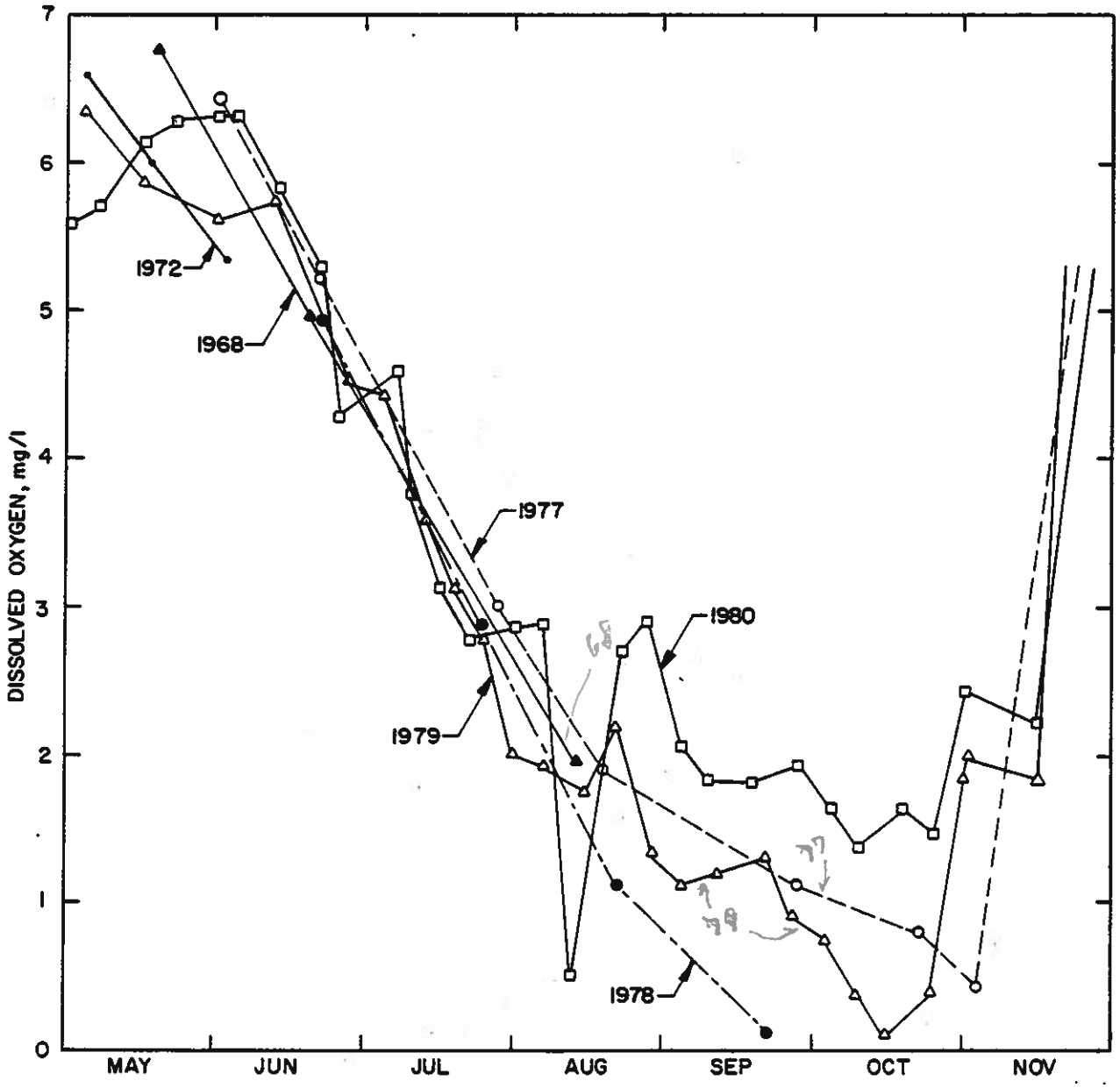


Figure 9-8 Minimum Historical DO Concentration of Station 5

waters. Johnson et al., attributed the oxygen depletion to respiration of organic material as it falls below the thermocline.[14] No data were provided to support this theory.

Comparison with Other Lakes. Table 9-2 compares data on the depletion of metalimnetic oxygen in Lake Mead to data on Lake Washington and Lake Powell. A limited amount of data on Lake Castaic, a reservoir north of Los Angeles, was available from Dr. Alex Horne.[15] Czeczuga presented data on a metalimnetic minimum in Lake Rajgrod, Poland.[16] The data on these two lakes are included in Table 9-2. There are two major similarities between the lakes: (1) the minimum concentrations are all quite low (less than 3 mg/l) and (2) depletion begins in the spring and ends with fall overturn in three of the lakes. The minimum DO concentration of 0.1 mg/l in Las Vegas Bay is comparable to the minimum of 0 mg/l in bays of Lake Powell, but it is lower than the minimum in the other three lakes. The natural or background condition in Bonelli Bay is similar to the condition in Lake Washington prior to the diversion of wastewaters.

Table 9-2. Comparison of Metalimnetic Oxygen Depletion in Lake Mead to Other Lakes

Lake	Minimum DO concentration, mg/l	Year	Period of depletion	Comments
Lake Mead				
Las Vegas Bay	0.1	1979	May to Oct.	Station 5
Bonelli Bay	2.6	1979	May to Oct.	Station 10
Lake Powell				
Bays	0	1971 to 1974	Aug to Oct.	
Central lake	2.4	1971 to 1974	Aug to Oct.	
Lake Washington	2.2	1961	May to Oct.	After wastewater diversion in 1969, DO increased to 6 mg/l.
Lake Castaic	1.1	1973	May to Oct.	Metalimnetic minimum occurs in small area of the reservoir.
Lake Rajgrod	2.5	1958	Not reported	Minimum first observed in 1922

ANALYSIS

There are several potential factors contributing to the depletion of DO in the metalimnion of Las Vegas Bay. A mass balance of oxygen was calculated for Las Vegas Bay to determine the relative impact of the oxygen demanding factors on the depletion. A separate DO balance was calculated for the inner bay since the depletion of DO is more severe near Stations 3 and 4. Data collected in Las Vegas Bay were extrapolated to Bonelli Bay, and a mass balance was calculated for Bonelli Bay. Finally, relationships between DO depletion and chlorophyll and DO depletion and wash BOD load were examined.

Factors Affecting the Minimum

The metalimnetic oxygen depletion in Las Vegas Bay could result from several factors including:

1. Oxidation of carbonaceous and nitrogenous oxygen-demanding materials (BOD) from Las Vegas Wash.
2. Microbial respiration in the metalimnion.
3. Oxygen utilization at the sediment-water interface.
4. Inflow of oxygen-deficient water from surface or groundwater sources.

Oxygen can be supplied to the metalimnion by three sources:

1. Transfer of oxygen from the epilimnion across the thermocline (reaeration).
2. Inflow of oxygen-rich water from Las Vegas Wash.
3. Photosynthesis below the thermocline.

Each of these factors is discussed in detail in the following section on the Las Vegas Bay mass balance. The oxygen demand or supply attributed to each factor is calculated for the entire bay. Modifications made to the calculations in determining the inner bay and Bonelli Bay mass balances are described in the sections on inner Las Vegas Bay and Bonelli Bay.

Las Vegas Bay Mass Balance

A mass balance of oxygen in the depleted zone of Las Vegas Bay during the 1980 period of depletion was calculated to determine if the oxygen demands were realistic in terms of the oxygen supplied to, and the oxygen lost from, the metalimnion. The mass balance also puts the various oxygen demands into perspective.

The depleted zone was defined as the volume below the thermocline. The thermocline was about 10m deep during the early summer and generally near to 15m deep at the end of the summer. For the purposes of this analysis, it was assumed that the thermocline was constantly at a depth of 12m throughout the depleted period.

The depleted period was defined as the 157 days between April 23 and September 27, 1980. There was no evidence of oxygen depletion in Las Vegas Bay on April 23, 1980; however, when samples were collected the next week, oxygen depletion was evident. It was assumed that oxygen depletion started on April 24. The thermocline began to deepen after September 27, and the oxygen depletion was dissipated by mixing with well-oxygenated epilimnetic waters.

The following equation describes the mass balance of oxygen in Las Vegas Bay:

Demand - Supply = Oxygen Visibly Lost

The mass balance equation is based on the following equations for demand and supply:

Demand = Wash BOD + Microbial Respiration + Sediment Demand + Demand from Oxygen-Deficient Water

Supply = Reaeration + Inflow of Oxygen-Rich Water + Photosynthesis

The oxygen visibly lost was determined by subtracting the oxygen content of the depleted zone at the end of the period from the oxygen content of the depleted zone at the beginning of the period. The oxygen content of the depleted zone was calculated as follows:

Average DO concentration x volume = DO content

The DO content of the depleted zone on April 23, 1980, was calculated as follows:

April 23, 1980, conditions
Average DO concentration = 10.8 mg/l
Volume below thermocline = 7.2×10^{11} l
DO content = 10.8 mg/l x 7.2×10^{11} l = 7.8×10^{6} kg

The DO content of the depleted zone on September 27, 1980, was calculated as follows:

September 27, 1980, conditions
Average DO concentration = 4.2 mg/l
Volume below thermocline = 7.2×10^{11} l
DO content = 4.2 mg/l x 7.2×10^{11} l = 3.0×10^{6} kg

The oxygen visibly lost during the depleted period was:

7.8×10^{6} kg - 3.0×10^{6} kg = 4.8×10^{6} kg

Each of the oxygen-demanding factors and oxygen supply factors is described in this section. A summary of the Las Vegas Bay mass balance is presented at the end of this section.

Oxidation of Las Vegas Wash BOD. The metalimnetic DO depletion in Las Vegas Bay is more severe than in Bonelli Bay. The major difference between the two bays is the load of nutrients and oxygen-demanding materials entering Las Vegas Bay in the Las Vegas Wash plume. The two major direct oxygen-demanding factors in the plume are carbonaceous BOD and BOD due to the oxidation of ammonia to nitrate.

The maximum potential BOD demand has been calculated. There are several factors that could cause the actual demand to be less than the maximum potential demand and they are described. The carbonaceous BOD load for the period from April 23, 1980, to September 27, 1980, was calculated on a monthly basis using the carbonaceous BOD measurements determined in the wash study and USGS flow data. A detailed discussion on the calculation of wash loads is contained in Chapter 6. The total five-day carbonaceous BOD load for the depleted period was 3.6×10^5 kg. No long-term BOD tests were performed to determine a bio-oxidation rate coefficient, so a rate coefficient of 0.10 per day was assumed. On that basis, the five-day BOD represents 68 percent of the ultimate carbonaceous BOD load. The ultimate carbonaceous BOD load was approximately 5×10^5 kg.

Ammonia is oxidized to nitrate in the presence of oxygen. The following reactions describe the nitrification process.[17]

$$NH_4^+ + 1.5\ O_2 = 2H^+ + NO_2^- + H_2O$$
$$NO_2^- + 0.5\ O_2 = NO_3^-$$

On a mass basis, each kilogram of ammonia requires 4.57 kg of oxygen to convert it to nitrate. Each kilogram of nitrite requires 1.14 kg of oxygen to convert it to nitrate. The potential oxygen demand due to nitrification of the wash ammonia and nitrite load in Las Vegas Bay was determined as follows:

Ammonia load (April 23, 1980 to September 27, 1980) = 280,000 kg
Oxygen demand = (280,000 kg x 4.57) = 1.3×10^6 kg
Nitrite load (April 23, 1980 to September 27, 1980) = 50,000 kg
Oxygen demand = (50,000 kg x 1.14) = 5.7×10^4 kg
Nitrogenous oxygen demand = (1.3×10^6 kg + 5.7×10^4 kg)
= 1.4×10^6 kg

The total maximum potential oxygen demand from both carbonaceous and nitrogenous BOD was 1.9×10^6 kg during the summer of 1980.

There are a number of factors that influence the exertion of the theoretical total carbonaceous plus nitrogenous BOD in the zone of oxygen depletion.

1. Particulate carbonaceous BOD--Some of the BOD entering the bay from the wash may be in the particulate form. Some of the particulate BOD may settle out of the water column near Stations 1 and 2 and never be transported to the zone of depletion and exert an oxygen demand.

2. Algal uptake of ammonia and nitrite--Some of the ammonia and nitrite may be taken up by algae rather than oxidized to nitrate. The amount of algal uptake occurring in Las Vegas Bay is unknown.

3. Total BOD exertion--In this analysis, it is assumed that the total amount of BOD is exerted in the depleted zone

of Las Vegas Bay. Some of the BOD may be mixed into the surface waters above the depleted zone and exerted in the surface waters where oxygen is replenished by reaeration.

These factors cannot be quantified in this analysis. The total demand due to BOD of 1.9×10^6 kg is the maximum potential oxygen demand. The actual demand in Las Vegas Bay is probably lower than this maximum value.

Examination of the concentrations of the various nitrogen species (ammonia, nitrate, and nitrite) in Las Vegas Bay indicates that the ammonia is converted to nitrite and nitrate in the bay. The dilution of the Las Vegas Wash plume in the bay was calculated from conductivity measurements. The dilution of ammonia was also calculated during the summer of 1980. The dilution data indicated that more ammonia was being lost than could be accounted for by dilution alone. In most cases, during the summer of 1980, the ammonia concentrations in the center of the plume at Station 5 were essentially equal to the background level of about 5 ug/l. This indicates that the nitrogenous BOD is exerted in the inner portion of Las Vegas Bay.

The ammonia dilution data were used to calculate the actual load of BOD to the depleted zone. Some of the BOD load from Las Vegas Wash is exerted in the area near Stations 1 and 2 in Las Vegas Bay. This area is shallow and well mixed so a zone of depletion does not develop. The actual zone of depletion develops near Station 3. Examination of the ammonia data collected in the plume during the summer of 1980 indicates that about 80 percent of the ammonia was lost between Northshore Road and Station 3 and about 50 percent was lost between Northshore

Road and Station 2. The load of BOD to the depleted zone was estimated as 50 percent of the load at Northshore Road. This yielded a carbonaceous BOD load of 2.5×10^5 kg and a nitrogenous BOD load of 7×10^5 kg for a total BOD load of 9.5×10^5 kg.

Microbial Respiration in the Metalimnion. The wash discharge indirectly increases oxygen depletion by providing nutrients which stimulate microbial growth and, thus, microbial respiration. The oxygen demand in the metalimnion may be increased due to greater numbers of phytoplankton and zooplankton and due to bacterial degradation of organic matter settling through the thermocline.

Phytoplankton, zooplankton, and bacterial respiration were discussed by previous researchers as possible causes of the metalimnetic depletion of DO.[7,8,9,10] Total and phytoplankton respiration were measured during the metalimnetic DO depletion study. The zooplankton respiration was calculated by subtracting the phytoplankton respiration from the total respiration. Table 9-3 contains the respiration rates measured during the DO study. In many cases, the algal respiration rates exceeded the total respiration rates. There are two possible explanations regarding the procedures used that may have caused this situation:

1. The procedure used to determine algal respiration rates involved filtering the water through a zooplankton net. This aerated the water and generally increased the DO in the initial samples from 2 to 3 mg/l to about 5 or

6 mg/l. In the total respiration rate determination, the organisms' respiration rates were measured under ambient conditions of 2 to 3 mg/l of DO. The algal respiration rates were measured in samples containing higher DO concentrations. The lower DO concentrations in the total respiration samples may have inhibited respiration.[18]

2. In the total respiration samples, zooplankton were grazing on algae and, therefore, reducing the algal component of respiration. In the algal respiration samples, the zooplankton had been removed so no grazing occurred.

Table 9-3. Respiration Rates Determined During Dissolved Oxygen Study

Station	Depth,m	Respiration rates, ug/l/day			
		Algal	Zooplankton	Total	Mean total
3	18	707	—	657	657
	14	—	—	597	
4	16	647	—	279	
	18	299	198	497	456
	17	—	—	157	
5	18	394	—	341	
	19	813	—	315	271
	16	178	25	203	
6	17	229	—	102	
	18	76	51	127	144
	36	76	—	0	
	38	152	—	25	
	40	152	—	25	17

The total respiration rates were used in the calculation of the demand due to respiration since the total respiration samples more closely resembled the actual conditions in the metalimnion. Burke reported a total respiration rate of 89 to

143 ug/l/day at Saddle Island in Boulder Basin.[9] This was based on actual numbers of zooplankton and phytoplankton and literature values for respiration rates. The respiration rate during the DO study could have been calculated in the same manner; however, the respiration rates determined in the DO study are comparable to the rates determined by Burke.

The mean total respiration rates in Table 9-3 show a smooth decreasing gradient from Station 3 out to Station 6. This is consistent with the gradient in chlorophyll levels that occurs in Las Vegas Bay.

To determine the total demand due to respiration in Las Vegas Bay, the respiration rates measured at Stations 3 through 6 in the DO study were extrapolated to the other stations as shown in Table 9-4. The lower respiration rate of 17 ug/l/day measured betwen 36m and 40m deep at Station 6 was assumed to apply below 30m at Stations 5, 6, and 7. The total oxygen demand for Las Vegas Bay was 6.7×10^4 kg/day. When this daily rate is applied to the 157 days in the 1980 depleted period, the total oxygen demand due to respiration is estimated to be 1.0×10^7 kg. The respiration rates during the early summer may have been lower since the water temperature was lower. No attempt was made to calculate respiration rates early in the summer based on lower water temperatures. This respiration figure includes the oxygen demand from carbonaceous BOD in the wash plume. Since the carbonaceous BOD of 2.5×10^5 kg was accounted for in the Las Vegas Wash BOD demand, it was subtracted from the respiration demand. The corrected respiration demand is, therefore, 9.8×10^6 kg.

Table 9-4. Oxygen Demand Due to Respiration

Station	Respiration rate, ug/l/day	Volume in depleted zone, l	Oxygen demand kg/day
1-3	657	1.5×10^{9}	9.9×10^{2}
4	456	2.1×10^{10}	9.6×10^{3}
5 above 30m	271	5.5×10^{10}	1.5×10^{4}
5 below 30m	17	2.5×10^{10}	4.3×10^{2}
6 above 30m	144	1.4×10^{11}	2.0×10^{4}
6 below 30m	17	1.7×10^{11}	2.9×10^{3}
7 above 30m	144	1.0×10^{11}	1.4×10^{4}
7 below 30m	17	2.1×10^{11}	3.6×10^{3}
Total	—	7.2×10^{11}	6.7×10^{4}

Oxygen Utilization at the Sediment-Water Interface. Organic matter sinking down into the hypolimnion is degraded by bacteria in the water column and at the sediment-water interface. In productive lakes, decomposition of organic matter at the sediment-water interface is the major oxygen-consuming process.[17] If the slope of the bottom is gentle where it coincides with the metalimnion, respiration of bacteria and other organisms at the sediment-water interface can reduce oxygen concentrations in the metalimnion. The slope of the basin is gradual near Stations 3 and 4 in Las Vegas Bay. These stations are relatively shallow (20m and 30m), and the lowest oxygen concentrations were often found near the bottom of the water column.

In the sediment report (see Appendix D), Murray calculated an oxygen demand from the sediments of Las Vegas Bay of 3.2×10^{5} kg/year. He used Fick's law of diffusion and assumed that there was no DO at the sediment-water interface since sulfide was present. The bottom DO concentration on one sampling day in August was used to determine the gradient across the sediment-

water interface at Stations 1 through 4. The fluxes calculated for Stations 1 through 4 were averaged, and this average value was multiplied by the entire sediment surface area of Las Vegas Bay to determine the sediment oxygen demand. This method provided a rough estimate of the sediment oxygen demand.

The same basic method was used to calculate the demand for the oxygen balance; however, average bottom water concentrations during the depleted period were used. The flux of oxygen into the sediments was calculated for Stations 3 through 7 since the sediments in this region are in contact with the depleted zone. The total sediment area of Las Vegas Bay is 2.44×10^{11} cm^2. The area of sediments around each station was not known so it was assumed that the sediment area was proportional to the volume of water in each section. The oxygen flux into the sediments at each station was multiplied by the estimated sediment area in that section to determine the oxygen demand. The total sediment oxygen demand during the 1980 depleted period was 9.6×10^4 kg.

Inflow of Oxygen-Deficient Water. When groundwater or surface water inputs of low DO content are substantial, mixing of these waters with lake water will lower the DO concentration of the lake water. In Lake Mead, groundwater inputs are relatively small, and the Colorado River and Las Vegas Wash are high in oxygen content. This factor was deemed insignificant in the mass balance of oxygen in Las Vegas Bay.

Reaeration Through the Thermocline. A major source of oxygen to the metalimnion is the mixing of oxygen-rich, epilimnetic water through the thermocline into the metalimnion. The DO study was not designed to provide a precise determination

of reaeration through the thermocline. However, there are some indirect methods that can be used to approximately estimate the amount of oxygen supplied to the metalimnion. Direct calculations of reaeration are very complex and involve field and laboratory work to develop oxygen transfer functions.

As discussed in Chapter 8, approximately one percent of the epilimnion is mixed below the thermocline each day. The same volume of water from the area below the thermocline is mixed into the epilimnion. The oxygen load to the metalimnion from the epilimnion is described by the following equation:

$$O_2 \text{ load/day} = 0.01 \text{ Volume}_E \times (DO_E - DO_m)$$

Where: Volume_E = epilimnetic volume in liters
DO_E = epilimnetic DO concentration in mg/l
DO_m = metalimnetic DO concentration in mg/l

The average change in concentration between the epilimnion and the depth of minimum DO in the metalimnion during the depleted period was calculated for Stations 3 through 7. The average change in concentration at each station was multiplied by the epilimnetic volume at the station and then multiplied by 0.01. The total load of oxygen to the metalimnion was then determined by summing the load at the individual stations. This resulted in a supply of 2.1×10^6kg of oxygen during the depleted period.

Inflow of Oxygen-Rich Water. The DO concentration of Las Vegas Wash at Northshore Road was typically in the range of 8 to 10 mg/l. The Las Vegas Wash plume flows into Las Vegas Bay below the thermocline during the summer months. It contributes

a significant amount of oxygen to the metalimnion. The load of DO from Las Vegas Wash during the summer of 1980 was calculated on a monthly basis from WQSS DO measurements and USGS flow measurements. The oxygen load during the depleted period was 2.3×10^5 kg.

Photosynthesis in the Metalimnion. Through the process of photosynthesis, algae use carbon dioxide to produce organic material and oxygen. If there are sufficient light and algae present below the thermocline, photosynthesis can contribute oxygen to the metalimnion. The primary productivity data routinely collected during the WQSS were used to determine the amount of oxygen produced below the thermocline in Las Vegas Bay. Primary productivity was measured every two weeks at Stations 2 and 5 in Las Vegas Bay and Station 8 in Boulder Basin. The primary productivity data were reported as the amount of carbon fixed/m^3/day. The photosynthesis reaction was used to determine the amount of oxygen produced by the fixation of carbon:

$$6\ CO_2 + 12\ H_2O \longrightarrow 6O_2 + C_6H_{12}O_6 + 6\ H_2O$$

The average productivity below the thermocline was calculated at Stations 2, 5, and 8 for the depleted period. Productivity was measured to a depth of 10 meters at Station 2. It was assumed that there was no productivity at 15 meters. The productivity in the zone of depletion was assumed to be 50 percent of the productivity at 10 meters. At Stations 5 and 8, productivity was measured to a depth of 25 meters. It was assumed that there was no productivity at 30m. The productivity in the zone of depletion was the mean of the productivity at 10, 15, 20, 25, and 30m. The total productivity below the thermocline was determined by dividing the bay into three zones.

1. Stations 1 to 3--The productivity at Station 2 was multiplied by the volume of water below the thermocline at Stations 1 through 3, and by the 157-day period. The productivity (expressed as mg C) was converted to kg O_2 produced.

2. Stations 4 to 6--The productivity at Station 5 was multiplied by the volume of water below the thermocline at Stations 4 through 6 and by the time period. It was then expressed as kg O_2 produced.

3. Station 7--The productivity at Station 8 was multiplied by the volume of water below the thermocline at Station 7 and by the time period. It was then expressed as kg O_2 produced.

The total amount of oxygen produced by photosynthesis below the thermocline was 2.4×10^5 kg.

Summary of Oxygen Supply and Demand in Las Vegas Bay. Table 9-5 summarizes the oxygen demand and oxygen supply from each factor. The total oxygen demand due to all factors during 1980 was 10.9×10^6 kg. Respiration accounted for 90 percent of this demand, nitrogenous and carbonaceous BOD from Las Vegas Wash accounted for 9 percent, and sediment demand accounted for 1 percent. The total oxygen supply during this period was 2.5×10^6 kg. The theoretical oxygen depletion (demand-supply) was, therefore, 8.4×10^6 kg. The visible change in oxygen content of the depleted zone from April 23, 1980, to September 27, 1980, was only 4.8×10^6 kg, so a supply of 3.6×10^6 kg of oxygen cannot be accounted for. Alternatively, the demands could be overestimated.

Table 9-5. Las Vegas Bay Mass Balance

Factor	Oxygen demand or supply, 10^6 kg of O_2	Percent of demand or supply, percent
Oxygen demand		
BOD in plume	1.0	9
Respiration	9.8	90
Sediment demand	0.1	1
Total demand	10.9	100
Oxygen supply		
Reaeration	2.1	84
DO in plume	0.2	8
Photosynthesis	0.2	8
Total supply	2.5	100
Theoretical depletion (demand-supply)	8.4	
Actual depletion (oxygen visibly lost)	4.8	

Although a perfect mass balance on oxygen was not achieved with this method, the relative ranking of the various demand factors is legitimate. Some extrapolation was necessary to determine the oxygen demand from each factor; however, all calculations were based on some direct field measurements. No direct measurements of the key supply factor, reaeration, were made. Respiration is by far the key oxygen demanding factor in Las Vegas Bay.

Inner Las Vegas Bay Mass Balance

A separate mass balance was calculated for inner Las Vegas Bay since oxygen depletion is more severe in this area. This inner bay is also most heavily influenced by the plume. The depleted zone was defined as the volume below the 12-meter depth. Stations 1 and 2 are less than 12 meters deep so depletion is minimal due to high DO input from Las Vegas Wash and a great deal of reaeration due to wind mixing. The depleted zone was

defined as the volume of water below 12 meters in Sections 3 and 4. The depleted period was defined as the 157 days between April 23 and September 27, 1980.

The oxygen visibly lost was determined by subtracting the oxygen content of the depleted zone at the end of the period from the oxygen content of the depleted zone at the beginning of the period. The oxygen visibly lost during this period was 4.6 x 10^5 kg. Each of the demand and supply factors is briefly discussed in this section. The oxygen demand and supply were calculated in the same manner as they were for the entire bay. The major difference is that the depleted zone was confined to Sections 3 and 4 rather than the entire bay.

Oxidation of Las Vegas Wash BOD. It was assumed, based on the ammonia and nitrate data, that all of the wash carbonaceous and nitrogenous BOD was exerted in the inner bay. As discussed previously, the load of BOD to the depleted zone was assumed to be 50 percent of the load at Northshore Road. The carbonaceous BOD load to the inner bay was 0.25 x 10^6 kg, the nitrogenous BOD load was 0.7 x 10^6 kg, and the total BOD load was 0.95 x 10^6 kg. As stated previously, this estimate is a maximum figure for several reasons: sedimentation of some particulate BOD may occur, there may be some algal uptake of ammonia and nitrite, and all of the oxidation may not necessarily occur in the depletion zone.

Microbial Respiration in the Metalimnion. The respiration rates measured at Stations 3 and 4 during the DO study were multiplied by the volume of the depleted zone in the inner bay and the 157 days of the depleted period to obtain the respiration demand of the inner bay. The total demand due to respiration during the 1980 depleted period was 1.8 x 10^5 kg.

Oxygen Utilization at the Sediment-Water Interface. The sediment demand for the inner bay was calculated by the same method used for the entire bay. The sediment area of the inner bay was estimated from the sediment area of the entire bay and the relative volume of the inner bay to the entire bay. The flux of oxygen into the sediments at Stations 3 and 4 was multiplied by the estimated sediment area of the inner bay and the 157 days of the depleted period to obtain a demand of 5.4×10^4 kg.

Reaeration Through the Thermocline. The method described in the Las Vegas Bay balance was used to calculate reaeration at Stations 3 and 4 in the inner bay. The total supply of oxygen due to reaeration during the 1980 depleted period was 3.0×10^5 kg.

Inflow of Oxygen-Rich Water. It was assumed that the entire supply of oxygen in the Las Vegas Wash plume was mixed in the depleted zone of the inner bay. The oxygen load from Las Vegas Wash was 2.3×10^5 kg.

Photosynthesis in the Metalimnion. The amount of oxygen produced by photosynthesis below the thermocline in the inner bay was calculated from the primary productivity data at Stations 2 and 5. It was assumed that the productivity, and hence, oxygen production at Station 3, was equal to the measured productivity at Station 2, and the productivity at Station 4 was equal to the measured productivity at Station 5. The total oxygen supply due to photosynthesis was 1.4×10^4 kg.

Summary of Oxygen Supply and Demand in Inner Las Vegas Bay. The oxygen demand and supply from each factor are presented

in Table 9-6. The total oxygen demand due to all factors during 1980 was 12.3 x 10^5 kg. In the inner bay, the BOD from the Las Vegas Wash plume was the major oxygen demanding factor. About 80 percent of the demand was due to the assumed plume BOD, and 15 percent of the demand was due to respiration. The direct influence of the plume resulted in the much more severe oxygen depletion in the inner bay compared to the outer bay and Bonelli Bay. The 80 percent figure is a maximum estimate and in all likelihood is somewhat lower, since all of the BOD load is not oxidized in the depletion zone for the inner bay.

Table 9-6. Inner Las Vegas Bay Mass Balance

Factor	Oxygen demand or supply, 10^5 kg of O_2	Percent of demand or supply, percent
Oxygen demand		
BOD in plume	10.0	81
Respiration	1.8	15
Sediment demand	0.5	4
Total demand	12.3	100
Oxygen supply		
Reaeration	3.0	56
DO in plume	2.3	42
Photosynthesis	0.1	2
Total supply	5.4	100
Theoretical depletion (demand-supply)	6.9	
Actual depletion (oxygen visibly lost)	4.6	

The total oxygen supply during this period was 5.4 x 10^5 kg. The theoretical oxygen depletion (demand-supply) was, therefore, 6.9 x 10^5 kg. The visible change in oxygen content of the depleted zone from April 23, 1980, to September 27, 1980, was only 4.6 x 10^5 kg, so a supply of 2.3 x 10^5 kg of oxygen cannot be accounted for. Alternatively, the demands could be overestimated.

Bonelli Bay Mass Balance

The depletion of metalimnetic DO in Bonelli Bay is not as severe as in Las Vegas Bay. As discussed previously, only a small volume of water is depleted of oxygen, and the minimum concentration was generally near 3 to 4 mg/l. The major difference between Bonelli Bay and Las Vegas Bay is the Las Vegas Wash plume. The special DO study originally included respiration rate measurements, and zooplankton and phytoplankton identification and enumeration in the metalimnion of Bonelli Bay. The study was not conducted in Bonelli Bay because authorization for the work was delayed and the depleted zone was confined to a small area at the bottom of Station 10 when authorization was received. In lieu of having direct measurements for some of the demand or supply factors, the data collected in Las Vegas Bay were extrapolated to Bonelli Bay to calculate an approximate mass balance.

The depleted zone was defined as the volume below the 12-meter depth at Stations 10 and 11. As in Las Vegas Bay, the depleted period was defined as the 157 days between April 23 and September 27, 1980. The oxygen visibly lost during this period was 1.3×10^6 kg. The key oxygen-demanding factors in Bonelli Bay are respiration and sediment demand. Reaeration and photosynthesis supply oxygen to the depleted zone.

Microbial Respiration in the Metalimnion. Since respiration rates were not measured in Bonelli Bay, the Station 6 respiration rates were normalized by the average chlorophyll concentrations in Bonelli Bay as follows:

mean chlorophyll at Station 6 = 3 ug/l
mean chlorophyll at Station 10 = 1.2 ug/l
adjustment factor = $\frac{1.2}{3} = 0.4$

The Station 6 respiration rates were multiplied by 0.4 to approximate the Bonelli Bay respiration rates. The adjusted Station 6 rates were multiplied by the volume of the depleted zone in Bonelli Bay and the 157 days of the depleted period to obtain the respiration demand of Bonelli Bay. The total demand due to respiration during the 1980 depleted period was 1.1×10^6 kg.

Oxygen Utilization at the Sediment-Water Interface. The sediment demand for Bonelli Bay was calculated by the same method used in Las Vegas Bay. The area of the sediments was assumed to be equal to the lake surface area at the average 1980 elevation of 1,204 feet. The flux of oxygen into the sediments at Stations 10 and 11 was multipled by the estimated sediment area and the 157 days of the depleted period to obtain a demand of 4×10^4 kg.

Reaeration Through the Thermocline. The method described in the Las Vegas Bay balance was used to calculate reaeration in Bonelli Bay. The total supply of oxygen due to reaeration during the 1980 depleted period was 2.3×10^5 kg.

Photosynthesis in the Metalimnion. The amount of oxygen produced by photosynthesis below the thermocline in Bonelli Bay was calculated from the primary productivity data at Station 10. The method used was identical to the method used at Station 5 in Las Vegas Bay. The total oxygen supply due to photosynthesis was 5.2×10^4 kg.

Summary of Oxygen Supply and Demand in Bonelli Bay. The oxygen demand and supply from each factor are presented in Table 9-7. The total oxygen demand due to all factors during

1980 was 1.14 x 10^6 kg. Respiration accounted for 96 percent of the demand. There was a small demand from the sediments. The total oxygen supply was 0.25 x 10^6 kg. Reaeration accounted for 80 percent and photosynthesis accounted for 20 percent of the supply.

Table 9-7. Bonelli Bay Mass Balance

Factor	Oxygen demand or supply 10^6 kg of O_2	Percent of demand or supply, percent
Oxygen demand		
Respiration	1.1	96
Sediment demand	0.04	4
Total demand	1.14	100
Oxygen supply		
Reaeration	0.2	80
Photosynthesis	0.05	20
Total supply	0.25	100
Theoretical depletion (demand-supply)	0.9	
Actual depletion (oxygen visibly lost)	1.3	

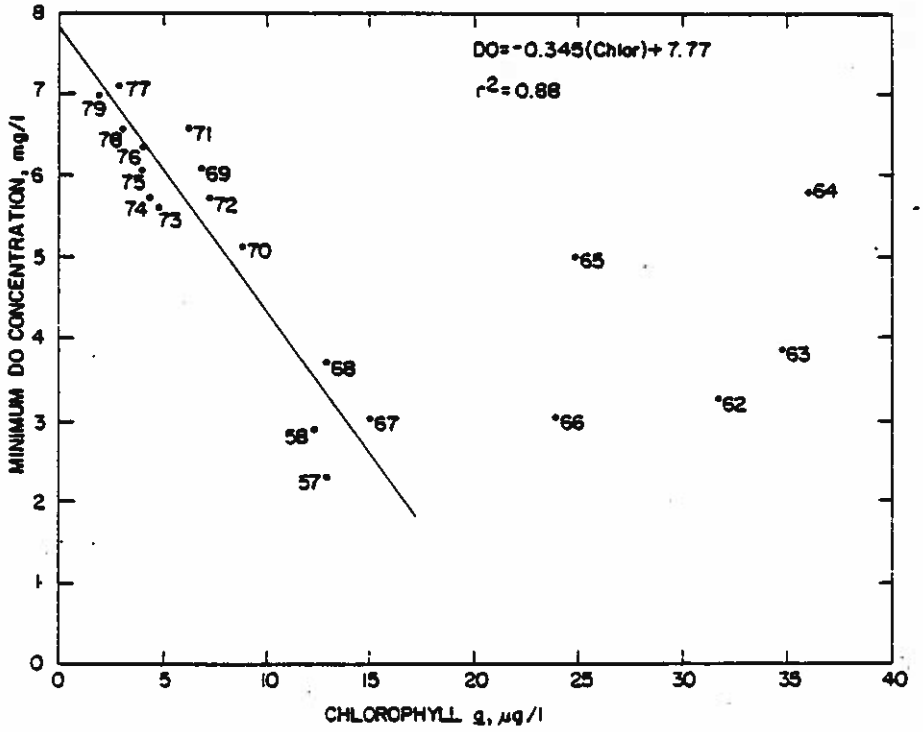
The theoretical oxygen depletion (demand-supply) was 0.9 x 10^6 kg. The visible change in oxygen content of the depleted zone during the depleted period was 1.3 x 10^6 kg, so a demand of 0.4 x 10^6 kg cannot be accounted for.

Oxygen Depletion/Chlorophyll Relationship

Since respiration is one of the major oxygen-demanding factors in Las Vegas Bay, the relationship between oxygen demand and chlorophyll was investigated. The chlorophyll concentration is a measure of the amount of algae present. The amount of

algae present directly influences oxygen depletion through algal respiration. Zooplankton feed on algae so algae indirectly influence oxygen demand through zooplankton respiration.

As discussed previously, Shapiro found that the oxygen minimum in Lake Washington was due to zooplankton respiration.[1] The average summer chlorophyll concentrations and the minimum DO concentrations in the metalimnion of Lake Washington from 1957 through 1979 were plotted on Figure 9-9. In general, there is a good inverse relationship between minimum DO and chlorophyll concentrations. The data from 1962 to 1966 do not fit the relationship developed with the other data. During this period of time, the wastewater diversion program was started and the lake was readjusting to the new phosphorus loads.[12] By 1967, most of the wastewater had been diverted from Lake Washington. Examination of Figure 9-9 shows that it was necessary to reduce the chlorophyll concentration to 8 ug/l to achieve a minimum DO of at least 5 mg/l in Lake Washington.



NOTE: Unpublished data from Edmondson

Figure 9-9 Relationship Between Average Summer Chlorophyll a and Minimum DO Concentration in Lake Washington

Figure 9-10 shows the average summer chlorophyll concentrations and the minimum DO concentrations measured at each station during the WQSS for Lake Mead. Examination of the data shows that there is a general trend with the higher DO concentrations corresponding to the lower chlorophyll values and the lower DO concentrations corresponding to higher chlorophyll values. For example, all minimum DO levels occurred in cases where the mean chlorophyll was 5 ug/l or greater; however, there was a very wide range of minimum DO levels associated with mean chlorophyll values less than 5 ug/l. This may be due to the limit of detection at very low chlorophyll levels. None the less, it is clear that extremely low chlorophyll concentrations of 1 and 2 ug/l correspond to minimum DO concentrations of 2 and 3 mg/l. The historical data at Station 5 for 1977 and 1978 were examined but no relationship could be developed. Since there has been some phosphorus removal at the treatment plants between 1978 and 1980, it might be that Las Vegas Bay is in the adjustment period that Lake Washington went through between 1962 and 1966. There is no consistent relationship between chlorophyll and minimum DO in Lake Mead.

Although there appears to be no reliable relationship between chlorophyll and minimum DO, the relationships between intermediate parameters have also been analyzed. Using the data collected during the metalimnetic DO survey in September 1980, respiration rates and the corresponding chlorophyll concentration are plotted in Figure 9-11. As expected, the respiration rate increases with chlorophyll. However, this relationship is based on only one set of data. More measurements would be required before such a relationship could be reliably used. The respiration rate could then be used to compute a DO depletion amount.

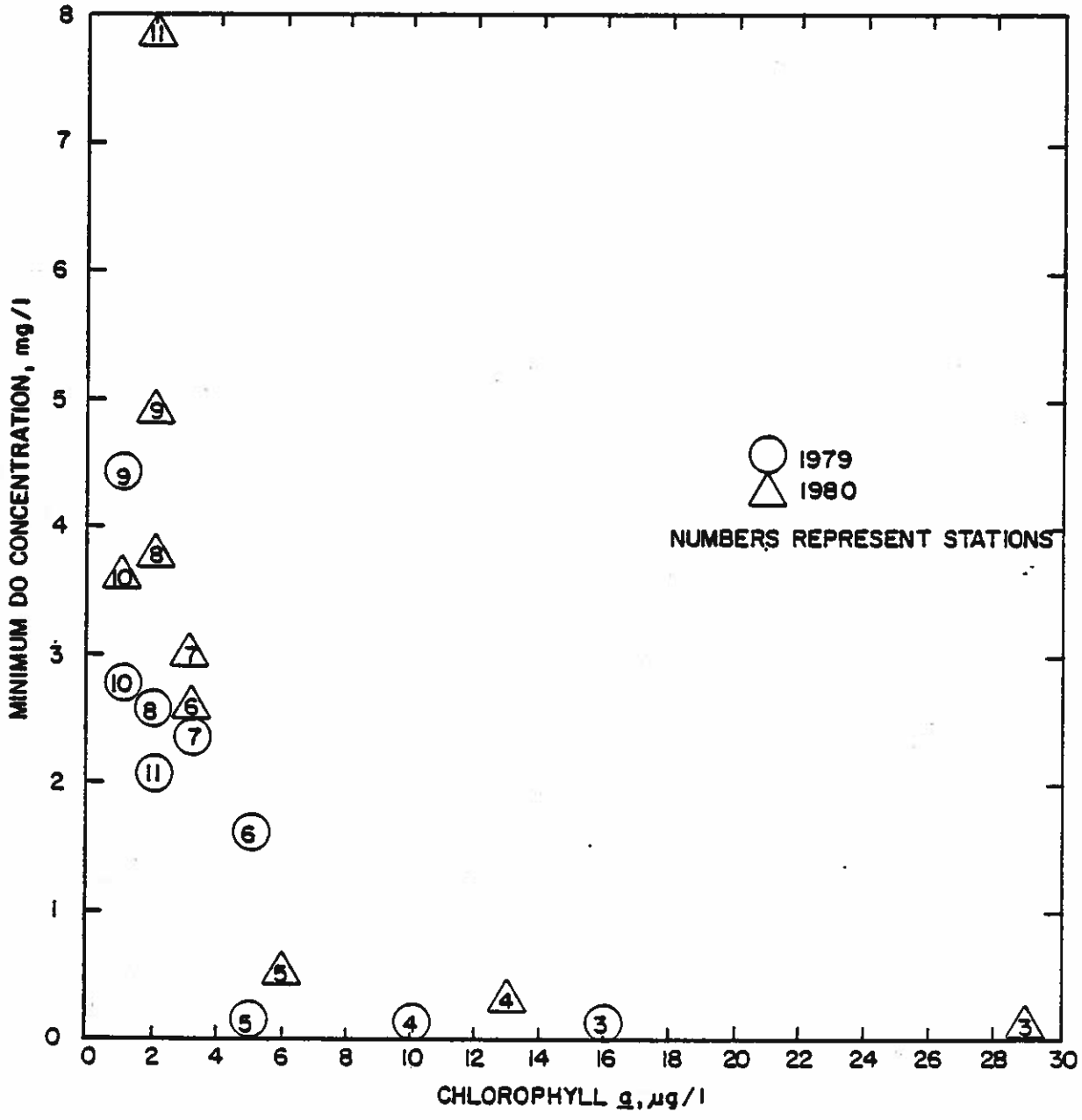


Figure 9-10 Relationship Between Average Summer Chlorophyll a and Minimum DO Concentration in Lake Mead

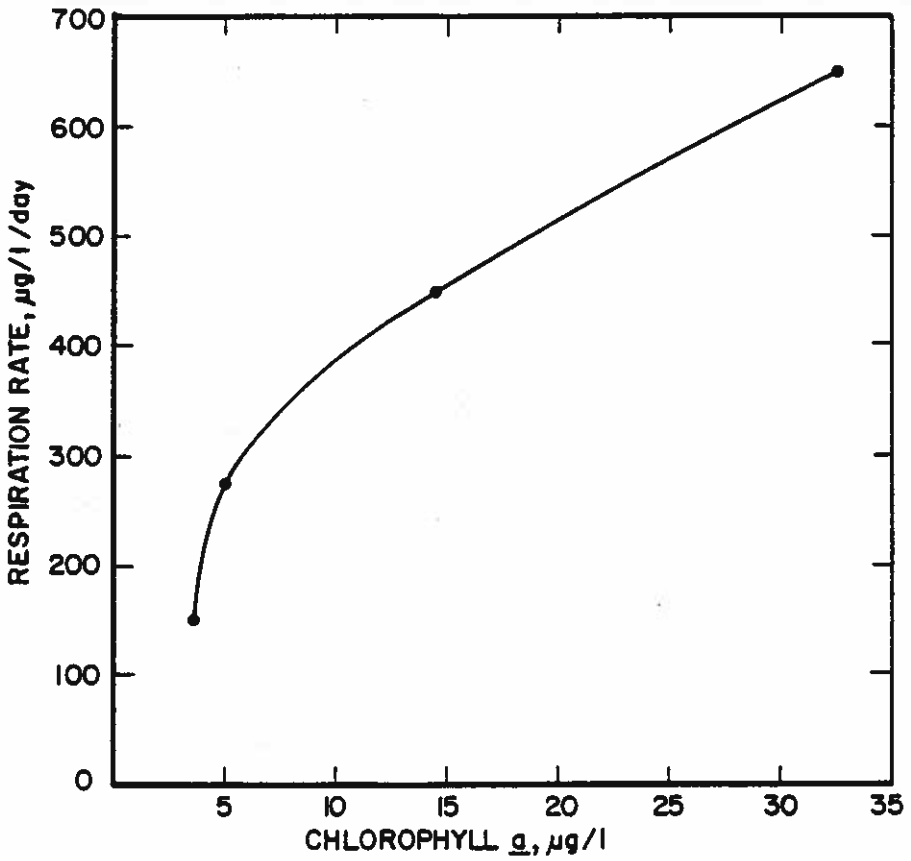


Figure 9-11 Respiration Rate Versus Chlorophyll

Oxygen Depletion/BOD Relationship

As demonstrated in the DO balances presented previously, the BOD load from the wash (primarily the nitrogenous portion) is the major oxygen demanding factor in the inner bay. Thus, the relationship between oxygen demand and BOD load was investigated. Oxygen data from Station 3 were available from 1977 through 1980. Ammonia and nitrite loads from 1977 through 1980 were used to calculate the nitrogenous BOD load to the inner bay. The relationship between the carbonaceous BOD load and the nitrogenous BOD load in 1980 was used to estimate the carbonaceous BOD for 1977 through 1979. The average daily total BOD load during the depleted period (April through September)

was calculated. The total BOD load (nitrogenous and carbonaceous) is plotted against three DO parameters on Figure 9-12:

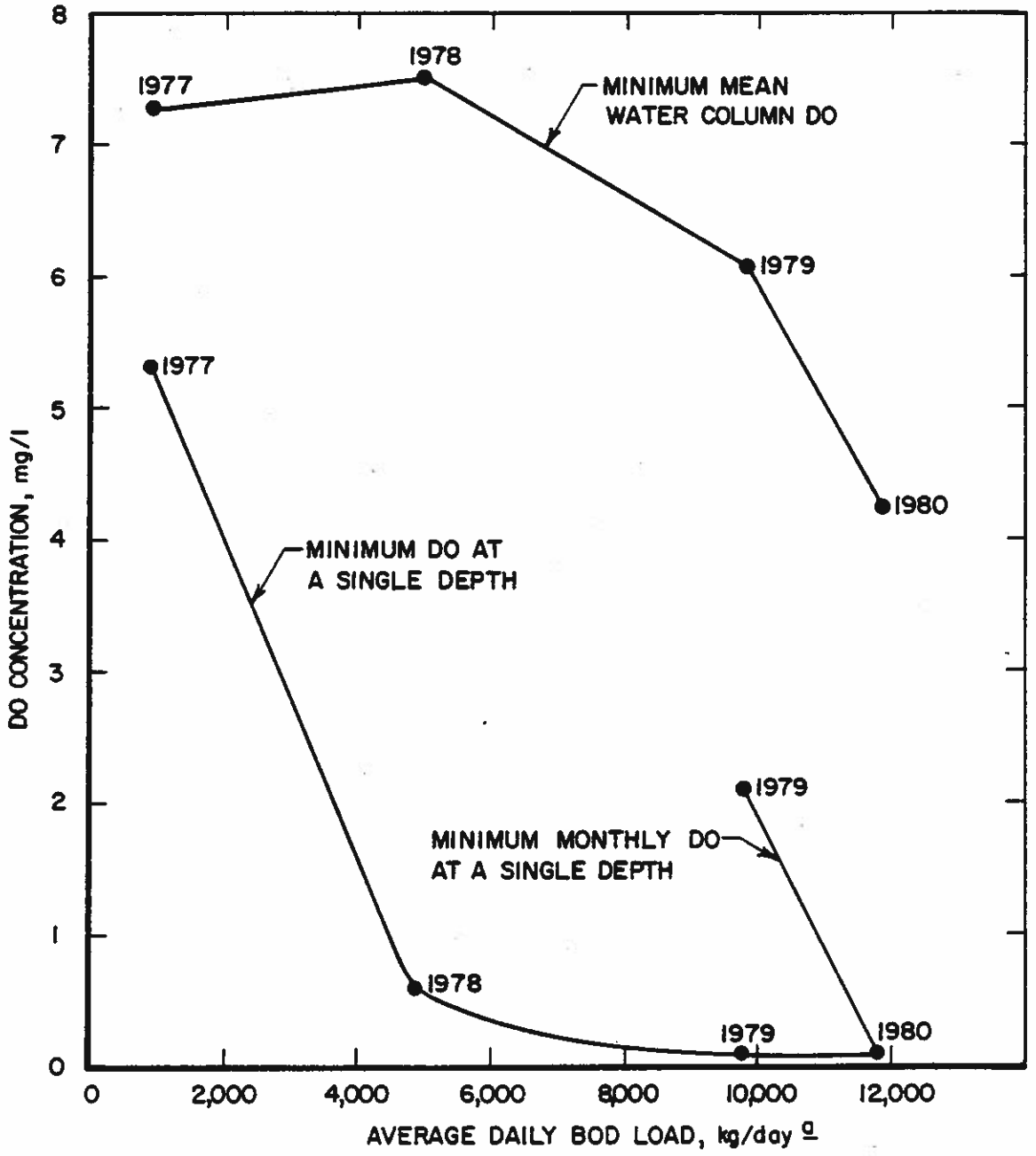
1. Minimum DO at a single depth--This value is the lowest DO measured at Station 3 for each year.

2. Minimum mean water column DO--The mean DO over the water column was computed for each sampling run during the summer and the lowest mean was selected for each year.

3. Minimum monthly DO at a single depth--The approximate depth of lowest DO was determined for each sampling run. The mean of the weekly DO concentrations at that depth for each summer month were averaged and the lowest monthly mean was selected. This value could not be determined for 1977 and 1978 since only one sampling run was conducted.

There is a general trend of decreasing DO as the total BOD load increased. For example, between 1977 and 1978, the BOD load increased five fold. During this time, the minimum DO concentration at Station 3 dropped from 5.3 mg/l to 0.6 mg/l, although this DO decrease is not reflected in the minimum mean water column DO. There were further increases in the BOD load during 1979 and 1980. The minimum DO dropped to 0.1 mg/l. More data are needed in the 1 to 5 mg/l DO range to better define the DO/BOD relationship. Once the DO drops below about 0.5 mg/l, further increases in BOD will have little effect on the minimum DO concentration since it is already near zero. These relationships are not sufficiently precise for use in computing a TMDL, but they do provide an approximate indication of the DO/BOD relationship for the inner bay. The curves in Figure 9-12 are very sensitive in the low DO areas and could be affected by low DO measurements made at the sediment-water interface.

1981 BOD Loads



a This is ultimate oxygen demand and consists of both carbonaceous and nitrogenous BOD

Figure 9-12 Relationship Between Las Vegas Wash BOD Load and Minimum DO Concentration in Inner Las Vegas Bay, WQSS Station 3

EFFECT ON BENEFICIAL USES

The current beneficial uses of Lake Mead are water supply, recreation, boating, fish and wildlife, irrigation, and hydropower. These uses are discussed in detail in Chapter 4. Dissolved oxygen concentrations affect the beneficial uses of water supply, body-contact recreation, boating, and fish and wildlife. Of these uses, the fishery is the one which is most sensitive to DO concentrations, and thus, is the focus of this discussion.

Criteria Review

The DO concentrations in the lake are compared to criteria published by the State of Nevada, U.S. Environmental Protection Agency (EPA), the National Academy of Sciences (NAS), and the European Inland Fisheries Advisory Commission (EIFAC) in this section.

The dissolved oxygen concentration of a waterbody affects the beneficial uses of recreation, water supply, and fish. The water must remain aerobic to avoid septic conditions associated with anaerobic water. If there is insufficient oxygen in the water column anaerobic decomposition of organic matter produces noxious gases such as hydrogen sulfide.[19] The resultant "rotten-egg" odor interferes with the aesthetic enjoyment of recreational users.

The water must remain aerobic for municipal water supplies.[19] Dissolved oxygen in the water prevents the chemical reduction and leaching of iron and manganese. If these

metals are present in the water, more expensive treatment of drinking water is required. The presence of these metals leads to consumer taste problems and stained plumbing fixtures.[19] Ammonia is reduced to nitrate when DO is present in the water. This reduces the chlorine demand and improves the effectiveness of chlorination for disinfection.

The current State of Nevada dissolved oxygen standard for Lake Mead is stated as follows:[20]

For various points in Lake Mead:	
Average (June through September)	Not less than 6.0 mg/l
Single value	Not less than 5.0 mg/l

Although not specifically stated, the 5.0 mg/l standard is intended to apply year-round. The primary purpose of this standard is to provide an environment conducive to the development and maintenance of a diverse fishery. The EPA recommends DO concentrations greater than or equal to 5 mg/l for the maintenance of a fishery.[19]

The NAS recommends criteria based on the naturally occurring minimum DO concentration in the waterbody.[21] The naturally occurring minimum DO is defined as the minimum saturation value unless there is data to show that lower DO levels prevailed naturally. The NAS criteria are summarized below:

1. For maximal protection of fish and other aquatic life, the minimum DO should not be less than the natural minimum.

2. For a high level of protection of fish
   criterion = $1.41M - 0.0476M^2 - 1.11$.

3. For a moderate level of protection of fish criterion = $1.08M - 0.0415M^2 - 0.202$.

4. For a low level of protection of fish criterion = $0.674M - 0.0264\ M^2 + 0.577$.

In all of these equations M is the naturally occurring minimum DO concentration

The NAS also recommends a minimum DO value of 4 mg/l except in situations where the naturally occurring DO level is less than 4 mg/l. In those cases, no further depression of the DO concentration should occur. The NAS recommends that the criteria not apply to the hypolimnion of eutrophic lakes.

According to the EIFAC, the oxygen requirements of fish differ between species, between the various life stages (eggs, larvae, and adults) and between the different life processes (feeding, growth, and reproduction).[22] A DO standard must reflect these factors in addition to the type of fishery, the times and places the fish occur, and the likely impact on the fishery of impairment of each part of the life cycle. The EIFAC recommend a criterion for moderately tolerant freshwater fish, such as roach, of greater than 5 mg/l for 50 percent of the year and greater than 2 mg/l for 95 percent of the year. The recommended criterion for salmonids is greater than 9 mg/l for 50 percent of the year and greater than 5 mg/l for 95 percent of the year.

According to the EIFAC, mature fish can survive in water containing 3 mg/l of DO when other conditions are favorable.

Lethal levels are often lower than this. Lethal levels of DO for salmonids range from 0.95 to 3.4 mg/l. The lethal levels for non-salmonid species range from 0.42 mg/l to 3.0 mg/l. Young fish tend to be less tolerant than mature fish. According to Coutant, striped bass prefer DO concentrations greater than 3 mg/l.[23]

Laboratory data indicate that DO concentrations lower than 5 mg/l impair fish survival, growth, reproduction, swimming ability, and behavior. Little information is available on the effect of DO on fertilization and fecundity.[22] Turner and Farley reported a decrease in survival of striped bass eggs with an increase in temperature or a decrease in DO.[24] Development and embryonic growth of salmonids are retarded when DO concentrations are reduced below the saturation level. Most salmonids will hatch successfully at 2 to 3 mg/l and produce small viable larvae. Largemouth bass will produce normal larvae at 2 mg/l to 3.5 mg/l at temperatures ranging from 15 to 25°C. Growth of juvenile fish is slowed when DO concentrations drop to 3 mg/l to 4 mg/l.

Low DO concentrations affect fish behavior. Swimming speeds are reduced when the DO concentration drops to 4 mg/l to 5 mg/l.[22] This makes it more difficult to catch food and to avoid predators. There is some evidence that fish will avoid areas of low DO, although there is considerable variation in the levels avoided by fish.[22] Serns demonstrated that rainbow trout will swim through a 1 to 2 meter layer of water in the metalimnion with less than 2 mg/l of DO.[25]

In summery, our review of the literature indicates that 5 mg/l of DO is needed to protect a diverse fishery and that

concentrations less than 3 mg/l can have acute effects on non-salmonid species. On this basis, the following DO criterion is recommended: the average DO concentration over the water column should not be less than 5 mg/l and the monthly average DO concentration at any point in the water column should not be less than 3 mg/l. Since low DO concentrations occur in most lakes at the sediment-water interface, approximately the lower 1m of the water column should be excluded.

Comparison of Criteria to Existing Conditions

From December through May, DO concentrations are close to saturation throughout the water column. However, DO depletion occurs below the thermocline when the lake is stratified. A zone of oxygen depletion occupies a large volume of water in Las Vegas Bay during the summer months. As illustrated on Figure 9-6, 50 percent of the volume of Las Vegas Bay has DO concentrations less than 5 mg/l during the end of the summer. Approximately 25 percent of the volume has DO concentrations less than 3 mg/l at that time. Although the zone of depletion occupies a large volume of water in Las Vegas Bay during the summer months, there is only a small volume of water in other areas of the lake in which the DO concentration drops below 5 mg/l. Less than 10 percent of the volume of Bonelli Bay had DO concentrations less than 5 mg/l during the fall of 1980. Based on data collected in Boulder Basin, Virgin Basin, and Bonelli Bay, concentrations lower than 3 mg/l occur infrequently.

Table 9-8 compares DO conditions during the summer of 1980 to the proposed DO criterion. The DO concentration was slightly less than the mean water column DO criterion of 5 mg/l

during July through September at Station 4, during August and September at Station 5, and during July at Station 3. DO concentrations at Stations 3 and 4 were significantly less than the monthly mean DO criterion of 3 mg/l and the DO concentration at Station 5 was less than the 3 mg/l criterion during the month of September. The very low DO values at Station 3 may be measurements made very close to the lake bottom and would likely be excluded from the proposed criterion.

Table 9-8. Comparison of 1980 Dissolved Oxygen Conditions to Proposed Criterion

	Dissolved Oxygen, mg/l					
	Station					
Parameter	1	2	3	4	5	6
Minimum mean water column DO on a single day						
July 1980	8.9	7.7	4.3	4.1	5.0	5.9
August 1980	9.0	7.6	5.5	4.2	4.2	5.6
September 1980	8.9	6.6	5.4	4.1	4.5	5.1
Minimum monthly DO at a single depth						
July 1980	9.9	6.0	0.6	2.8	3.8	5.1
August 1980	10.6	7.5	0.1	1.7	3.0	3.9
September 1980	9.0	6.7	1.8	1.4	2.0	3.4

There are several other important factors that must be considered in addition to oxygen concentrations in assessing the effects on the fishery. These factors include availability of spawning habitat, fish population dynamics, food sources, and temperature.

As discussed previously, largemouth bass and striped bass are the two major game species in Lake Mead. The largemouth bass population has declined steadily since the formation of Lake Powell in 1963. This is most likely due to decreased spawning areas due to the spring drawdown in Lake Mead.[26] The striped bass population increased dramatically between 1978 and 1979, but the condition of the fish has worsened. Researchers at UNLV claim that the game fish are starving because their prime food source, threadfin shad, have declined.[26] The decline in the threadfin shad population may be due to decreased algal productivity of the lake.[27]

The echo sounding data on fish distribution collected during the WQSS indicate that threadfin shad were often found above 10 meters at Station 2 and near the surface at Station 5. Fish were occasionally detected at Station 8 and very rarely detected at Stations 9 and 10. The shad population appeared to be primarily confined to the surface waters of the inner bay based on the limited data collected in the WQSS. Since shad feed on plankton, their preference for the inner bay is probably related to the large phytoplankton and zooplankton populations in this area.

According to Coutant, striped bass prefer temperatures less than 23°C.[23] Temperatures below 23°C were generally confined to the area below the thermocline during the summer months. This coincides with the area depleted of oxygen during the summer months. Striped bass generally stay below the thermocline and then swim up into the surface waters to feed. They feed in the surface waters for a few seconds to a minute and then swim down into the cooler water.[27]

Figure 9-13 shows the areas of Las Vegas Bay in which the temperature exceeds 23°C and the DO concentration is less than 3 mg/l for several dates during the summer of 1980. The areas of the lake where shad populations were detected on those dates are also shown. In the early summer, the low DO zone (less than 3 mg/l) was confined to a small area near Stations 3 and 4. The striped bass could avoid the low DO area and still remain in the cooler water below the thermocline. They could swim into the surface waters without going through a low DO zone. Toward the end of the summer, the low DO zone occupied much of the area below the thermocline at Stations 4 and 5 and a small area at Station 6. If the striped bass avoided this more extensive zone of low DO, they would be forced to remain in the surface waters where the temperature ranged from 24° to 26°C or they would be forced into the area below the thermocline in the outer bay. This would remove them from their food supply in the surface waters of the inner bay.

The low concentrations of DO in the inner and middle portions of Las Vegas Bay may be stressing the fish population for a few months during the late summer. The Nevada Department of Wildlife is currently conducting studies of the largemouth bass and striped bass populations in Lake Mead.[27] The results of these studies will provide more information on the fish populations.

CONCLUSIONS

Based on the dissolved oxygen analysis performed, the following conclusions can be made:

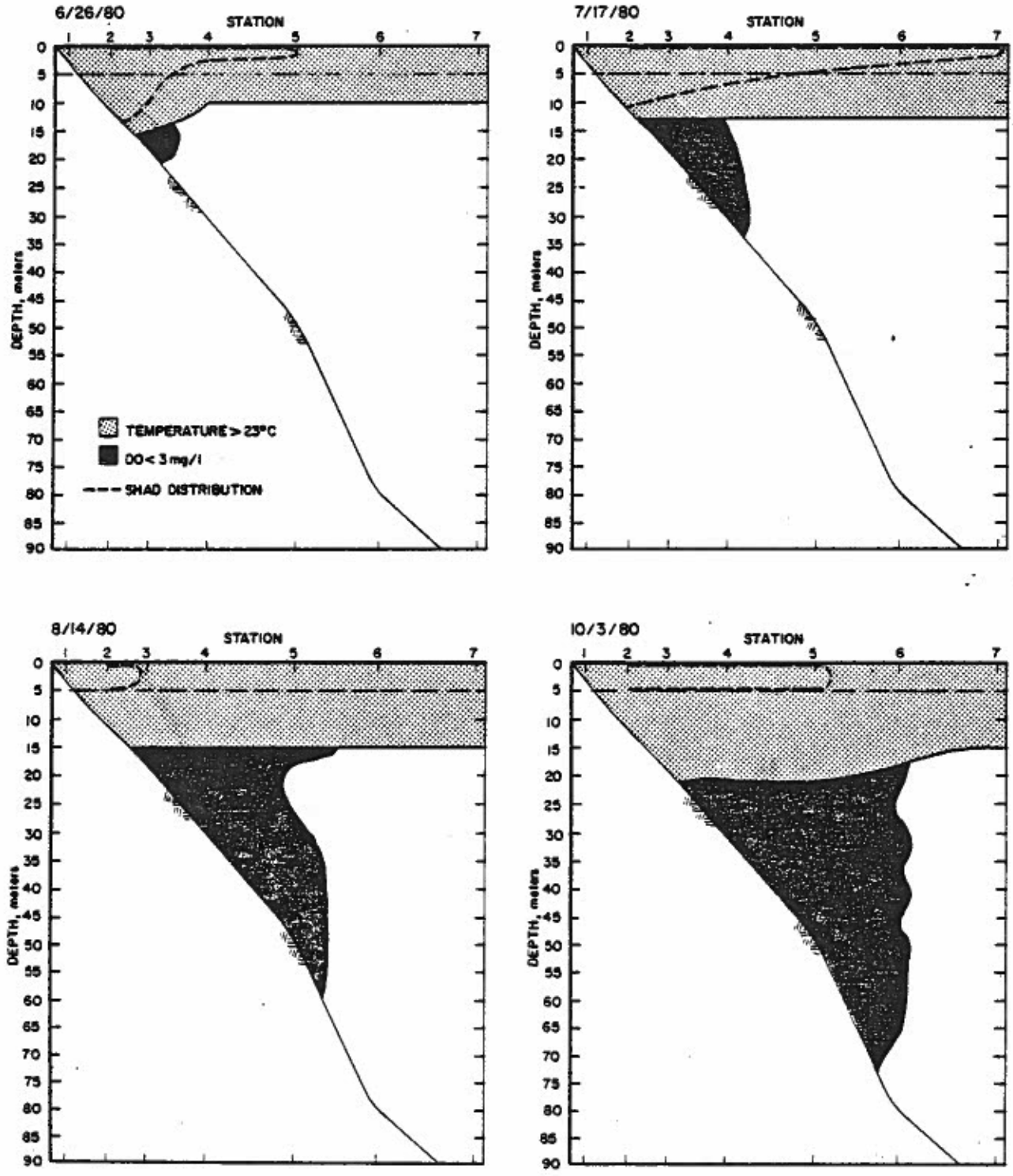


Figure 9-13 Toxic Zones and Shad Distribution in Las Vegas Bay

1. The metalimnetic minimum of DO occurs throughout Lake Mead during the summer period of thermal stratification. The depletion in Las Vegas Bay is more severe than in Bonelli Bay and Virgin Basin. In Las Vegas Bay, DO concentrations drop below the current standard of 5 mg/l between depths of 15 meters and 50 meters throughout most of the summer.

2. The minimum DO concentration in Bonelli Bay was generally near 3 to 4 mg/l, whereas the minimum concentration in Las Vegas Bay was less than 1 mg/l. The oxygen-depleted zone occupied a greater volume of water in Las Vegas Bay. For example, 40 to 50 percent of the volume of Las Vegas Bay and 5 to 10 percent of the volume of Bonelli Bay had dissolved oxygen concentrations less than 5 mg/l during September.

3. Results of the DO balance for overall Las Vegas Bay indicated that respiration by algae and zooplankton accounted for about 90 percent of the oxygen demand, while nitrogenous and carbonaceous biochemical oxygen demand (BOD) from the wash accounted for most of the remainder. In the inner bay, the BOD from the wash was the major oxygen-demanding factor accounting for about 80 percent of the demand, while respiration accounted for most of the remainder.

4. Based on a review of agency criteria documents and literature sources, the following water quality criterion is recommended to protect the Lake Mead fishery: mean DO over the water column should not be less than 5 mg/l and monthly mean DO at any point in the water column should not be less than 3 mg/l.

where is bars for 22,000 lbs TMDL in chap 13?

CHAPTER 10

AMMONIA

A large amount of ammonia (2,100 kg) is discharged from Las Vegas Wash to Las Vegas Bay each day. The ammonia load from the wash has been increasing since 1977. This chapter analyzes ammonia data collected in Lake Mead and assesses the potential for ammonia toxicity to the fishery.

INTRODUCTION

The need to analyze the potential for ammonia toxicity was identified during Water Quality Standards Study (WQSS) planning and preliminary data analysis work. This section describes the background of the ammonia issue, objectives of the analysis, and the organization of this chapter.

Background

Un-ionized ammonia is toxic to fish and other forms of aquatic life. Un-ionized ammonia (NH_3) dissociates in water to form ammonium ions (NH_4^+) and hydroxide ions (OH^-). The concentration of un-ionized ammonia is a function of the concentration of total ammonia, temperature, pH, and the total dissolved solids concentration of the water. The concentration of un-ionized ammonia increases as temperature and pH increase and the total dissolved solids concentration decreases. The un-ionized form of ammonia is the toxic form.[1] A study by Tabata suggests that NH_4^+ may also be toxic but it is about 1/50 as toxic as the un-ionized form of ammonia.[2] In most natural waters the ammonium ion form of ammonia predominates, however, in alkaline waters the concentration of un-ionized ammonia can reach toxic levels.

The need to address the ammonia issue was identified in the preliminary WQSS work. Ammonia data were compiled for two data review summaries and were discussed at the review meetings. The need to conduct further analysis on the ammonia issue was reiterated in the Annual Report. During the Annual Report review process, supplemental funding for the ammonia analysis was proposed, but was never authorized by the Water Quality Study Board (WQSB).

Objectives

The major objectives of the ammonia toxicity analysis are:

1. Determine the magnitude and extent of un-ionized ammonia concentrations in Las Vegas Bay.
2. Determine if the un-ionized ammonia concentrations in the bay have an impact on the beneficial uses of the bay.

Chapter Organization

This chapter is organized into seven sections:

1. Introduction.
2. Methodology--The field and laboratory methods and the method of calculating un-ionized ammonia concentrations are discussed.
3. Results--The seasonal and spatial variations in un-ionized ammonia concentrations are discussed. Las Vegas Bay is also compared to Bonelli Bay.

4. Data Comparisons--The historical un-ionized ammonia concentrations are compared to concentrations during the WQSS.

5. Analysis--The factors affecting ammonia toxicity, the relationship between chlorophyll and pH, and the relationship between ammonia loads and un-ionized ammonia concentrations in the bay are presented.

6. Effect on Beneficial Uses--The effects of un-ionized ammonia on the beneficial uses of the bay and criteria necessary to protect the uses are discussed. The extent of the toxic zone in the bay is presented.

7. Conclusions.

METHODOLOGY

The field and laboratory methods for parameters related to the ammonia toxicity issue are presented in this section. The factors affecting un-ionized ammonia concentrations and the method of calculating un-ionized ammonia concentrations are also presented.

Field and Laboratory Methods

Several parameters related to the ammonia toxicity issue were measured as part of the routine limnological monitoring program. Ammonia concentrations were determined in the epilimnion, metalimnion, and hypolimnion at most stations in Las Vegas Bay. Samples were only collected at the surface at

Station 1 and in the epilimnion and at 10 meters at Station 2. Profiles of pH, conductivity, and temperature were taken during every sampling trip. Alkalinity was measured at 5 meter intervals at Stations 2, 5, 8, 9, and 10 on the days that primary productivity was determined. A list of the parameters analyzed and the purpose of each analysis are presented in Table 10-1. A detailed description of the analysis techniques is presented in Appendix A.

Table 10-1. Parameters Related to Ammonia Toxicity Issue

Analysis	Purpose of analysis
Ammonia	Ammonia concentrations needed to calculate un-ionized ammonia.
pH	Used in un-ionized ammonia calculation.
Conductivity	Used to calculate total dissolved solids (TDS). TDS used in un-ionized ammonia calculation.
Alkalinity	Indicates buffering capacity of water.
Temperature	Used in un-ionized ammonia calculation.

Factors Affecting Un-ionized Ammonia Concentrations

Ammonia dissociates in water to form the ammonium ion, as illustrated by the following reaction:

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

The pH, temperature, and total dissolved solids concentration of the water affect the amount of ammonia in the un-ionized form (NH_3). As the pH of the water increases, the percent of ammonia in the un-ionized form increases. For example, the amount of ammonia in the un-ionized form at 25°C increases from

0.057 percent of the total ammonia concentration at pH 6.0 to 64 percent at pH 9.5. An increase in temperature also increases the amount of un-ionized ammonia in the water. Temperature does not influence the percent of un-ionized ammonia as strongly as pH does. For example, the percent of ammonia in the un-ionized form at pH 8.0 increases from 1.2 percent at 5°C to 7.5 percent at 30°C. As the total dissolved solids (TDS) concentration of freshwater increases, the fraction of un-ionized ammonia decreases. The impact of the TDS concentration on the un-ionized ammonia concentration is much less than the impact of temperature or pH. For example, the percent of ammonia in the un-ionized form at 25°C and pH 6.0 decreases from 0.057 percent at 0 mg/l TDS to 0.044 percent at 3,000 mg/l TDS. The pH and total ammonia concentration of the water are the main factors influencing the amount of ammonia in the un-ionized form.

Un-ionized Ammonia Calculation

To calculate the fraction of ammonia that is in the un-ionized form the total ammonia concentration, pH, temperature, and total dissolved solids concentration are needed. Since TDS measurements were not made during the WQSS, the following relationship between conductivity and TDS was used to estimate the TDS of the water:

Dissolved solids (mg/l) = 0.7 conductivity (umhos/cm)

This relationship has been found in many natural waters[3] and is applicable to Lake Mead based on a review of WQSS data. Tables presenting the fraction of ammonia in the un-ionized form developed by the Sanitary Engineering Research Laboratory (SERL) of the University of California at Berkeley were used to determine the un-ionized ammonia

concentrations in Lake Mead.[4] An example calculation of the un-ionized ammonia concentration of a hypothetical sample is presented below.

Sample conditions

total ammonia = 5.0 mg/l
pH = 9.0
temperature = 20°C
total dissolved solids = 1,000 mg/l

Excerpt from SERL table

TDS = 1,000 mg/l

	Temperature, °C	
pH	20	30
7.0	0.0067	0.0136
9.0	0.253	0.408

For the conditions given above, the fraction of ammonia that is in the un-ionized form is 0.253. The un-ionized ammonia concentration is:

total ammonia (5.0 mg/l) x 0.253 = 1.3 mg/l of un-ionized ammonia

This method was used to calculate the un-ionized ammonia concentrations in Las Vegas Bay and Bonelli Bay during the WQSS.

RESULTS

The concentrations of un-ionized ammonia were calculated for the Las Vegas Bay and Bonelli Bay stations. Seasonal, spatial, and frequency distributions of the data are presented in this section. The Las Vegas Bay data are compared to the natural or background conditions that occur in Bonelli Bay.

Seasonal Distribution

The concentrations of un-ionized ammonia at Stations 1 to 4 in Las Vegas Bay are presented on Figure 10-1. The concentrations were highest during the spring and summer months when temperatures were highest and algal-induced increases in pH were greatest. The concentrations were generally near 0.001 mg/l during the winter months at all four stations. The concentrations at the surface of Station 1 ranged from less than 0.001 mg/l to 0.46 mg/l during the spring and summer. The concentrations during the winter and fall ranged from less than 0.001 to 0.062 mg/l. The same seasonal trend occurred at Stations 2 and 3. At Station 3, the concentrations in the integrated samples ranged from less than 0.001 to 0.122 mg/l during the spring and summer and from less than 0.001 to 0.048 mg/l during the fall and winter months. At Station 4, the concentrations were generally less than 0.02 mg/l and often less than 0.001 mg/l. On several occasions, the 10 meter and peak samples exceeded 0.02 mg/l. The concentrations were greatest in the plume as shown by the samples collected at 10 meters at Station 2 and at the depth of highest conductivity at Station 3. The higher un-ionized ammonia concentrations in the plume were a result of the higher concentrations of total ammonia in the plume. The un-ionized ammonia concentrations were greater in 1980 than in 1979 at all four stations.

In addition to the total ammonia concentrations, pH, temperature, and conductivity or total dissolved solids concentrations influence the un-ionized ammonia concentrations. The alkalinity of the water affects the ability of the water to buffer changes in pH. The temperature and conductivity data are discussed in Chapter 8. A brief summary of the pH and alkalinity data are presented in this section.

Figures 10-2 and 10-3 present pH and alkalinity profiles at Stations 2 and 5 in Las Vegas Bay for representative seasonal periods during 1980. All of the alkalinity and pH data are contained in the STORET data base. The pH profiles at both stations were similar to the dissolved oxygen (DO) profiles. The pH was generally lowest near the bottom at Station 2 where the DO concentrations were lowest in the summer months. During the spring and early summer, the pH was generally between 8.0 and 8.5 in the surface waters. The elevated pH during those months may be due to the increased photosynthetic activity that occurred in the spring and summer. Through photosynthesis, algae decrease the CO_2 content of the water and this results in elevated pH values. The lowest pH values occurred in the metalimnion at Station 5 where the DO concentrations were lowest during the summer months. The pH of the surface waters during the summer months was generally near 8.5. The pH was reduced to 7.5 in the metalimnion. During the winter months, the pH was generally in the range of 7.5 to 8.2 and was usually constant from surface to bottom. A diurnal study was conducted on November 1 and 2, 1979, at Stations 2 and 5. There were no diurnal variations in pH during that 24-hour period. During the spring and summer months when chlorophyll concentrations are highest, there would likely be some diurnal variation in pH.

Alkalinity measurements were made on the days and at the depths that primary productivity was measured. The alkalinity profiles were generally opposite of the pH profiles as shown on Figures 10-2 and 10-3. The total alkalinity at Station 2 ranged from 87 to 146 mg/l as $CaCO_3$. The alkalinity of the surface waters was generally lower than the bottom waters. The highest alkalinity concentrations

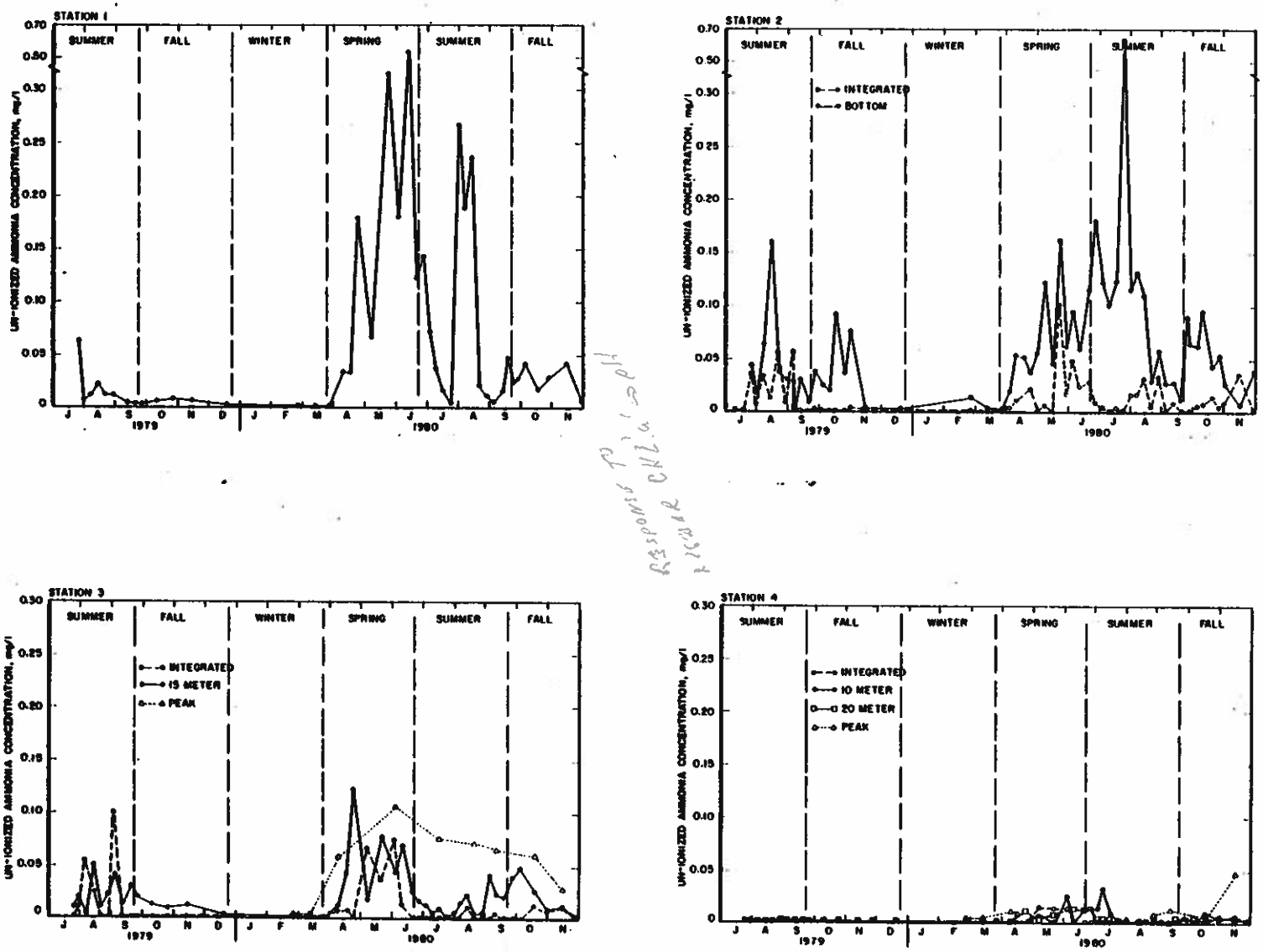


Figure 10-1 Un-Ionized Ammonia Concentrations During the WQSS

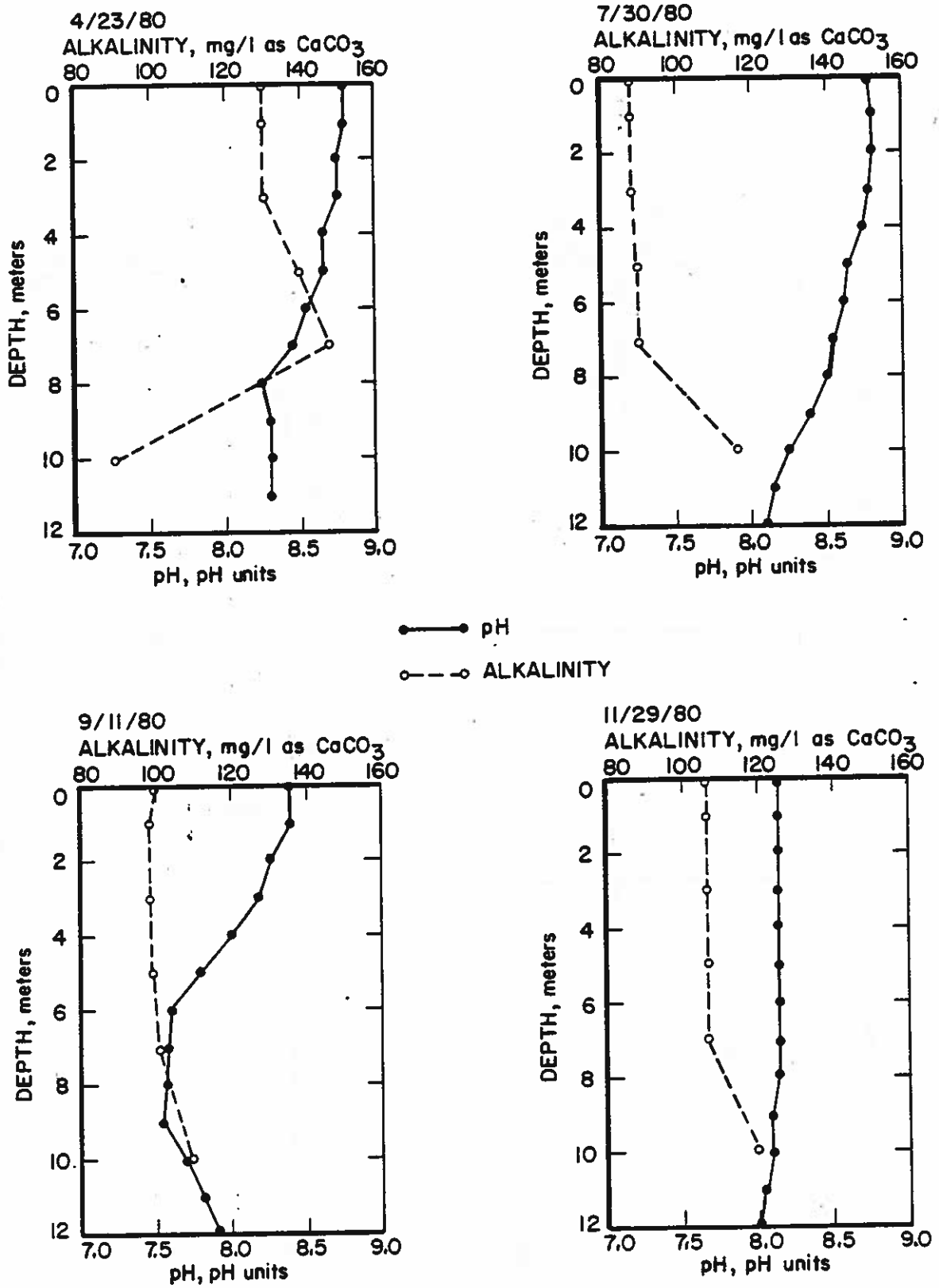


Figure 10-2 pH and Alkalinity Profiles at Station 2

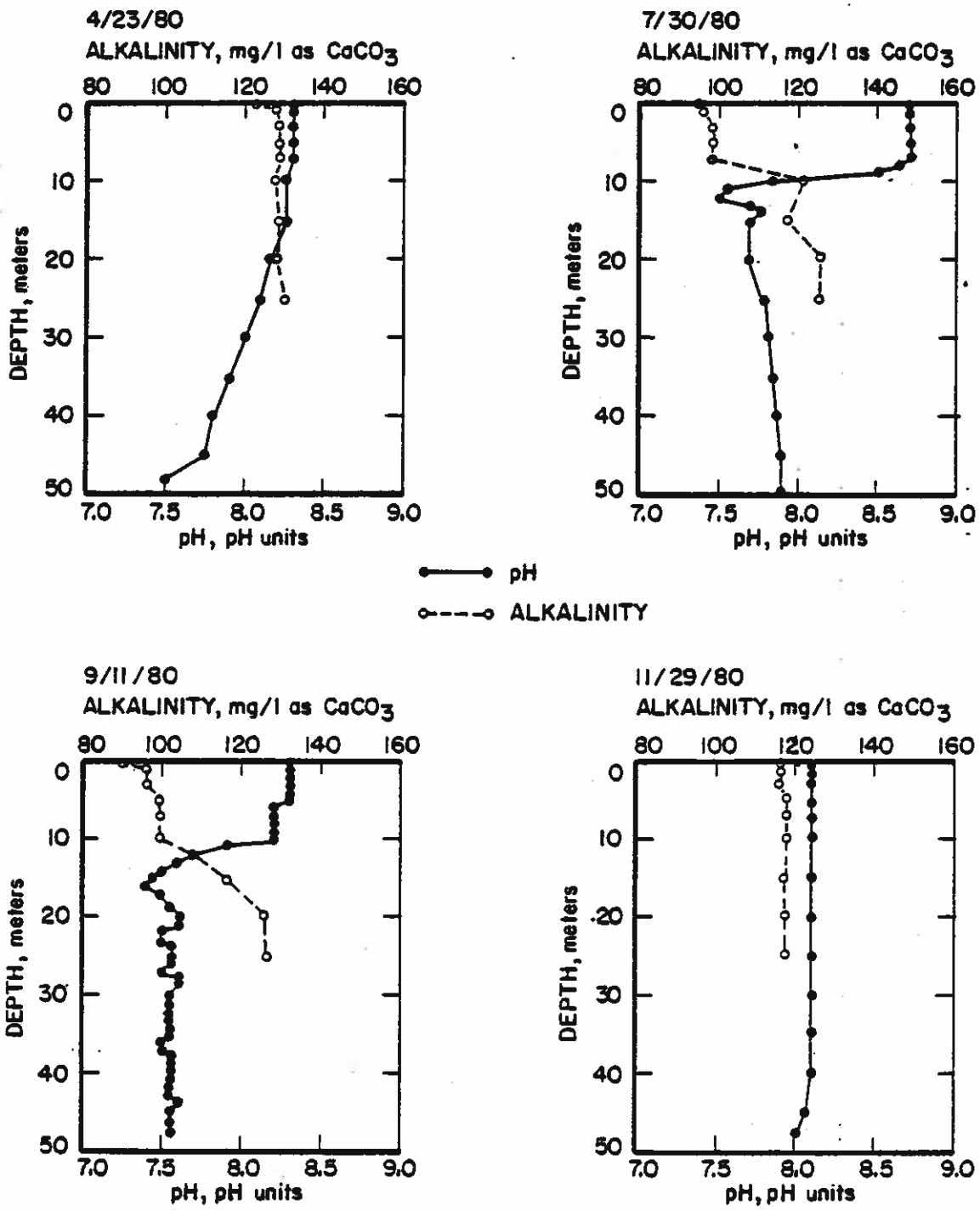


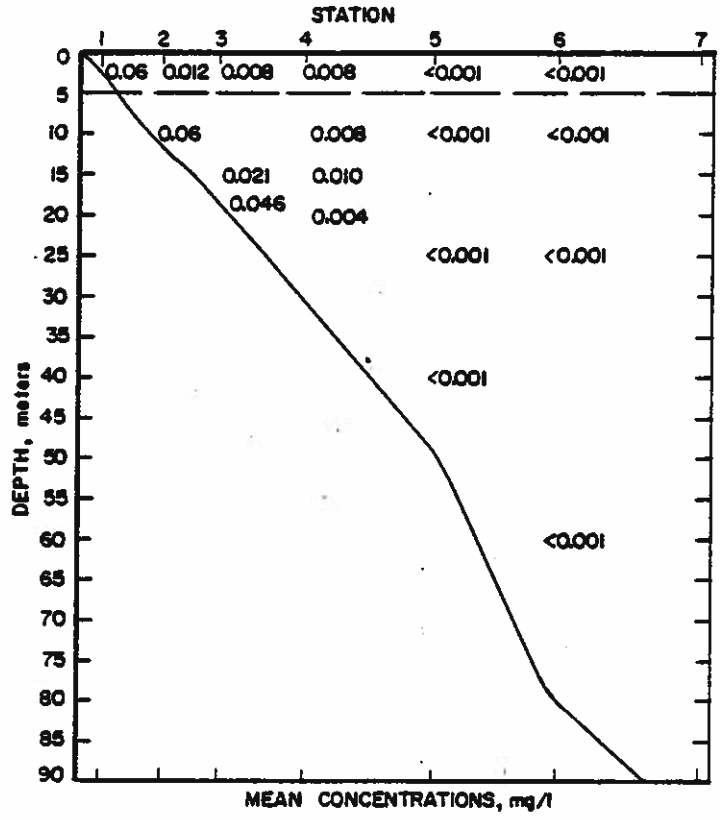
Figure 10-3 pH and Alkalinity Profiles at Station 5

occurred in the area of low DO concentrations where the pH was lowest. The total alkalinity ranged from 91 to 129 mg/l as $CaCO_3$ at Station 5. The lowest values were found in the surface waters and the highest values were found in the metalimnion.

Spatial Distribution

As shown on Figure 10-1, the un-ionized ammonia concentrations were highest at Station 1 and in the plume at Station 2. The concentrations decreased rapidly in the bay; and by Station 4, the concentrations were generally less than 0.02 mg/l. The mean and maximum un-ionized ammonia concentrations at Stations 1 to 6 during the study are presented on Figure 10-4. The highest mean and maximum concentrations occurred in the inner bay near Stations 1 and 2 and in the plume. The mean concentrations were quite low at Station 4 and were less than 0.001 mg/l at Stations 5 and 6. The maximum concentration in the plume at Station 5 was quite high (0.09 mg/l). The maximum concentration decreased to 0.008 mg/l at Station 6. The high un-ionized ammonia concentrations were generally confined to the inner bay near Stations 1 and 2 and in the plume. High concentrations were generally not found beyond Station 3.

The spatial distribution of the pH data in the surface waters at all 11 stations is shown on Figure 10-5. In general, the range of pH values narrowed and the median value decreased with increasing distance from the mouth of Las Vegas Wash in Las Vegas Bay. The median pH value was 8.7 in the surface waters at Station 1. The median value decreased gradually to 8.35 at Stations 6, 7, and 8. The median value ranged from 8.25



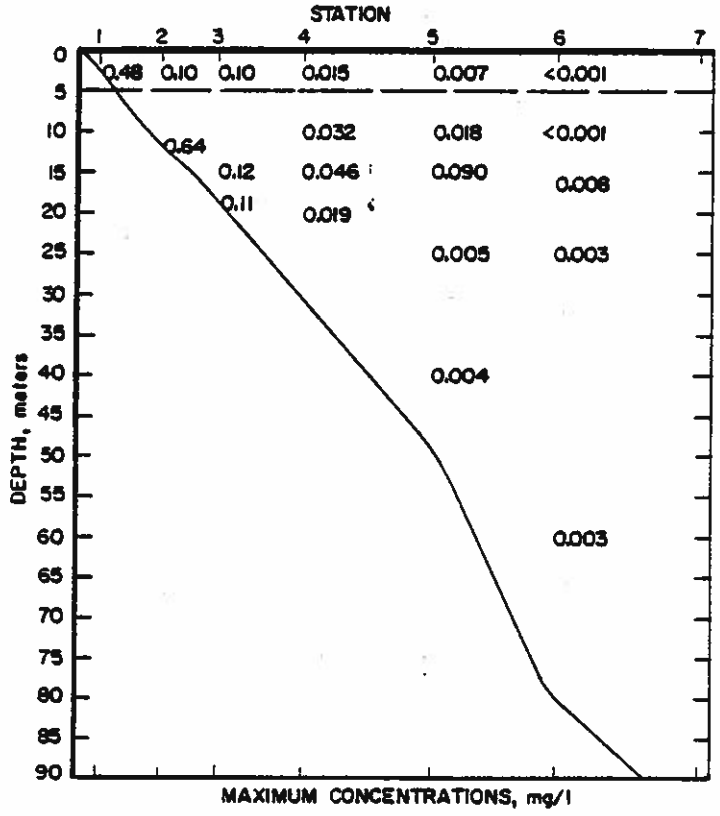


Figure 10-4 Mean and Maximum Un-ionized Ammonia Concentrations in Las Vegas Bay

to 8.3 at Stations 9, 10, and 11. The range of pH values in Bonelli Bay and Virgin Basin was larger than the range in outer Las Vegas Bay and Boulder Basin.

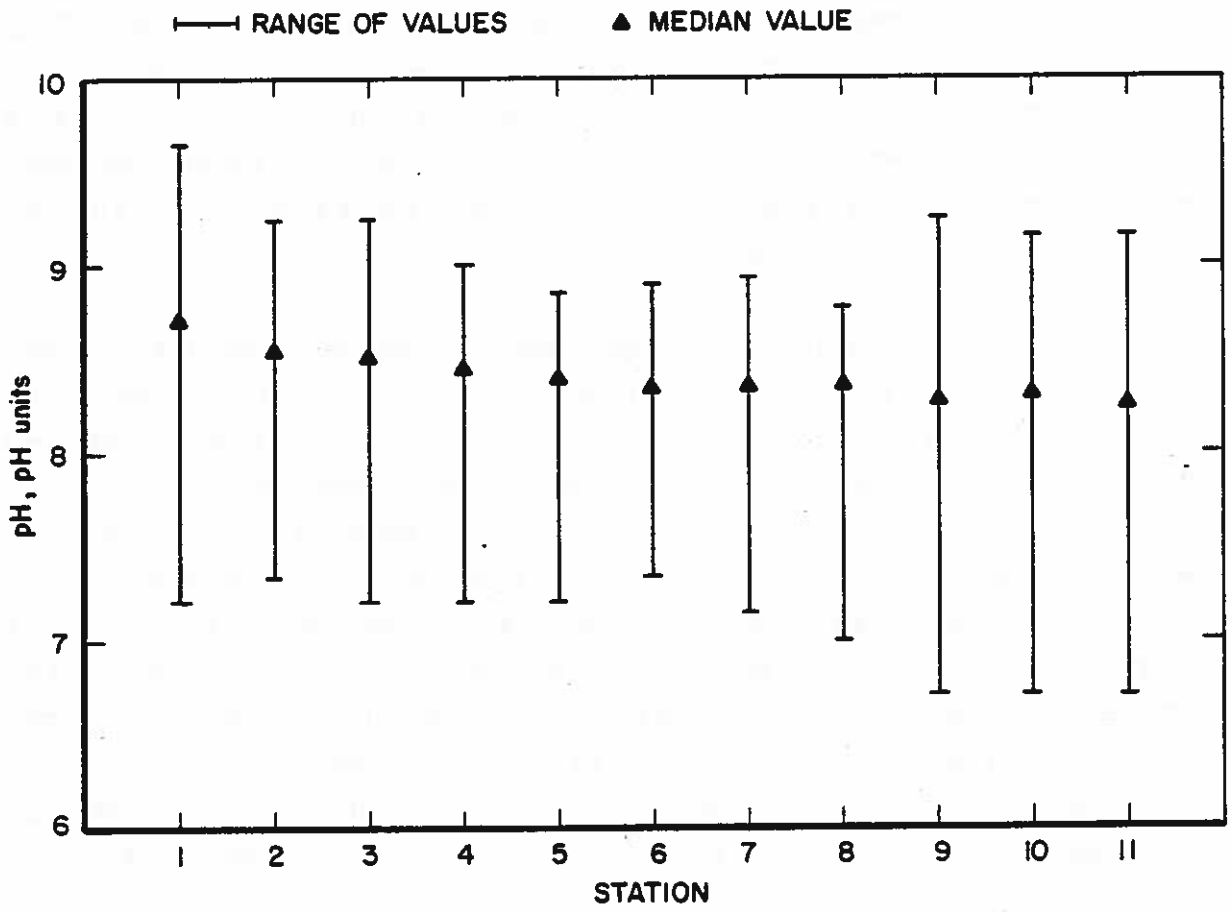


Figure 10-5 Summary of pH Data in Surface Waters

Frequency Distribution

The frequency distributions of the un-ionized ammonia concentrations at Stations 1 to 5 are presented on Figure 10-6.

Since samples were collected more frequently during the summer months than during the winter months, average monthly concentrations were calculated and plotted. In this way, the frequencies represent percent of time, rather than percent of samples. The frequency distributions cover the period from July 1979 through November 1980 so they are still weighted more toward the summer months. Since the un-ionized ammonia concentrations were generally higher during the summer months, the frequency distributions do not represent an annual distribution of the data.

The monthly mean un-ionized ammonia concentrations at the surface at Station 1 ranged from less than 0.001 mg/l to 0.23 mg/l. The median or 50 percentile concentration was 0.024 mg/l. The Las Vegas Wash plume was generally near the bottom at Station 1 so un-ionized ammonia concentrations were higher in the bottom waters than at the surface. Only two measurements were made below the surface at Station 1. A sample was collected at 2.5 meters on August 27, 1980. The un-ionized ammonia concentrations were 0.013 mg/l at the surface and 0.046 mg/l at 2.5 meters. A sample was collected at 3 meters on September 25, 1980. The un-ionized ammonia concentrations were 0.024 mg/l at the surface and 0.082 mg/l at 3 meters. On both of these dates, the surface samples contained 30 percent of the un-ionized ammonia found in the bottom samples.

The monthly mean un-ionized ammonia concentrations in the surface waters at Station 2 ranged from less than 0.001 to 0.038 mg/l. The median concentration was 0.014 mg/l. The concentrations at 10 meters ranged from 0.003 to 0.220 mg/l with a median concentration of 0.041 mg/l. The un-ionized ammonia

concentrations at 10 meters were greater than the concentrations in the surface waters most of the time. The plume was generally at a depth of 12 to 15 meters. Samples were collected in the plume on August 27, 1980, and September 25, 1980. The un-ionized ammonia concentrations were 0.028 mg/l at 10 meters and 0.059 mg/l in the plume on August 27. The concentrations were 0.061 mg/l at 10 meters and 0.090 mg/l in the plume on September 25. On both of these dates, the plume samples were significantly higher than the 10 meter samples.

The monthly mean un-ionized ammonia concentrations in the surface waters at Station 3 ranged from 0.001 to 0.052 mg/l. The median concentration was 0.005 mg/l. The un-ionized ammonia concentrations ranged from 0.001 to 0.048 mg/l with a median concentration of 0.015 mg/l at 15 meters. Samples were collected at the depth of highest conductivity from February through November 1980. The monthly mean un-ionized ammonia concentrations ranged from 0.002 to 0.106 mg/l with a median concentration of 0.067 mg/l. The un-ionized ammonia concentrations in the plume were consistently higher than in the surface waters or at 15 meters.

The monthly mean un-ionized ammonia concentrations in the surface waters at Station 4 ranged from less than 0.001 to 0.015 mg/l with a median concentration of less than 0.001 mg/l. The concentrations were slightly higher at 10 and 20 meters The un-ionized ammonia concentrations ranged from less than 0.001 to 0.016 mg/l with a median concentration of 0.004 mg/l at 10 meters. The concentrations at 20 meters ranged from less than 0.001 to 0.014 mg/l with a median of 0.004 mg/l. Samples were collected at the depth of highest conductivity from February through November 1980. The concentrations ranged from 0.001 to 0.046 mg/l with a median concentration of 0.008 mg/l.

The monthly mean un-ionized ammonia concentrations in the peak conductivity samples at Station 5 from February to November 1980 ranged from 0.001 to 0.090 mg/l. The median concentration was 0.005 mg/l.

Comparison of Las Vegas Bay to Bonelli Bay

The concentrations of un-ionized ammonia at Stations 10 and 11 in Bonelli Bay were calculated for all depths that were sampled. The un-ionized ammonia concentrations were less than 0.001 mg/l at all depths at both stations most of the time. The monthly mean concentrations in the surface waters and at 10 and 40 meters at Station 10 were consistently less than 0.001 mg/l throughout the study. The monthly mean un-ionized ammonia concentration at 15 meters at Station 10 was 0.001 mg/l during June 1980. The monthly mean concentrations were consistently less than 0.001 mg/l during the remainder of the study. The un-ionized ammonia concentrations in the surface waters and at 15 meters at Station 11 were generally less than 0.001 mg/l.

There was generally less than 0.001 mg/l of un-ionized ammonia in Bonelli Bay during the WQSS. The lower un-ionized ammonia concentrations in Bonelli Bay were due to significantly lower concentrations of total ammonia in this area of the lake. The temperature and pH conditions in Bonelli Bay were similar to Las Vegas Bay. The TDS or conductivity in Bonelli Bay was generally slightly lower than in Las Vegas Bay. Since lower total dissolved solids concentrations increase the fraction of ammonia in the un-ionized form, the lower TDS in Bonelli Bay was not responsible for the lower un-ionized ammonia concentrations.

DATA COMPARISONS

The un-ionized ammonia data collected during the WQSS were compared to historical data to determine if the WQSS data represented typical conditions in the lake or if there were any trends in the un-ionized ammonia data.

The un-ionized ammonia concentrations at Station 3 during 1977 and 1978 are presented on Figure 10-7. These data were collected by the University of Nevada at Las Vegas (UNLV), and the samples were analyzed by the same ammonia procedure used during the WQSS so the data are comparable. There was no seasonal trend in the data during 1977. The highest un-ionized ammonia concentrations in the surface and 10 meter samples were found during the spring and summer months of 1978. The un-ionized ammonia concentrations during 1977 and 1978 were much lower than the concentrations during 1979 and 1980. The un-ionized ammonia concentrations in the surface waters ranged from less than 0.001 to 0.122 mg/l during the WQSS. In 1977 and 1978, the concentrations in the surface samples ranged from less than 0.001 to 0.01 mg/l.

Figure 10-8 presents frequency distributions of the mean monthly un-ionized ammonia concentrations in the integrated samples during 1979 and 1980 and in the surface samples during 1977 and 1978 at Station 3. The concentrations during 1977 and 1978 were lower than during 1979 and 1980. The median concentration during the WQSS was 0.005 mg/l during the WQSS and 0.003 mg/l during 1977 and 1978. Frequency distributions of the data collected at 10 meters during 1977 and 1978 and at 15 meters during 1979 and 1980 at Station 3 are presented on Figure 10-8. Since the peak conductivity was typically between

13 and 15 meters during the summer months, the data collected during the WQSS were closer to the plume than the historical data. In general, the WQSS concentrations were higher than the concentrations in 1977 and 1978. The median concentrations were 0.015 mg/l during the WQSS and 0.005 mg/l during 1977 and 1978.

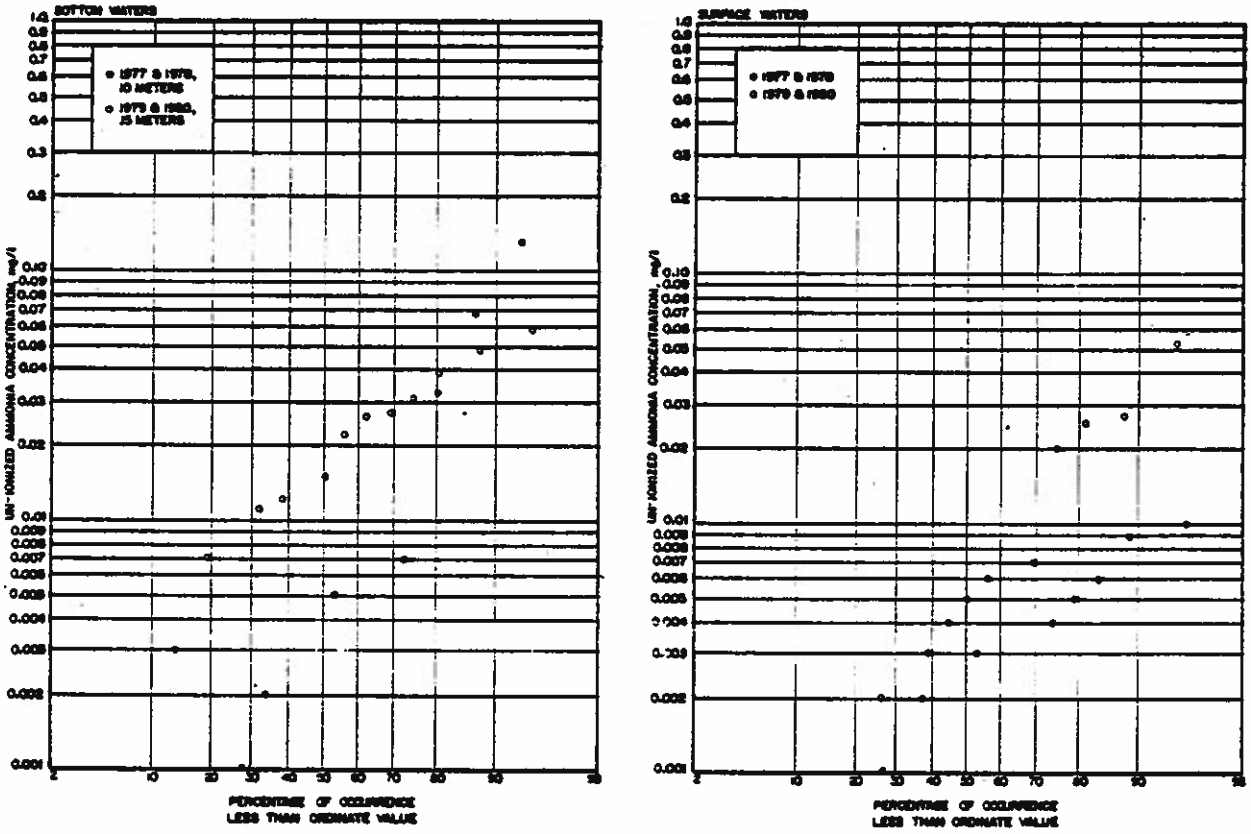


Figure 10-8 Comparison of Historical and WQSS Frequency Distributions of Un-ionized Ammonia Concentrations

The historical data show that the un-ionized ammonia concentrations at Station 3 were generally higher during the

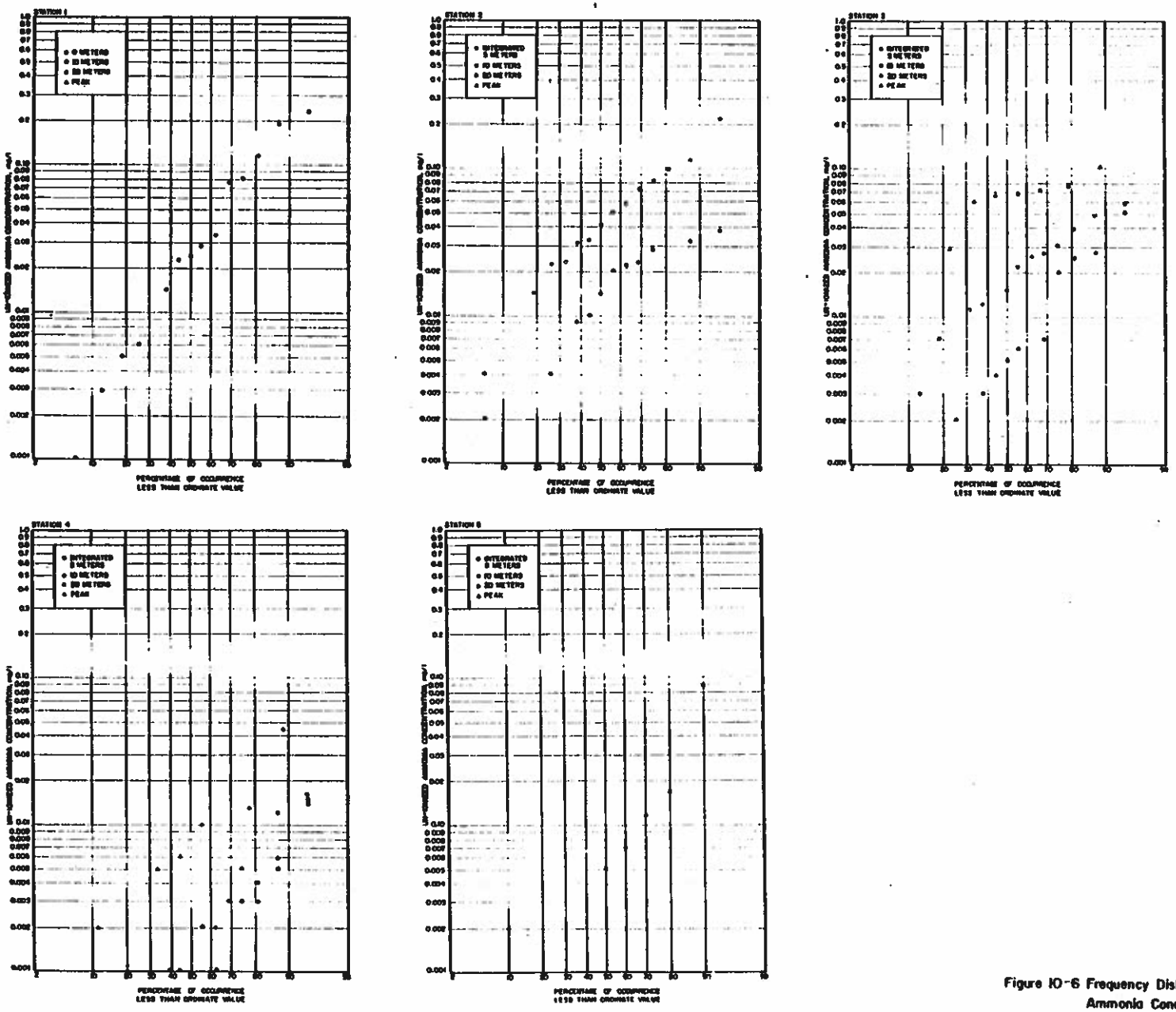


Figure 10-6 Frequency Distributions of Un-Ionized Ammonia Concentrations

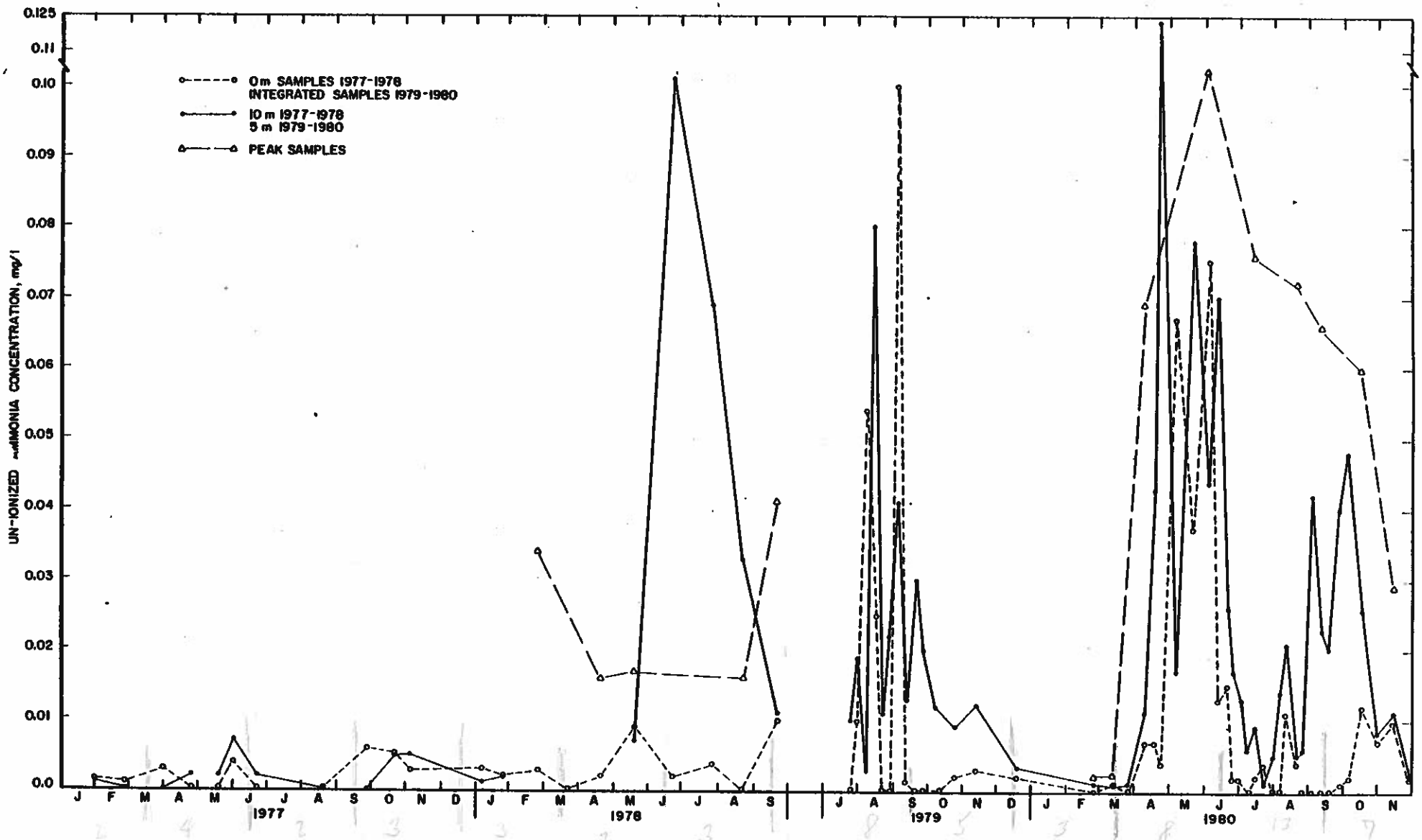


Figure 10-7 Comparison of Historical and WQSS Un-ionized Ammonia Concentrations at Station 3

WQSS than in 1977 and 1978. As discussed previously, the concentrations increased between 1979 and 1980 so it appears that there is an increasing trend in the un-ionized ammonia concentrations in Las Vegas Bay. The large increase between the 1977 to 1978 data and the WQSS data may be partially due to the fact that the WQSS samples were generally collected closer to the plume than the historical samples.

ANALYSIS

The mode of toxic action and the factors affecting ammonia toxicity are presented in this section. Since algae can affect the concentrations of un-ionized ammonia in the surface waters through photosynthetically induced rises in pH, the relationship between chlorophyll concentrations and pH in the surface waters is discussed. The relationship between the total ammonia load from Las Vegas Wash and the concentrations of un-ionized ammonia in the inner bay is also discussed.

Mode of Toxic Action

The mechanism of toxicity of un-ionized ammonia has been investigated by EPA.[5] Ammonia is a waste product produced by the degradation of protein by fish. Since ammonia is a toxic substance it must be excreted or detoxified. There is some evidence that teleost fish must excrete ammonia since they do not have the enzymes required to detoxify it. Since ammonia is soluble in water, it is normally easily excreted by fish across the gill membranes. At the pH of fish body fluids, less than one percent of the total ammonia exists as un-ionized ammonia. Ionized ammonia (NH_4^+) is instantaneously converted to un-ionized ammonia (NH_3) at the gill surface and excreted by

the fish. Ammonia excretion is inhibited if the un-ionized ammonia concentration in the water is high, resulting in toxic concentrations of ammonia in the fish blood.

Sub-lethal concentrations of ammonia have been investigated by EPA[5] and Alabaster and Lloyd.[6] Continuous exposure to sub-lethal levels of un-ionized ammonia causes gill, tissue, liver, and kidney damage. Exposure to ammonia concentrations greater than 12 percent of the LC_{50} increases the rate of absorption of water by fish.[6] The stress imposed by this water intake may explain the damage to gills, tissue, liver, and kidneys reported in other studies.

Factors Affecting Ammonia Toxicity

A number of factors influence the toxicity of ammonia to fish. Temperature, pH, and TDS directly affect toxicity by influencing the amount of ammonia that is in the toxic form. The concentration of un-ionized ammonia increases as temperature and pH increase and the TDS concentration decreases. Several other factors influence the toxicity of ammonia to fish. These factors are briefly summarized below.

Temperature. In addition to the effect temperature has on the proportion of ammonia in the un-ionized form, there is some evidence that extremely low temperatures increase the toxicity of ammonia to fish.[6] Alabaster and Lloyd state that their recommended criterion of 0.025 mg/l as NH_3 should not be applied to temperatures below 5°C. This factor does not need to be considered in the analysis of the Lake Mead data since temperatures never drop below 5°C.

pH. In addition to the effect pH has on the proportion of ammonia in the un-ionized form, there is some recent evidence that un-ionized ammonia is more toxic to fish at low pH values (6.5 to 7.5).[7] Thurston et al., demonstrated that the toxicity of un-ionized ammonia to rainbow trout and fathead minnows did not remain constant over the pH range considered acceptable to freshwater aquatic life (6.5 to 9.0). The 96-hour LC_{50} for rainbow trout ranged from 0.5 to 0.7 mg/l NH_3 at a pH range of 8.0 to 9.0. The LC_{50} decreased to 0.37 mg/l NH_3 at a pH of 6.5. A lower LC_{50} value indicates greater toxicity. This same pattern of increasing toxicity with decreasing pH was also found for the fathead minnows.

Dissolved Oxygen. According to Alabaster and Lloyd a reduction in the DO level of the water increases the toxicity of ammonia to fish.[6] Downing and Merkens showed that a reduction in the DO concentration to 50 percent of the air saturation value reduced the survival time of several fish species in lethal concentrations of ammonia to one third of the time in aerated water.[8] Lloyd hypothesized that the effect of low DO on ammonia toxicity is reduced as the concentration of free CO_2 increases.[9] In natural conditions a decrease in the DO concentration is often accompanied by an increase in the free CO_2 concentration and a decrease in the pH. The reduction in pH reduces the toxicity of un-ionized ammonia to a greater extent than the increased toxicity caused by low DO levels. In summary, the toxicity of ammonia increases as the DO concentration decreases. Under natural conditions, low DO concentrations are often accompanied by lowered pH values. The reduction in toxicity due to the lowered pH is greater than the increase in toxicity due to lowered DO.

Free Carbon Dioxide. Lloyd and Herbert demonstrated that the pH value of the water at the gill surface, rather than in the waterbody itself, determines the toxicity of ammonia to rainbow trout (Salmo gairdneri).[10] As discussed previously, fish excrete ammonia through their gills. If the un-ionized ammonia concentration in the water near the gills is high, the fish will be prevented from excreting ammonia and lethal concentrations will occur in the fish. Fish also excrete carbon dioxide (CO_2) through their gills. The CO_2 excreted by the fish reduces the pH in the immediate area near the fish gills. The reduction in pH reduces the concentration of un-ionized ammonia in the water near the gill surface. If the amount of CO_2 in the water is low, the amount excreted by the fish will reduce the pH value at the gill surface considerably. As the free CO_2 content of the water rises, the extent of the pH change at the gill surface will be reduced.

According to Alabaster and Lloyd, photosynthetically-induced increases in the pH of the water are accompanied by a reduction in the free CO_2 content of the water. When the pH of a waterbody rises above 8.0, the CO_2 content of the water is reduced and the pH at the fish gill surface is unlikely to exceed 8.0. The relationship between free CO_2 concentration and pH at Station 2 is presented on Figure 10-9. The CO_2 concentration dropped to less than 1.0 mg/l when the pH reached 8.0 and less than 0.1 mg/l at a pH of 9.0. Alabaster and Lloyd recommended substituting a pH value of 8.0 for the pH value of the water to calculate the un-ionized ammonia concentration that a fish is actually exposed to when the pH of the water rises above 8.0.

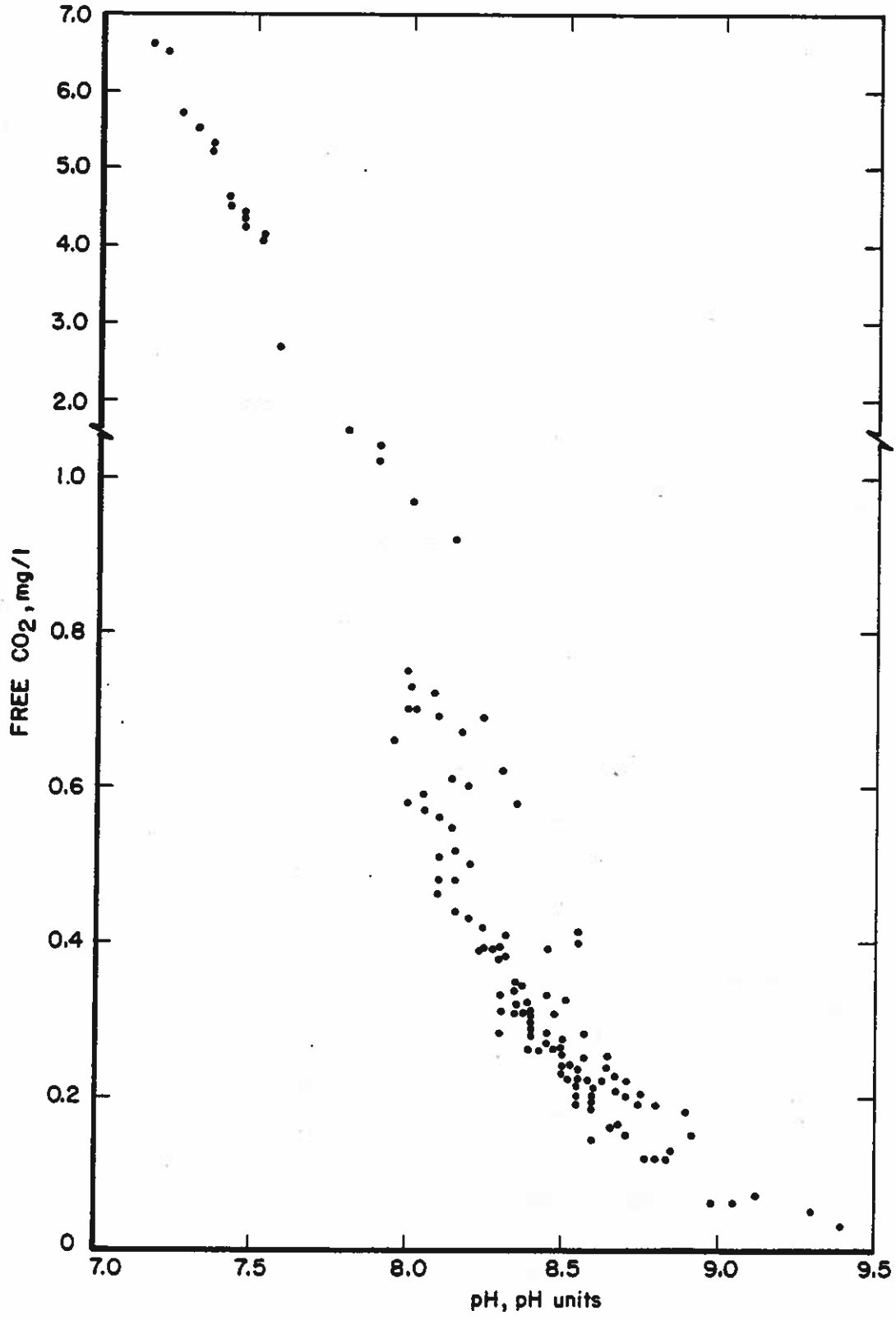


Figure 10-9 Relationship Between Free CO_2 and pH at Station 2

Alkalinity. Alkalinity is a measure of the ability of the water to neutralize acids. Alkalinity only indirectly affects ammonia toxicity because it affects the pH of the water.[6]

Other Toxicants. A limited amount of data are available on the toxicity of ammonia in the presence of other toxicants. Experiments with ammonia and cyanide showed that the combination was more toxic than either substance alone.[5] Some experiments suggest that the toxicity of combinations of ammonia and phenol, ammonia and copper, and ammonia and zinc can be determined by summing the individual toxicities of the substances.[5] More research needs to be conducted on the toxicity of ammonia in the presence of other toxicants before this effect can be fully understood.

Prior Exposure. According to Alabaster and Lloyd, exposure of fish to sub-lethal levels of ammonia increases their resistance to lethal levels.[6] More research needs to be done on the effect of prior exposure before this effect can be fully understood.

Avoidance Reactions. According to Alabaster and Lloyd, green sunfish, stickleback, and carp avoid lethal concentrations of un-ionized ammonia in the laboratory. The fish do not avoid sub-lethal concentrations of un-ionized ammonia.[6] There are no data on fish avoidance reactions in the field.

Chlorophyll/pH Relationship

Through photosynthesis, algae reduce the concentration of free carbon dioxide (CO_2) in the water. This results in an

increase in the pH of the water. As shown on Figures 10-2 and 10-3 in the Results section of this chapter, the pH values of the surface waters at Stations 2 and 5 were consistently greater than the pH values of the bottom waters. The highest pH values occurred during the summer months when the greatest chlorophyll concentrations also occurred. The relationship between chlorophyll and pH was explored to determine if reducing chlorophyll concentrations would result in lower pH values, and hence, lower concentrations of un-ionized ammonia in the surface waters.

A number of linear regressions between chlorophyll and pH were run to determine if there is a relationship between these two parameters. The linear regressions are summarized in this chapter. Table 10-2 summarizes the regressions between chlorophyll and pH that were analyzed and the resulting r^2 values. Each of these regressions were run for the following groups of stations:

1. All stations grouped together
2. Stations 1 to 8
3. Stations 9 to 11
4. Each individual station

The regressions were run with individual data points and with monthly mean values. As shown in Table 10-2, there was no statistically significant relationship between chlorophyll and pH. In most cases, the r^2 values were quite low and the slope of the regression equation indicated that pH was almost independent of the chlorophyll concentration.

Table 10-2. Summary of Chlorophyll/pH Relationship Analysis

Regression	r^2 range
pH versus chlorophyll	
Individual data points	0 -0.25
Monthly means	0.02-0.44
Log pH versus chlorophyll	
Individual data points	0 -0.28
Monthly means	0.02-0.42
^{1}/pH versus chlorophyll	
Individual data points	0 -0.26
Monthly means	0.02-0.41
Log pH versus log chlorophyll	
Individual data points	0 -0.44
Monthly means	0.01-0.63
Monthly means April to October	0 -0.17
Monthly means April to October 1979	0 -0.86[a]
Monthly means April to October 1980	0 -0.11

[a]The r^2 of 0.86 was at Station 4. The equation is log pH = 0.003 log chlor + 0.92.

One final regression was run between the average of the monthly mean chlorophyll concentrations and the median pH at each station from July 1979 through November 1980. The results of this regression are presented on Figure 10-10. There is a fairly good relationship (r^2 = 0.88) between these two variables. However, the slope of the regression equation is so low (0.006) that pH is almost independent of chlorophyll.

A reduction in the chlorophyll concentrations in the surface waters of the inner bay would probably have little effect on ammonia toxicity in the inner bay for two reasons:

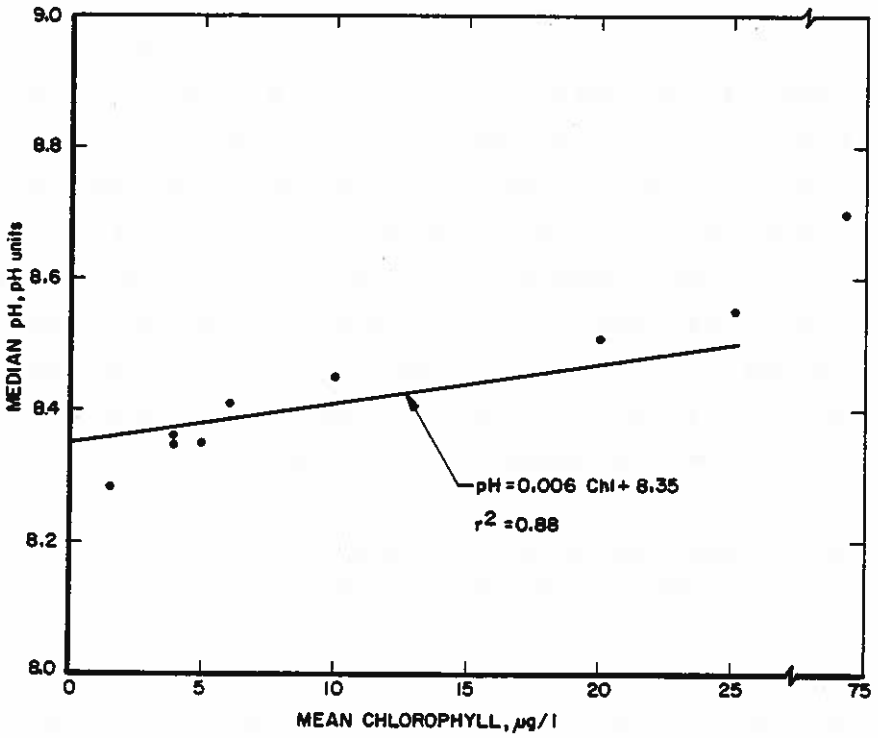


Figure 10-10 Relationship Between Chlorophyll and pH

1. The average chlorophyll concentration at Station 2 will be reduced to about 20 ug/l under the control strategy outlined in Chapter 8. According to the regression of chlorophyll versus pH, this would reduce the median pH at Station 2 from 8.55 to 8.47. At the average temperature of 24°C found in the surface waters at Station 2, this would reduce the percent of total ammonia in the un-ionized form from 14 to 12. This would not significantly reduce the un-ionized ammonia concentrations in the surface waters at Station 2.

2. Beyond Stations 1 and 2, the high un-ionized ammonia concentrations occur in the plume. As discussed previously and as shown on Figures 10-2 and 10-3 in the Results section of this chapter, the pH values in the plume are generally between 7.5 and 8.0, so the high un-ionized ammonia concentrations are due to high concentrations of total ammonia rather than to high pH values. Reducing the chlorophyll concentrations in the surface waters would not result in lower concentrations of un-ionized ammonia in the plume.

Relationships Between Ammonia Loads and Un-Ionized Ammonia Concentrations

As discussed in the Nutrient Budget, Chapter 7, the Las Vegas Wash plume is the major source of total ammonia to Las Vegas Bay. Thus, there should be a relationship between the total ammonia load measured at Northshore Road and total ammonia concentrations in the bay. Dilution calculations, similar to those presented for nutrients in Chapter 8, have been made to define the wash/bay ammonia relationship.

The change in total ammonia concentration that occurs between Northshore Road and a location in the bay is related to two factors: (1) the physical dilution that occurs as plume water is mixed with bay water and (2) chemical and biological mechanisms such as conversion of ammonia to nitrate and algal uptake of ammonia. A dilution calculation based on total ammonia concentration at Northshore Road and total ammonia concentration in the bay incorporates both of these factors and is referred to in this discussion as "effective dilution."

Dilution calculations have been made for both conductivity and ammonia to determine the relative significance of physical dilution and chemical/biological dilution. Figure 10-11 presents conductivity dilutions for surface samples at Stations 1, 2, 3, and 4, and samples collected in the vicinity of the plume at Stations 2, 3, and 4. As expected, increased dilution occurs in moving from Station 1 toward Station 4. It is also clear that surface dilutions are much greater than dilutions calculated in the vicinity of the plume.

The effective dilutions for total ammonia are presented on Figure 10-11. These dilutions also show the same trends exhibited by the conductivity dilutions. However, the effective dilution is generally 5 to 50 times greater than that accounted for by just physical dilution. This demonstrates that the chemical/biological mechanisms have the predominant effect in lowering total ammonia concentrations.

The effective dilutions for total ammonia can be used to develop a simplified method to relate total ammonia concentration at Northshore Road to un-ionized ammonia concentration in the inner bay. Table 10-3 summarizes the data needed for this relationship. The following data are contained in Table 10-3:

1. Mean effective total ammonia dilution--same data as presented on Figure 10-11.

2. Percentage of total ammonia that is un-ionized--the percentage has been computed using the mean pH, temperature, and total dissolved solids for the spring-

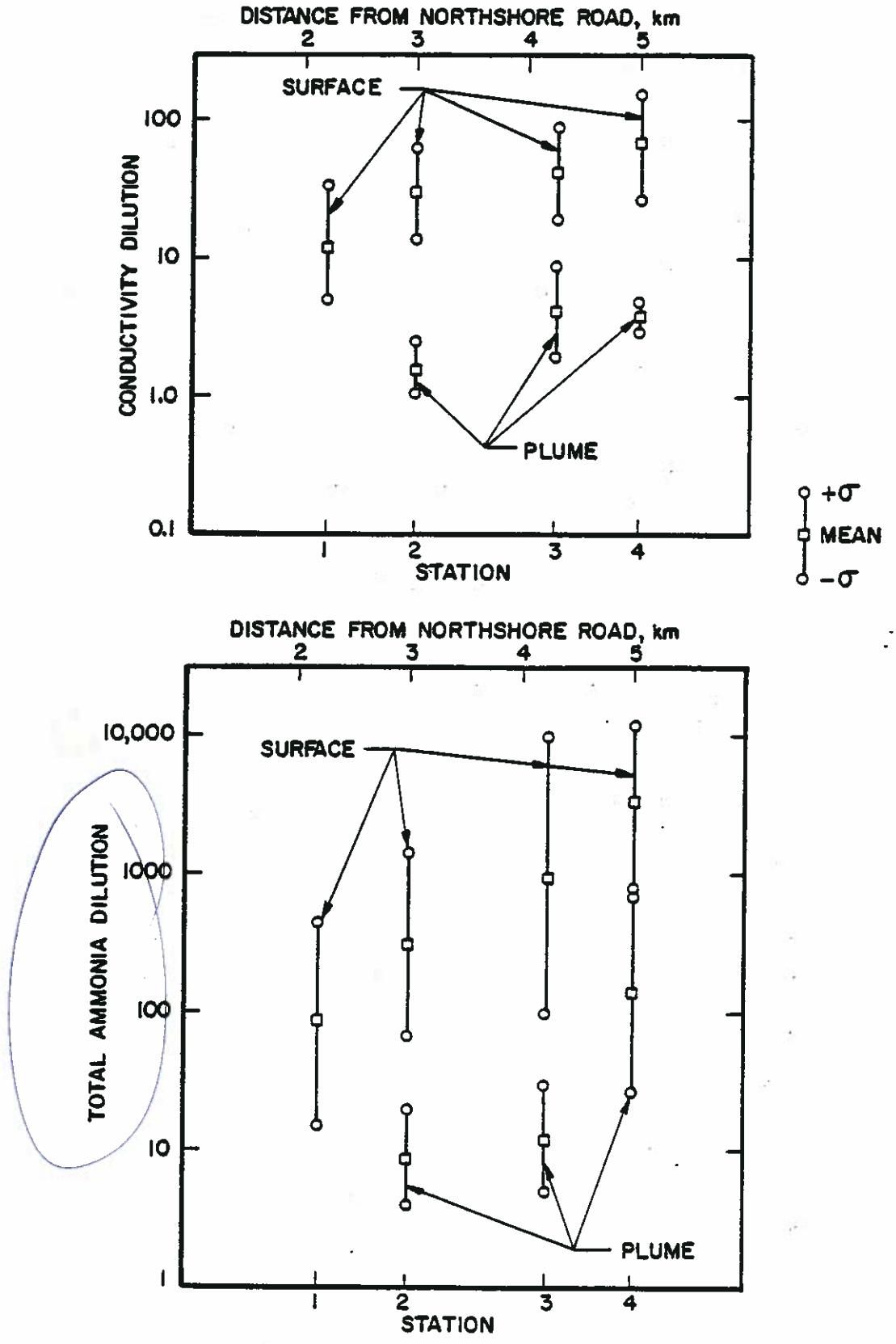


Figure 10-11 Conductivity Dilutions and Effective Total Ammonia Dilutions

summer period at each particular location. Winter values are excluded from the calculation, since un-ionized ammonia levels are very low during this period due to lower pH and temperature levels.

3. Mean effective un-ionized ammonia dilution--this value is computed by applying the percentage of un-ionized ammonia to the effective dilution of total ammonia (e.g. for the plume at Station 2, 9/0.06=150).

Table 10-3 can be used to estimate the allowable total ammonia concentration at Northshore Road to meet a specified un-ionized ammonia concentration in the inner bay. For example, if a mean concentration of 0.02 mg/l of un-ionized ammonia is desired at Station 2, the allowable total ammonia concentration at Northshore Road can be calculated as follows:

vicinity of plume - 0.02 mg/l x 150 = 3.0 mg/l
surface water - 0.02 mg/l x 1,530 = 30 mg/l

These calculations assume that the factors presently influencing effective total ammonia dilution (physical dilution, rate of nitrification and rate of uptake by algae) would remain relatively constant. The calculations could not be directly applied if any of those factors changed substantially from that observed during WQSS. Also, adjustments would have to be made in the percentage of ammonia in the un-ionized form if the algae concentrations changed enough to alter the mean pH level.

The method presented in this section for relating Northshore Road total ammonia concentration to un-ionized ammonia concentration in the inner bay can be used to compute

allowable ammonia loads at Northshore Road to meet a specific un-ionized ammonia criterion.

Table 10-3. Ammonia Effective Dilution Factors

Item	Station						
	1	2		3		4	
	Surface	Surface	Plume	Surface	Plume	Surface	Plume
Mean effective total ammonia dilution	87	315	9	946	12	3,226	142
Percentage of total un-ionized ammonia[a]	21.1	20.6	6.0	20.8	2.3	16.4	2.2
Mean effective un-ionized ammonia dilution	410	1,530	150	4,500	520	19,700	6,450

[a]Based on the average temperature and pH during the summer months.

EFFECT ON BENEFICIAL USES

The current beneficial uses of Lake Mead are water supply, recreation, boating, fish and wildlife, irrigation, and hydropower. These uses are discussed in detail in Chapter 4. Un-ionized ammonia concentrations affect the Lake Mead fishery but do not directly affect any of the other designated uses. In this section, the un-ionized ammonia concentrations in the lake are compared to various un-ionized ammonia criteria.

Criteria Review

Un-ionized ammonia criteria have been recommended by the National Academy of Sciences (NAS), the U.S. Environmental

Protection Agency (EPA), the American Fisheries Society (AFS), the State of Nevada, and the European Inland Fisheries Advisory Council (EIFAC). Each of these criteria are discussed in this section.

National Academy of Sciences. The NAS recommended a criterion based on applying an application factor of 0.05 to the 96-hour LC_{50} (the concentration that is lethal to 50 percent of the test organisms) for the most sensitive important species in a waterbody.[11] The purpose of the 0.05 application factor is to determine a chronic criterion based on the lethal concentration since NAS did not conduct chronic toxicity tests. The NAS also stated "no concentration greater than 0.02 mg/l is recommended at any time or place." This implies that 0.02 mg/l is a recommended acute criterion. NAS did not specify if the units were mg/l as NH_3 or mg/l as N.

U.S. Environmental Protection Agency. The EPA Quality Criteria for Water (Red Book) recommended a criterion of 0.02 mg/l as un-ionized ammonia (0.016 mg/l N for the protection of freshwater aquatic life).[1] Laboratory experiments have shown that the lethal concentration for a variety of fish species ranges from 0.2 mg/l as un-ionized ammonia for salmonids to 2.0 mg/l as un-ionized ammonia for carp. The EPA criterion of 0.02 mg/l NH_3 is based on applying an application factor of 0.1 to the lowest lethal concentration reported for rainbow trout, Salmo gairdneri, of 0.2 mg/l NH_3. In this case, the basis of the 0.1 application factor was not to translate an acute criterion to a chronic criterion. The EPA's stated purpose was "to provide safety for those forms not examined, 1/10th of the lower value of this toxic effect range results in

a criterion of 0.020 mg/l of un-ionized ammonia." This implies that the 0.02 mg/l NH_3 is an acute criterion. According to the EPA the difference in sensitivity among fish species to prolonged exposure to ammonia is probably small and concentrations below 0.2 mg/l NH_3 may have adverse physiological effects such as gill and tissue damage.

American Fisheries Society. The AFS reviewed the EPA criterion for un-ionized ammonia and concluded that the criterion of 0.02 mg/l NH_3 may be appropriate for freshwater salmonid fish. The American Fisheries Society reviewed the literature on ammonia toxicity to non-salmonid fish and found that toxic levels for non-salmonid species ranged from 0.35 to 1.24 mg/l NH_3. They noted that the lower value of 0.35 mg/l NH_3 is only slightly higher than the lowest reported value for salmonids. The lowest reported value for salmonids (0.2 mg/l NH_3) was calculated by EPA with out-dated ammonia equilibrium tables. The AFS recalculated the un-ionized ammonia concentration using more accurate aqueous ammonia equilibrium tables and determined that the toxic concentration was 0.32 mg/l NH_3 or 0.26 mg/l N. The AFS stated "A value of 0.2 mg/l un-ionized ammonia, although not substantiated by the Red Book, probably represents a concentration that is acutely toxic to salmonids. However, the scientific data base supporting the 0.1 application factor is not presented in the Red Book." The AFS assumed that the EPA 0.1 application factor was intended to determine a chronic criterion from the acute criterion.

European Inland Fisheries Advisory Council. The EIFAC, as cited in Alabaster and Lloyd recommended a criterion of 0.025 mg/l NH_3 (0.02 mg/l N).[6] They reviewed the literature on ammonia toxicity and found that the lowest lethal

concentration for salmonids was 0.2 mg/l NH_3 (0.16 mg/l N). They also found that adverse effects due to prolonged exposure to un-ionized ammonia were absent when the concentration was reduced to 0.025 mg/l NH_3 (0.02 mg/l N). They stated that fish species differed slightly in their tolerance to ammonia but the difference in tolerance was more significant for short periods of exposure and was not great enough to justify different criteria for different species. The 0.025 mg/l NH_3 criterion recommended by the EIFAC is a chronic criterion since adverse effects due to prolonged exposure were absent at this concentration.

State of Nevada. There is no existing standard for un-ionized ammonia in Lake Mead.[13] The State of Nevada guidelines for the protection of beneficial uses recommend 0.02 mg/l for the protection of cold-water aquatic life and 0.1 mg/l for the protection of warmwater aquatic life.[14] The guidelines do not specify if the criteria are chronic or acute and they do not specify the units. The State guidelines reference the EPA Red Book as the basis for the cold-water criterion of 0.02 mg/l, so it is assumed that the criterion is acute and the units are mg/l NH_3. The reference for the warmwater aquatic life criterion is the 1978 Colorado Water Quality Control Commission Water Quality Standards. The Colorado criteria specify 0.1 mg/l N for the protection of warmwater aquatic life, so it is assumed that the same units apply to the State of Nevada guidelines.[15]

The Colorado criterion for warmwater aquatic life was changed to 0.06 mg/l N in 1980.[14] The Colorado criteria are chronic criteria.[15] According to the Colorado Department of Health, the cold-water aquatic life criterion is designed to

protect sensitive species such as trout and bass. The warmwater aquatic life criterion is designed to protect carp, minnows, catfish, and other species that are more tolerant of un-ionized ammonia than trout and bass.[16] Table 10-4 summarizes all of the un-ionized ammonia criteria.

Recommended Criterion

There is currently a great deal of confusion over ammonia criteria needed to protect fish and other forms of aquatic life. Acute criteria range from 0.016 to 0.16 mg/l N. Chronic criteria range from 0.016 to 0.02 mg/l N for the protection of cold-water aquatic life, and from 0.06 to 0.1 mg/l N for the protection of warmwater aquatic life. A cold-water aquatic life criterion is needed for Las Vegas Bay since the most sensitive important fish species in the bay are striped bass and largemouth bass which are classified as cold-water species. Based on a review of the various criteria, the most appropriate chronic criterion for Las Vegas Bay is 0.02 mg/l as N. A chronic criterion is needed to protect the long-term health of the fishery. The 0.02 mg/l N is recommended by the EIFAC and the State of Colorado, both of whom based their recommendations on an extensive review of the literature on ammonia toxicity. It is recommended that the 0.02 mg/l criterion be applied as a mean water column criterion to be met at all times. This will allow concentrations to moderately exceed 0.02 mg/l in the plume, which occupies a relatively small portion of the water column.

According to Alabaster and Lloyd, the un-ionized ammonia concentrations should be based on a pH of 8.0 whenever the pH exceeds 8.0 since the pH at the gill surface never exceeds 8.0 due to the relatively high carbon dioxide concentration at the gill surface.[6] If a series of toxicity tests were run with a range of pH values, the results should show that the toxic concentration of un-ionized ammonia (calculated with the pH of the water) increases above pH 8.0, as illustrated on Figure 10-12.

Table 10-4. Summary of Un-ionized Ammonia Criteria

Source	Un-ionized ammonia criteria[a]				Comments
	Acute		Chronic		
	mg/l NH_3	mg/l N	mg/l NH_3	mg/l N	
NAS	0.02	0.016	0.05 (LC_{50})	0.05 (LC_{50})	Units were not specified. Since NAS quoted the same references cited by the EPA, it is assumed that their criterion of 0.02 mg/l is as un-ionized ammonia.
EPA	0.02	0.016	—	—	Criterion specified as 0.02 mg/l NH_3.
AFS	—	—	0.02	0.016	
EIFAC	0.2	0.16	0.025	0.02	Units specified as mg/l NH_3.
State of Nevada					
Cold-water aquatic life	0.02	0.016	—	—	Chronic versus acute and units not specified. Since EPA was cited, it was assumed that the criterion of 0.02 mg/l is an acute criterion as NH_3.
Warm-water aquatic life	—	—	0.125	0.1	Colorado standards cited so it was assumed that the criterion of 0.1 mg/l is a chronic criterion as NH_3.
State of Colorado					
Cold-water aquatic life	—	—	0.025	0.02	
Warm-water aquatic life	—	—	0.075	0.06	

[a]Dash (—) indicates criterion not specified.

laboratory conditions.[7] The lethal concentration remained constant in the pH range of 8.0 to 9.0. A schematic of their results is presented on Figure 10-12. The results of Thurston, et al. show that the toxic concentration of un-ionized ammonia remained constant above pH 8.0 rather than increasing, as predicted by Alabaster and Lloyd. One possible explanation for the conflicting results is that Thurston, et al. used sodium hydroxide to increase the pH above 8.0. In natural conditions, the pH rises above 8.0 when the carbon dioxide concentration of the water is lowered by photosynthesis. It is this decrease in CO_2 concentration in the waterbody that results in the effect described by Alabaster and Lloyd. If the experiments conducted by Thurston, et al. were conducted under natural conditions, different results might be obtained. Since there is conflicting evidence on the effect of pH on un-ionized ammonia, toxicity concentrations of un-ionized ammonia should be calculated in the traditional manner using the pH of the waterbody.

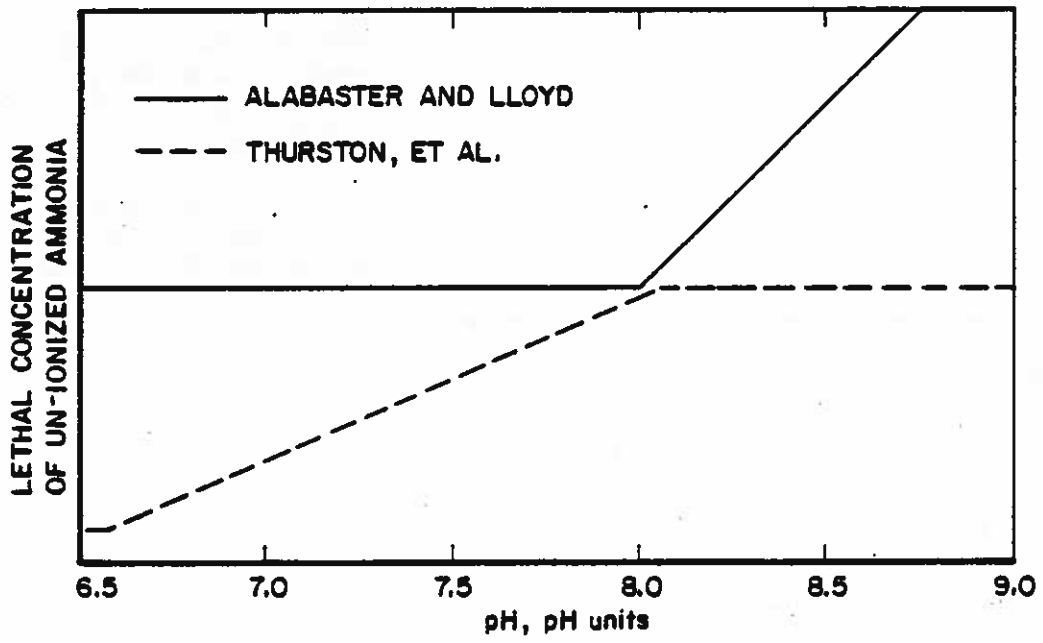


Figure 10-12 Relationship of Lethal Un-ionized Ammonia Concentration to pH

The EPA is currently preparing a criteria document on ammonia toxicity. They are evaluating all data related to ammonia toxicity including the work of Alabaster and Lloyd and Thurston, et al.[15] The recommended un-ionized ammonia criterion of 0.02 mg/l N should be reevaluated when the EPA criteria document is published.

Comparison of Criteria to Existing Conditions

The un-ionized ammonia concentrations in Las Vegas Bay are compared to the various criteria discussed in the preceeding section. Data on the area of Las Vegas Bay which contains un-ionized ammonia concentrations that exceed the recommended criterion of 0.02 mg/l N is also presented. Dissolved oxygen concentrations and temperature also affect the distribution of fish in Las Vegas Bay. The combined impact on the fishery of all of these factors are discussed.

Un-ionized Ammonia. The ranges and mean concentrations of un-ionized ammonia at the inner bay stations are compared to the various criteria on Figure 10-13. The mean concentration of un-ionized ammonia in the surface waters at Station 1 exceeded the 0.02 mg/l N criterion. The mean concentrations of un-ionized ammonia in the surface waters of Stations 2 and 3 were lower than the 0.02 mg/l N criterion, although the concentration ranges extended beyond the criterion at these stations. The mean concentrations of un-ionized ammonia in the samples collected near the plume exceeded the 0.02 mg/l N criterion at Stations 2 and 3. At Station 4, the mean concentrations were lower than 0.02 mg/l N although the range extended slightly beyond 0.02 mg/l N at 10 meters and at the depth of peak conductivity.

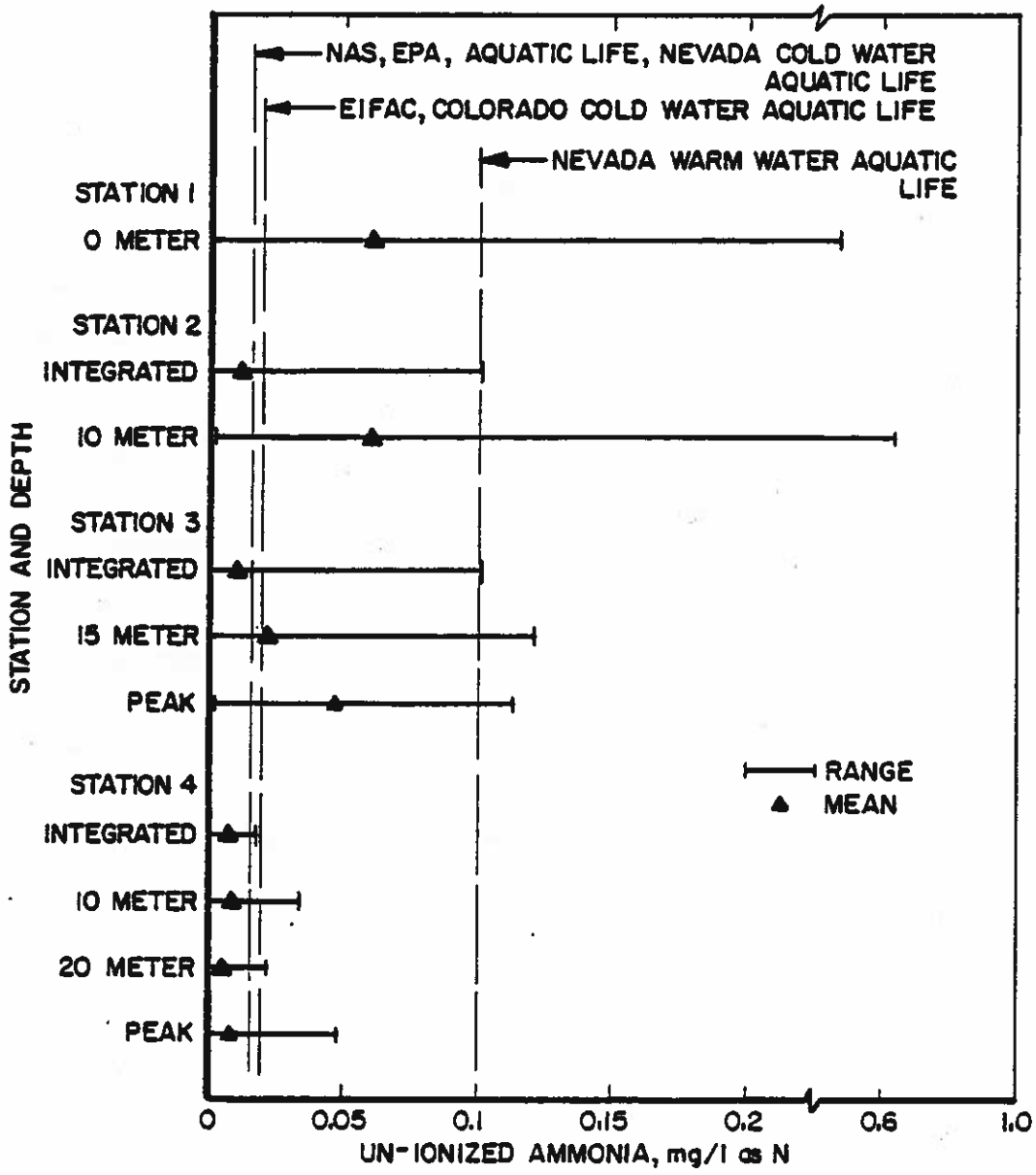


Figure 10-13 Comparison of Un-ionized Ammonia Concentrations to Criteria

Existing conditions can also be compared to the 0.02 mg/l criterion using longitudinal profile maps. Figure 10-14 shows the mean un-ionized ammonia concentrations determined during the WQSS in Las Vegas Bay. Based on the mean concentrations, the potentially toxic zone is reduced to the entire water column at Station 1 and the area near the plume at Stations 2 and 3. These areas of the bay have mean concentrations that exceed the recommended criterion of 0.02 mg/l N. It should be pointed out, however, that ammonia concentrations were never measured in the plume at Station 1 and were infrequently measured in the plume at Stations 2, 3, and 4.

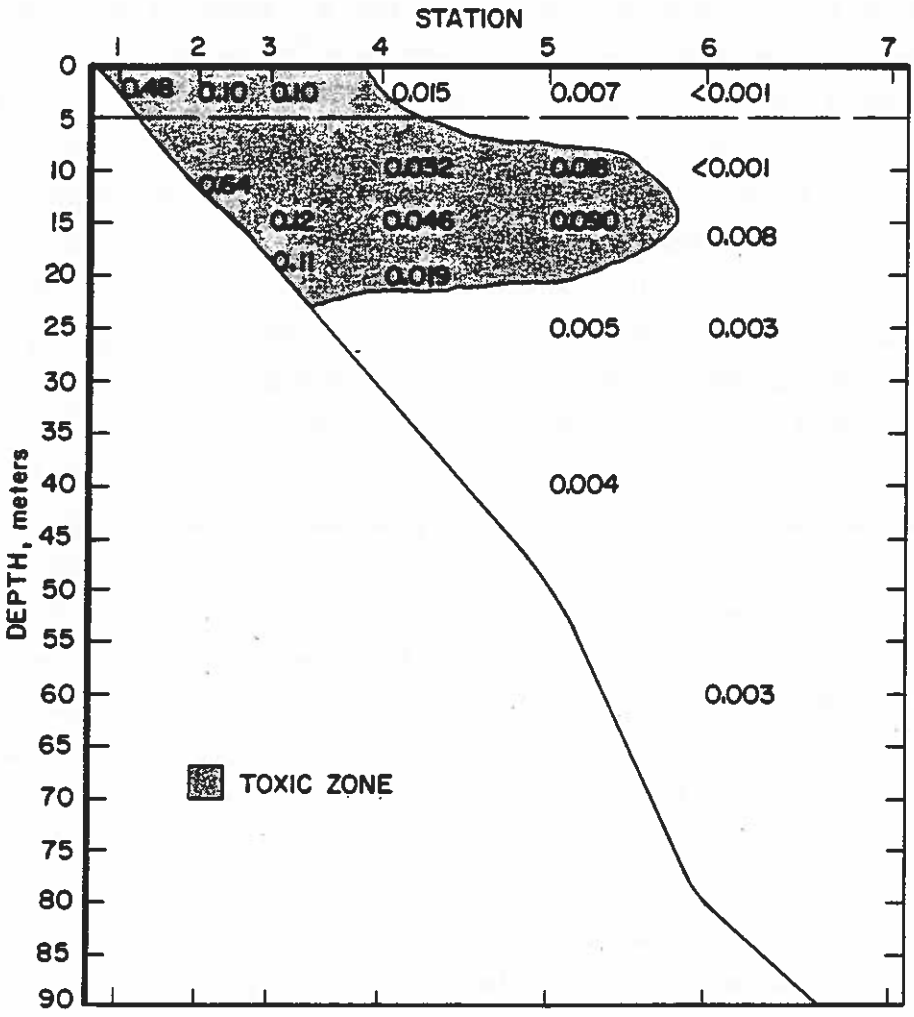


FIG. 9-13

Figure 10-14 Toxic Zone

Un-ionized Ammonia, Dissolved Oxygen and Temperature. There are several other factors that must be considered in addition to the un-ionized ammonia concentrations in assessing the effect of un-ionized ammonia on the fishery. The depletion of oxygen in the metalimnion is discussed in detail in Chapter 9. Temperature is another important factor. According to Coutant, striped bass prefer DO concentrations greater than 3 mg/l and temperatures less than 23°C.[17] Figure 10-15 shows for four dates in 1980 the areas of Las Vegas Bay in which the un-ionized ammonia concentration exceeds 0.02 mg/l, the DO is less than 3 mg/l and the temperature exceeds 23°C. The zone of high un-ionized ammonia concentrations corresponds with the area of the lake in which temperatures exceed 23°C during the summer months. This indicates that the striped bass would probably avoid this area of the lake during the summer months even if the un-ionized ammonia concentrations were lower. The high concentrations of un-ionized ammonia in the inner bay may adversely affect striped bass and other fish species during the spring spawning months. Striped bass, largemouth bass, and threadfin shad spawn in the shallow nearshore areas of the lake.[18] The highest concentrations of ammonia occur in the shallow area of Las Vegas Bay. The high un-ionized ammonia concentrations may affect the threadfin shad upon which the striped bass and largemouth bass feed. The threadfin shad generally inhabit the surface waters and they feed on plankton.[18] The greatest plankton concentrations occur in the inner bay near Stations 1 and 2. The high un-ionized ammonia concentrations in this area of the bay may separate the threadfin shad from their food supply.

There may be some variations in the precise values to use for DO and temperature in defining the potentially toxic zone

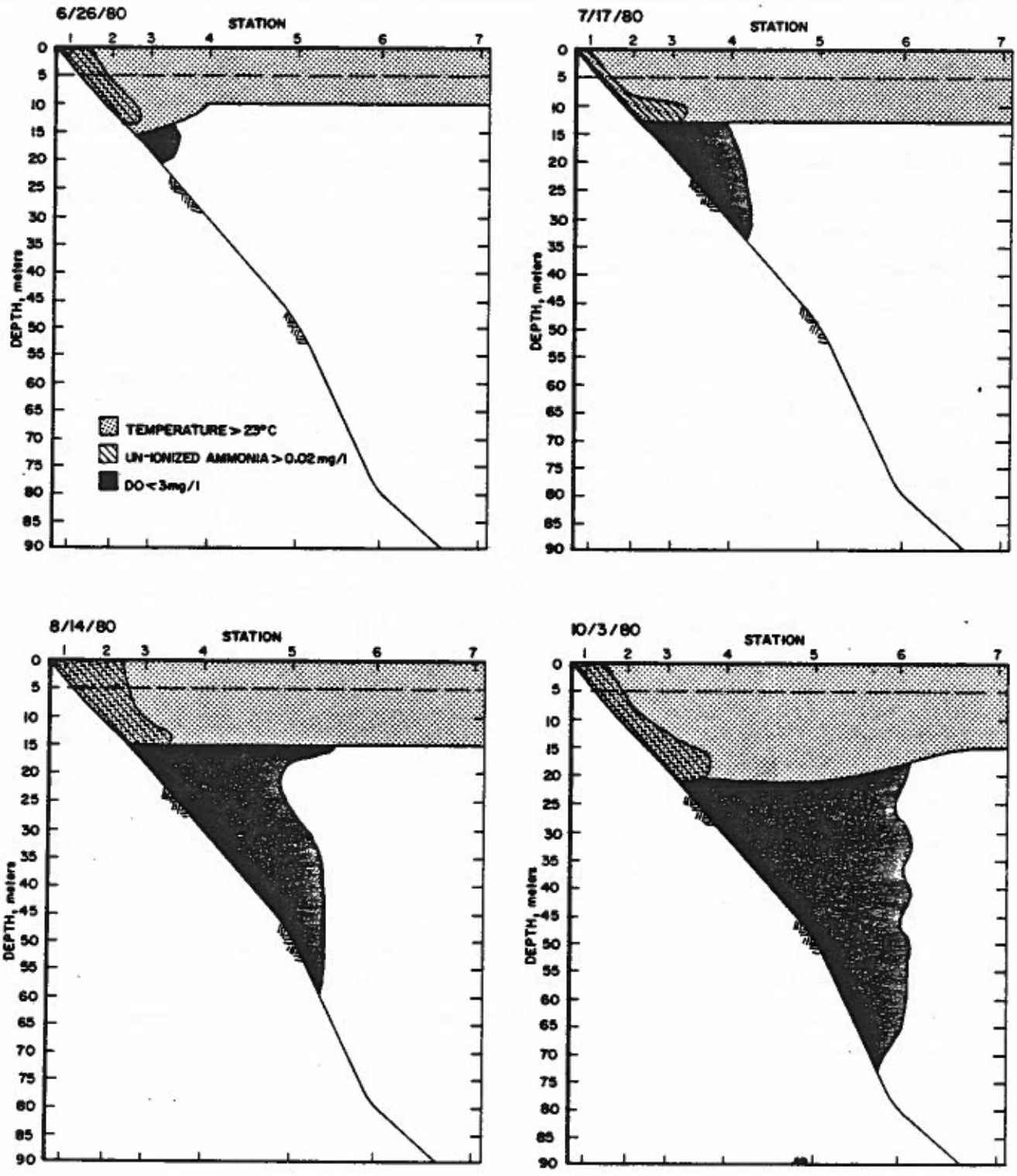


Figure 10-15 Combined Toxic Zones in Las Vegas Bay

for fish for the inner bay. Further review of the literature could be conducted and site-specific studies could be performed to develop more precise DO and temperature limits for the Lake Mead fishery. However, the data presented in Figure 10-14 are adequate to provide a reasonable indication of the toxic zone in the inner bay.

During the WQSS, toxic concentrations of un-ionized ammonia were generally confined to Station 1 and the area near the plume at Stations 2 and 3, and occasionally at Station 4. Since this represents a small volume of Las Vegas Bay, the impact on the fishery was probably minor during the WQSS. Although the un-ionized ammonia concentrations exceed the recommended criterion in waters near the plume, a large amount of the water column has safe concentrations of un-ionized ammonia. This provides a zone of passage which tends to lessen the potential adverse impact on the fishery. The zone of passage concept is recognized in water quality planning and is acknowledged in the Nevada regulations. The ammonia load from Las Vegas Wash has been increasing since 1977. During the WQSS, the ammonia load increased from 1,700 kg/day in 1979 to 2,100 kg/day in 1980. This resulted in higher un-ionized ammonia concentrations in 1980 than in 1979. If the ammonia load continues to increase, a larger area of Las Vegas Bay will have un-ionized ammonia concentrations that exceed the recommended standard of 0.02 mg/l N. This may have adverse effects on the fishery in the future.

CONCLUSIONS

1. Based on a review of the literature on un-ionized ammonia criteria, a criterion of 0.02 mg/l N is recommended for the protection of the Las Vegas Bay fishery.

2. Toxic concentrations of un-ionized ammonia probably had a minor effect on the fishery of Las Vegas Bay during the WQSS. Based on a criterion of 0.02 mg/l N, toxic concentrations were confined to Station 1 and the area near the plume at Stations 2 and 3. Occasionally, concentrations exceeded 0.02 mg/l N in the plume at Station 4.

3. Un-ionized ammonia may have a significant impact on the fishery in the future. The load of ammonia from Las Vegas Wash has been increasing since 1977. During the WQSS, the load increased from 1,700 kg/day in 1979 to 2,100 kg/day in 1980. This resulted in higher concentrations of un-ionized ammonia in 1980.

4. Reducing the chlorophyll concentrations in the inner bay will have little effect on the toxicity of un-ionized ammonia in the surface waters or in the plume. Since algae increase the pH of the surface waters through photosynthesis, a relationship was developed between chlorophyll and pH. The relationship showed that the median pH at Station 2 would be reduced by 0.1 pH units if the average chlorophyll concentration was reduced to 20 ug/l. This would have a minor effect on the un-ionized ammonia concentrations. The pH values of the plume waters were typically low, so the high concentrations of un-ionized ammonia were due to high concentrations of total ammonia. Reducing the chlorophyll concentrations of the surface waters would not affect the un-ionized ammonia concentrations in the plume.

CHAPTER 11

PERIPHYTON

The term periphyton refers to aquatic growth attached to a fixed surface or substrate. Periphyton often forms an important component of the productivity of lakes and reservoirs. The attached material can slough off and form floating mats. When periphyton growth is extensive, it can cause an aesthetic problem and can be a nuisance which can impair beneficial uses.

INTRODUCTION

The need to analyze periphyton conditions in Lake Mead was identified in the work plans for the Water Quality Standards Study (WQSS). This section describes the background of the periphyton work and identifies the specific objectives of this chapter.

Background

Concern over periphyton growth in Las Vegas Bay was first reported in 1967, when floating mats of Cladophora were sighted in Las Vegas Bay. Extensive growths of Cladophora were also observed in the Las Vegas Wash.[1] There are also reports of complaints about algae growth on boat hulls by boat owners at Las Vegas Wash Marina, particularly during the early 1970s. As a result of these concerns, a periphyton study was performed as part of the WQSS of Lake Mead.

Objective

The objectives of this chapter are to document periphyton conditions during the WQSS study period and to identify factors which affect periphyton growth. Currently, there are no federal or state standards for periphyton. Therefore, to put periphyton conditions in the study area in perspective, data for other lakes and rivers are reviewed. To meet these objectives, the chapter is organized as follows: methodology is discussed, including the purpose and procedures for the various analyses; results are presented; comparisons with other data are made; results are analyzed; effects on beneficial uses are discussed; and conclusions are drawn.

METHODOLOGY

Two types of surveys were conducted as part of the periphyton study: (1) routine sampling of periphyton at the WQSS index stations and nearshore stations lateral to the index stations and (2) four quarterly surveys involving rock scraping along the shorelines of Las Vegas and Bonelli Bays.

Routine sampling at the index (limnetic) and nearshore (littoral) stations involved collection of fiberglass samplers at approximately biweekly intervals. Samplers at the limnetic stations were suspended 3 meters below the lake surface. The sampling apparatus for the littoral stations consisted of fiberglass samplers attached to a concrete slab placed on the sediment surface approximately 3 meters below the lake surface. Sampling apparatus are shown on Figure 11-1. After an incubation period of 14 days, samplers were collected and returned to the University of Nevada at Las Vegas (UNLV)

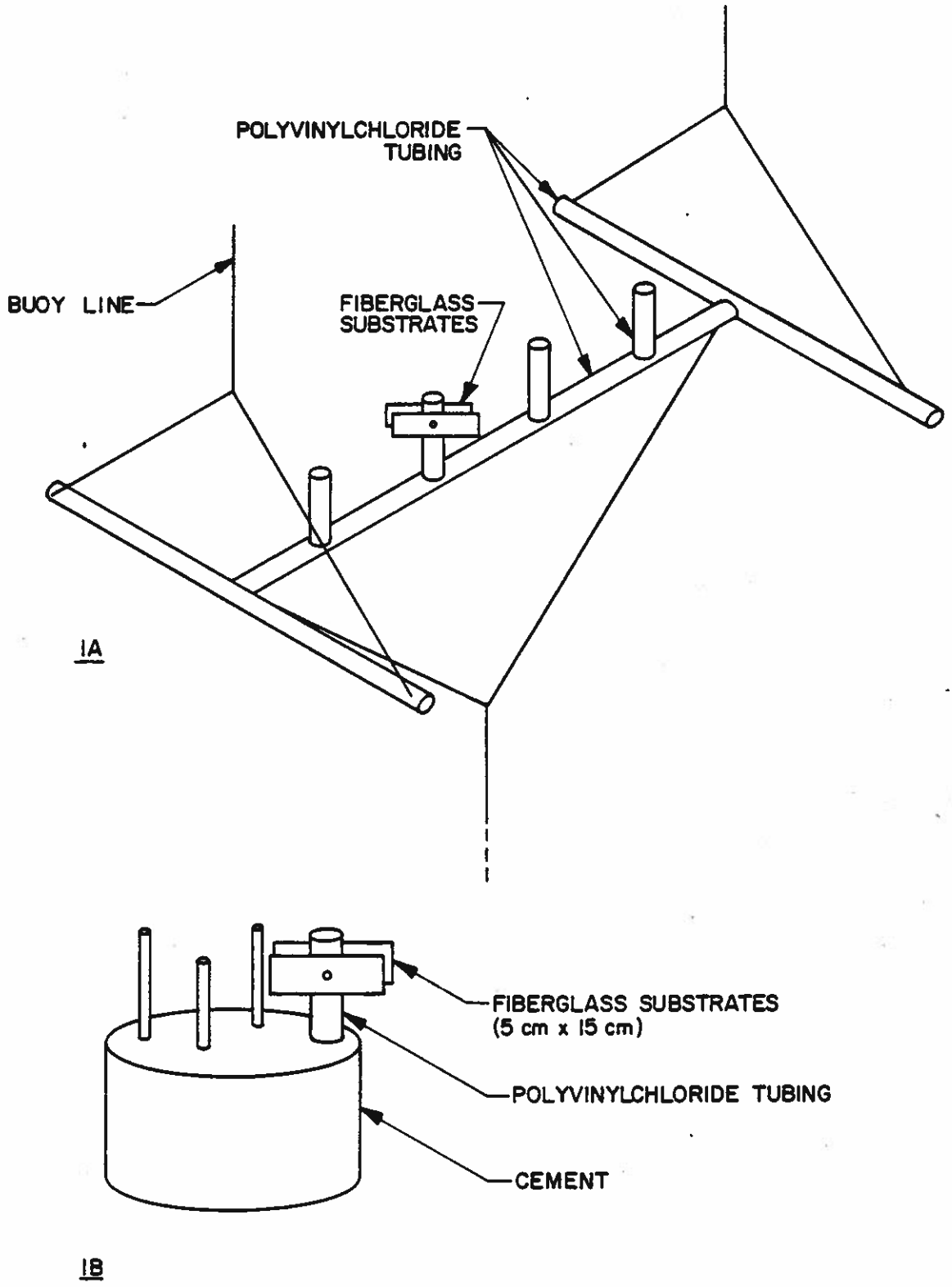


Figure 11-1 Apparatus for Sampling Periphyton Growth at Limnetic (1A) and Littoral (1B) Stations

laboratory for analyses. Identification and location of the sampling stations are shown on Figure 11-2. Periphyton was scraped from a standard area of each sampler, and the analyses listed in Table 11-1 were performed. Procedures for the analyses are detailed in Appendix A.

Table 11-1. Analyses Performed for Routine Periphyton Sampling

Analysis	Purpose of analysis
Ash-free weight--rate of accumulation	Rate of growth
Chlorophyll *a* and Pheophytin *a*--rate of accumulation	Chlorophyll *a* degrades to pheophytin *a* when cells die, thus the two measures indicate the viability of the periphyton community.
Alkaline phosphatase activity	Indicates potential phosphorus limitation.
Species identification	Indicates dominant species and shifts in population.

Four qualitative lakewide surveys of periphyton biomass and species composition were conducted in 1980. The lakewide surveys were conducted on March 2, June 30, September 8, and November 20, 1980. Samples were taken from representative substrates, a qualitative observation of biomass was made, and dominant species of periphyton were determined. The sampling sites for the lakewide surveys are shown on Figure 11-3.

RESULTS

The results of the various surveys are presented as seasonal and spatial distributions. For some stations, data

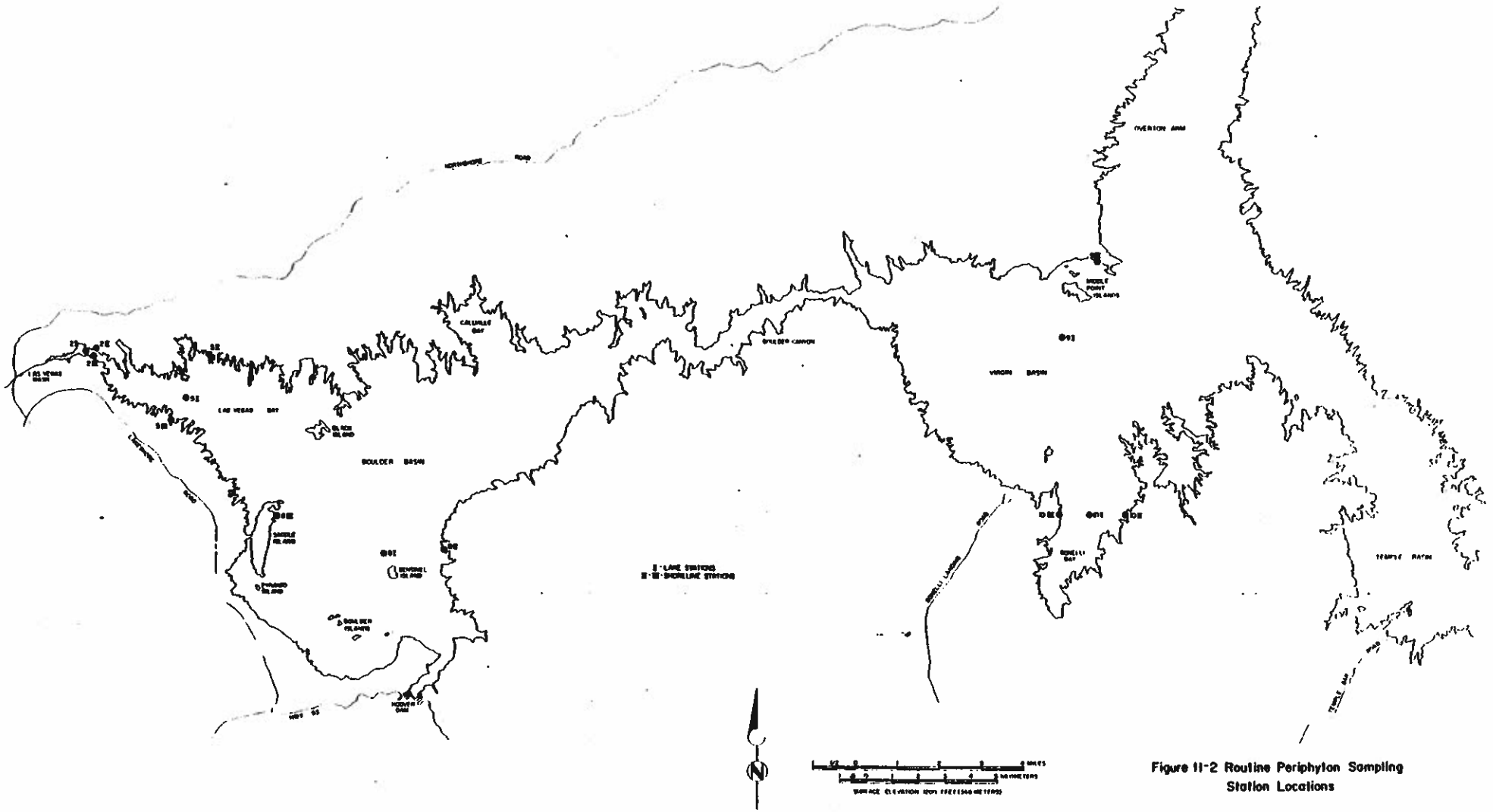


Figure 11-2 Routine Periphyton Sampling Station Locations

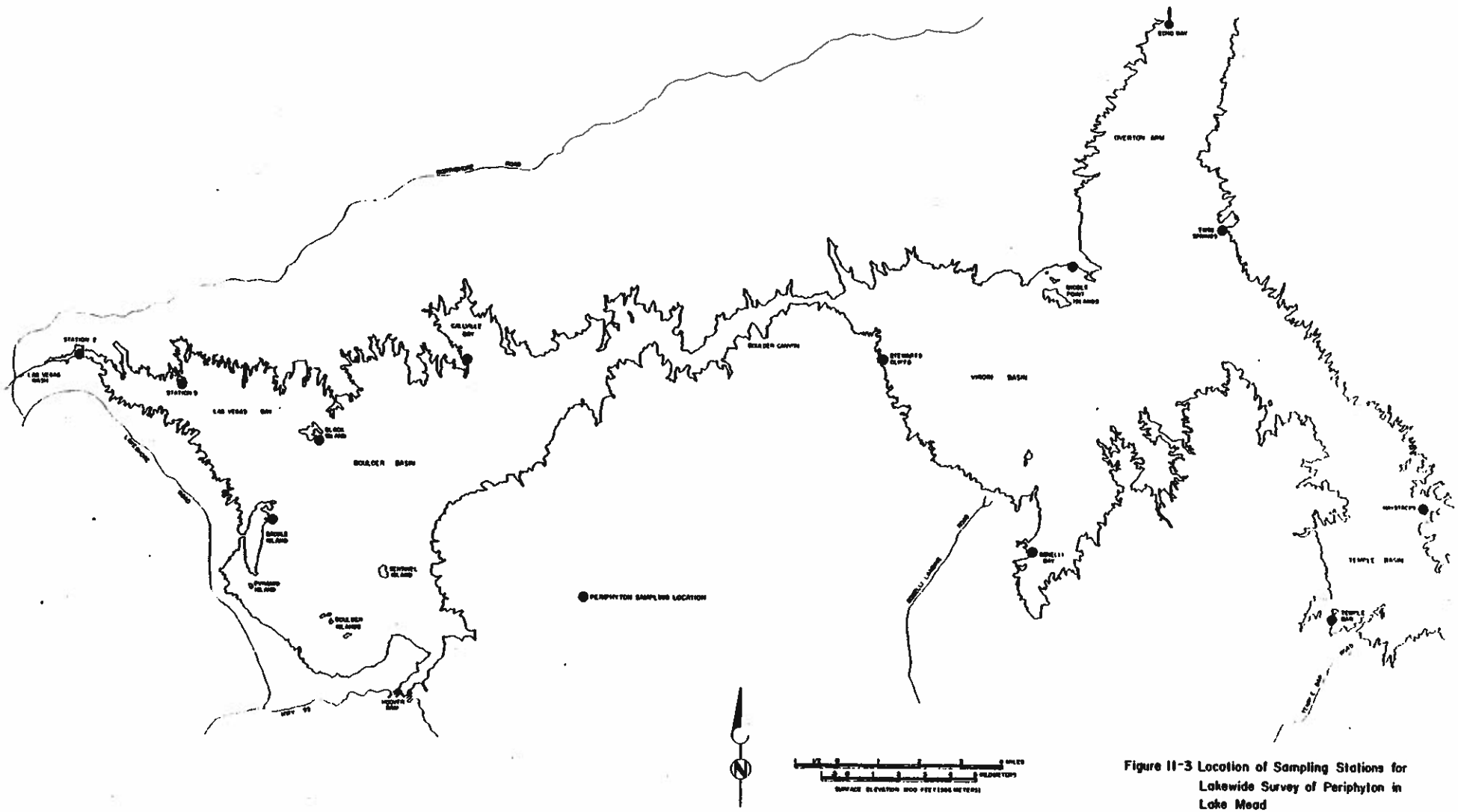


Figure II-3 Location of Sampling Stations for Lakewide Survey of Periphyton in Lake Mead

were collected too infrequently to enable meaningful presentation. UNLV prepared several reports describing the periphyton sampling program, which are contained in Appendix B.

Routine Sampling

The results of the routine sampling of periphyton on artificial substrates are discussed below.

Seasonal Distribution. Measurements of biomass growth rates (ash-free weight), chlorphyll a, and pheophytin a at the limnetic stations are presented on Figure 11-4. Measurements at the littoral stations are presented on Figure 11-5. Inspection of the plots indicates that the stations may be segregated into groups which exhibit roughly similar behavior. Stations 2I and 5I both exhibited peak growth rates in May 1980; however, a second peak growth period which occurred in December 1980 at station 5I was not evidenced at Station 2I. Stations 8I, 9I, and 10I also behaved similarly although generally growth rates were higher at Station 8I than Stations 9I and 10I. Growth at these stations was quite high during the winter of 1979, diminished during the spring of 1980, and peaked again during the summer. In March 1980, it was concluded that periphyton measurements at the littoral stations on the north shore were consistently lower than the south shore, and north shore measurements were discontinued. The chronological plots of biomass growth at the littoral stations (Figure 11-5) are difficult to interpret. While there are some similarities between the littoral and limnetic stations, there are also differences. Growth rates at littoral Station 2III were

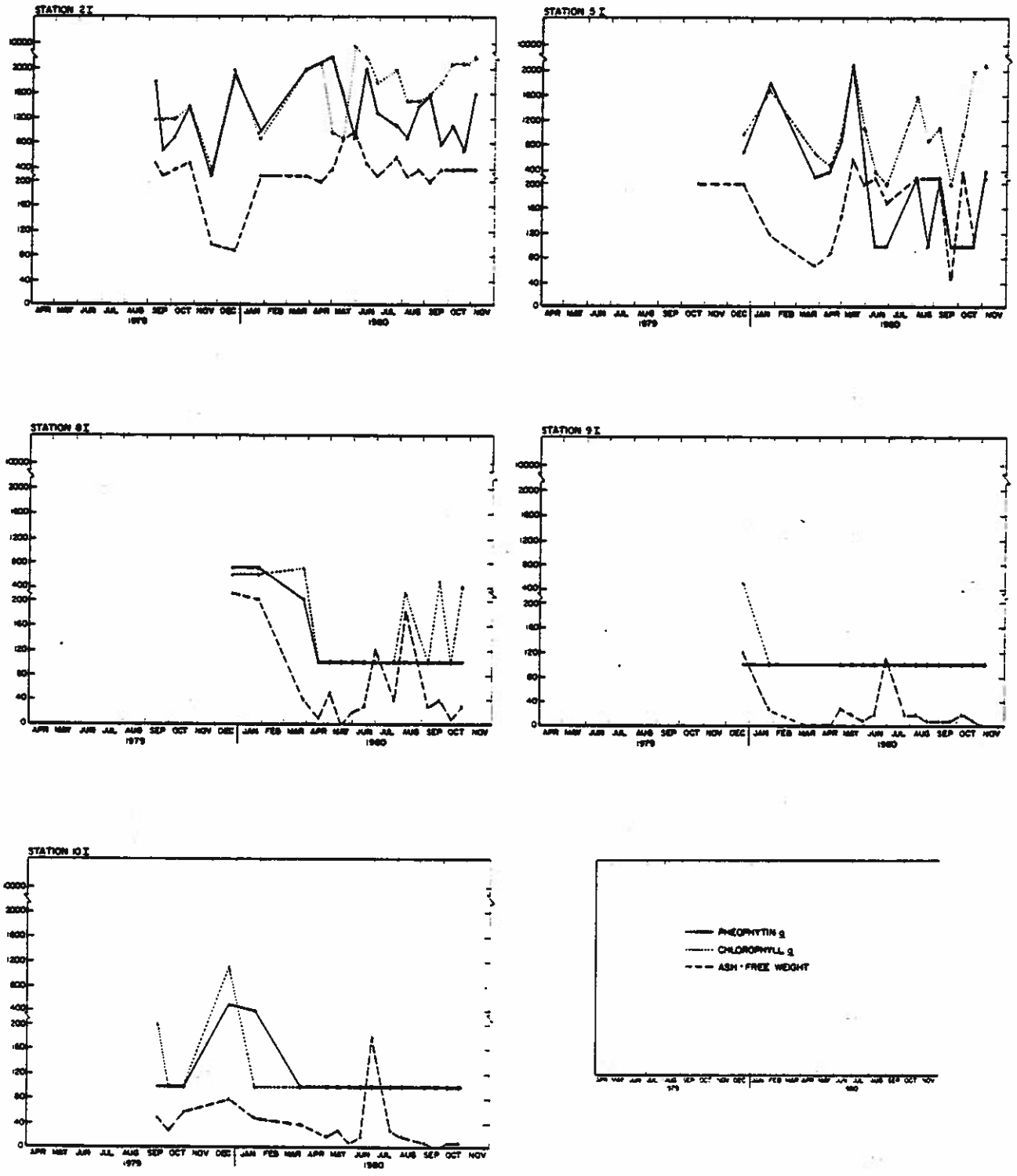


Figure II-4 Biomass Growth Rates, Chlorophyll a, and Pheophytin a at Limnetic Stations

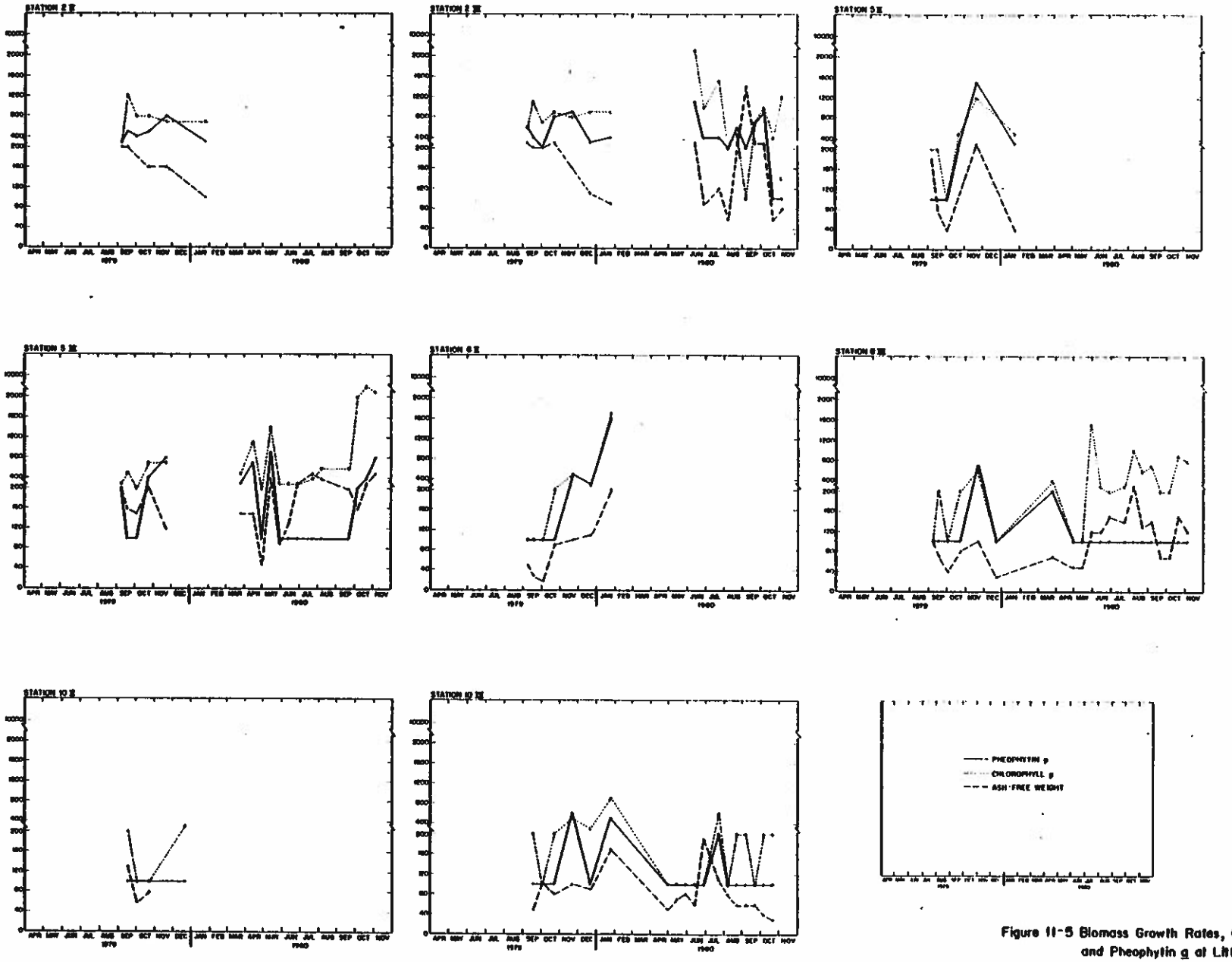


Figure II-5 Biomass Growth Rates, Chlorophyll a, and Pheophytin a at Littoral Stations

generally less than rates at limnetic Station 2I. At the other locations, littoral station growth rates were greater than at the limnetic stations.

Generally, the plots of chlorophyll parallel the corresponding plots of ash-free weight. This relationship is most evident at Stations 2I, 2III, 5I, 5III, 8I, and 8III. At the stations in Virgin Basin, the limits of detection for the chlorophyll measurements may obscure the ash-free weight/ chlorophyll relationship.

Chronological plots of periphyton alkaline phosphatase activity (APA) are presented on Figure 11-6. APA has been divided by ash-free weight to provide a clearer indication of potential phosphorus limitation. As described in Chapter 8, the higher the level of APA the stronger the indication of phosphorus limitation. The periphyton APA results, however, are far more erratic than bioassay results, which indicate that phosphorus stimulated growth at Stations 5I and 8I from October 1979 through August 1980, and during November and December 1979 and January, March, April, June, and July 1980 at Station 2 (Figure 8-57). Periphyton APA results are much more difficult to interpret with measurements fluctuating widely over short periods of time; although some similarities, particularly between Stations 9I and 10I, can be identified.

Spatial Distribution. Ash-free weight, chlorophyll *a*, and pheophytin *a* data are summarized in Tables 11-2 through 11-4, respectively. The decreasing trend in growth rates with increased distance from Las Vegas Wash is clearly evident in these data. Measurements of growth rates (ash-free weight) and chlorophyll *a* at individual stations span a range of one order of magnitude. Normalized APA data (APA divided by ash-free

Table 11-2. Summary of Periphyton Ash-Free Weight Measurements

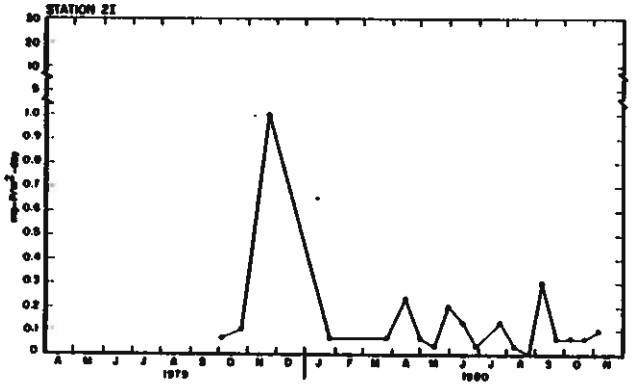
Station	Ash-free weight, mg/m^2-day[a]				
	Number of measurements	Mean	Minimum	Maximum	Standard deviation
2I	24	390	87	1,001	211
2II	5	171	97	225	51
2III	19	240	50	1,361	292
5I	19	255	47	821	184
5II	5	133	42	318	117
5III	20	256	47	647	152
8I	16	71	0	295	87
8II	7	91	21	228	70
8III	22	108	31	315	62
9I	18	26	0	124	35
9III	13	56	18	145	41
10I	18	38	0	179	41
10II	3	88	57	128	36
10III	18	81	31	193	42

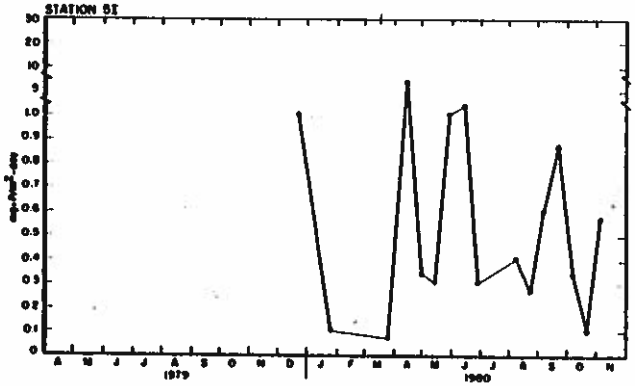
[a]Based on 14-day average incubation period.

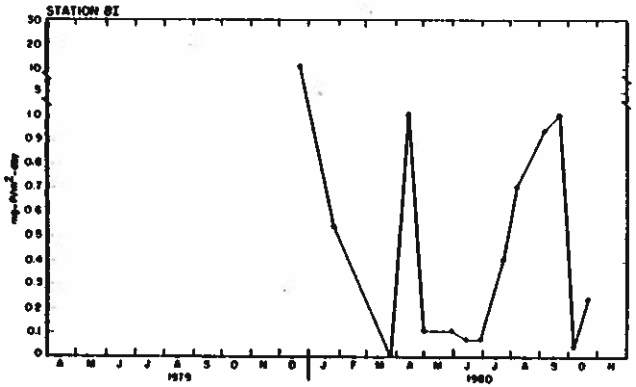
Table 11-3. Summary of Periphyton Chlorophyll a Measurements

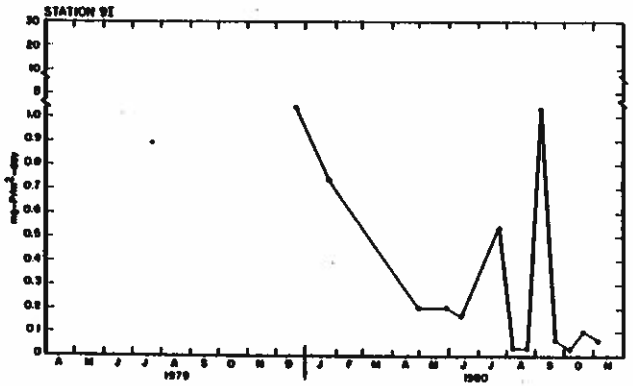
Station	Chlorphyll a, ug/m^2-day[a]				
	Number of measurements	Mean	Minimum	Maximum	Standard deviation
2I	24	2,671	400	9,200	2,084
2II	6	750	300	1,200	288
2III	19	995	<100	4,000	814
5I	18	1,756	200	8,300	1,945
5II	6	450	<100	1,200	404
5III	20	1,435	<200	7,600	1,944
8I	16	256	<100	700	225
8II	7	429	<100	1,700	579
8III	22	527	<100	1,900	498
9I	16	125	<100	500	100
9III	14	129	<100	400	83
10I	18	161	<100	1,100	235
10II	4	175	<100	300	96
10III	18	239	<100	900	217

[a]Based on 14-day average incubation period.









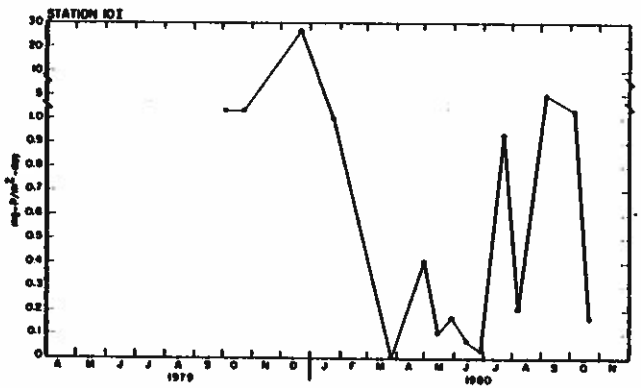


Figure II-6 Normalized Alkaline Phosphatase Activity Versus Time

Table 11-4. Summary of Periphyton Pheophytin a Measurements

Station	Pheophytin a, ug/m²-day[a]				
	Number of measurements	Mean	Minimum	Maximum	Standard deviation
2I	24	2,308	<100	22,000	4,347
2II	6	467	300	800	186
2III	19	447	<100	1,100	313
5I	18	556	<100	3,500	849
5II	6	400	<100	1,500	548
5III	20	310	<100	900	281
8I	16	181	<100	700	204
8II	7	400	<100	1,600	551
8III	22	132	<100	700	129
9I	16	<100	<100	<100	0
9III	14	<100	<100	<100	0
10I	18	139	<100	500	114
10II	4	<100	<100	<100	0
10III	18	156	<100	600	146

[a]Based on 14-day average incubation period.

Table 11-5. Summary of Alkaline Phosphatase Activity Measurements

Station	Alkaline phosphatase activity/ash-free weight[a]				
	Number of measurements	Mean	Minimum	Maximum	Standard deviation
2I	21	0.164	0.006	1.639	0.346
2II	0	—	—	—	—
2III	2	0.287	0.136	0.437	—
5I	18	0.892	0.047	6.865	1.596
5II	1	0.958	—	—	—
5III	2	1.246	0.333	2.159	—
8I	14	1.082	0.004	9.496	1.082
8II	2	1.699	1.547	1.851	—
8III	1	1.594	—	—	—
9I	15	0.404	0.001	2.170	0.666
9III	0	—	—	—	—
10I	16	6.410	0.004	25.988	2.658
10II	2	1.187	0.036	2.339	—
10III	2	1.702	0.015	3.388	—

[a]mg-P/m²-day
mg/m2-day

weight) are summarized in Table 11-5. A general trend of increasing phosphorus limitation with increased distance from Las Vegas Wash can be seen in the data, particularly at the index stations. Results at Station 9I do not seem to fit this pattern.

For purposes of comparing stations during the recreational season, results have been averaged by month. The monthly averages have then been combined to obtain seasonal averages. Biomass growth rates, summarized for 1980 and the 1980 summer season, May through September, are presented on Figure 11-7. Growth rates in the inner Las Vegas Bay (Stations 2I, 2III) were three to five times greater than in central Boulder Basin (Stations 8I, 8III) and five to ten times greater than measurements made in Bonelli Bay.

Species Identification. For each sample taken in the routine monitoring program, the five dominant species were identified by microscopic examination. Over the course of the program, 89 different species were identified. To simplify presentation of the results, the species have been summarized into four major divisions. Sixteen species of Chlorophyta (green algae), 15 species of Cyanophyta (blue-green algae), 57 species of Bacillariophyta (diatoms), and one species of Pyrrophyta (dinoflagellates) were identified. Occurrence of the various major divisions is tabulated in Table 11-6.

Diatoms represented the overall majority of dominant species. At Station 2, green algae were among the dominant species during most of the sampling runs; however, the other stations showed a trend toward green algae among the dominant species only in late summer and fall. Although blue-green

Table 11-6. Major Divisions of Algae Determined From Periphyton Sampling

Date	Number of species identified													
	Station													
	2			5			8			9		10		
	I	II	III	I	II	III	I	II	III	I	III	I	II	III
09/07/79	2bg 3d	2g 3d	5d		1g 4d			3g 2d	3g 2d					
09/19/79	4d	2g 3d	1g		1g 3d	2g 1bg 1d		1bg 1d	1g 1bg 2d			1g 1bg 2d	1g 1bg 3d	1g 1bg 3d
10/03/79			3g 1d			3g 1bg					2g 3d	1g 1d		2g 3d
10/24/79	1g 4d		4g 1d			3g 1bg 1d			2g 3d			2g 2d		1bg 4d
11/21/79	3g 4d		2g 3d			3g 1bg			2g 1bg 2d					
12/21/79	2g 3d		1g 1bg 3d						2g 1d			1g 1d		1g 4d
01/26/80	2g 3d		1g 4d	1bg 4d		1g 1bg 3d								1g 4d
03/25/80	1g 4d			4d		2bg 2d	5d		5d	1g 4d		1g 4d		2g 1bg 2d
04/15/80	1g 1bg 3d			5d		2bg 3d	1g 4d		1bg 4d		1g 4d	5d		2bg 3d
05/02/80	2bg 3d			1bg 4d		5d								
05/15/80	2g 1bg			2bg 2d		1g 2bg 1d	3d		5d	2d	5d	5d		3d
05/29/80	1g 1bg 3d			5d		1g 4d	1g 4d		5d	1g 4d	5d	1g 3d		5d
06/16/80	1g		1g 2d	4d		5d	5d		5d	4d	5d	1g 4d		5d
06/30/80	1bg 4d		1bg 4d	2g 3d		1bg 3d	1g 4d		1bg 4d	5d	5d	1g 4d		5d
07/25/80	1bg 4d		1bg 4d			2bg	1g 1bg		2g 1bg 1d	1g 4d	2g 3d	1g 3d		1g 1bg 3d
08/07/80	1g 4d		2g 3d	1g 2bg 1d		1bg			1g 2bg 2d	1g 4d	1g 4d	1g 4d		
08/21/80	2g 3d		2g 3d	2g 3bg			2g			1g 4d	2g 3d			2g 3d
09/08/80	5d		2d	1g 1bg 3d			2g 3d		2g 1bg 2d	1g 4d	2g 3d	1g 4d		2g 3d
09/23/80	2g 3d		1g	3g 2d		2g 1bg 2d	1g 1d		3g 2d	2g 3d	1g 4d	2g 3d		1g 4d
10/07/80	5d		1g 1bg 3d	2g 1bg 2d		2g 1bd 2g	1g 1d		2g 1bg 1d	1g 4d	2g 1bg 2d	1g 2d		1g 4d
10/20/80	1g 4d		1g 2d	1g 2d		2g 1d			2g 1bg 2d	2g 2d	2g 3d	2g 3d		2g 3d
11/06/80	1g 1bg 3d		3g 2d	2g 1bg 2d		3g 2bg	1g 1d		3g 1bg 1d	2g 3d	2g 3d			
11/20/80	1g 4d		1g 1bg 3d	1g 2d		2g 1bg			3g 1bg 1d	1g	2g	1g 2d		
12/19/80	1g 1bg 3d		1g 4d	1g 1d		1g			1bg 2d		2g 3d			

g = green, bg = blue-green, d = diatoms, di = dinoflagellates

algae were often among the dominant species at Stations 2 and 5, they were less frequent at Station 8, and nearly absent at Stations 9 and 10.

Lakewide Surveys

Results of the lakewide surveys are summarized on Figure 11-8. Periphyton biomass was qualitatively estimated as sparse, moderate, or abundant. Data for the dominant species identified are contained in Appendix B and general trends are described below.

During the March 2, 1980, lakewide survey, blue-green algae were present at all Boulder Basin stations except the inner Las Vegas Bay. Blue-greens were also present in Virgin Basin at Stewart's Cliffs, Bonelli Bay, and Haystacks. Diatom-dominated communities occurred at all stations except Station 5, the outer Las Vegas Bay, Saddle Island, Black Island, and Bonelli Bay. Green-dominated communities occurred on salt cedar and rock at Station 2 and Saddle Island, respectively. Growth was sparse in Las Vegas Bay and Middle Point, and totally absent in Twin Springs. Growth was moderate to abundant elsewhere in the lake.

On June 30, 1980, blue-green algae occurred in small numbers at all Boulder Basin stations, except the inner Las Vegas Bay, and were also present at Stewart's Cliffs and Virgin Basin. Raphidiopsis, a blue-green, was dominant along with diatoms at Bonelli Bay and in Temple Basin. Diatom-dominated communities occurred at outer Las Vegas Bay, Boulder Basin, Stewart's Cliffs, and Virgin Basin. Green-dominated communities occurred on salt cedar at the outer Las Vegas Bay and on rocks in Callville Bay. Growth was very sparse at Twin Springs and Echo Bay. Abundance data at other stations were unavailable.

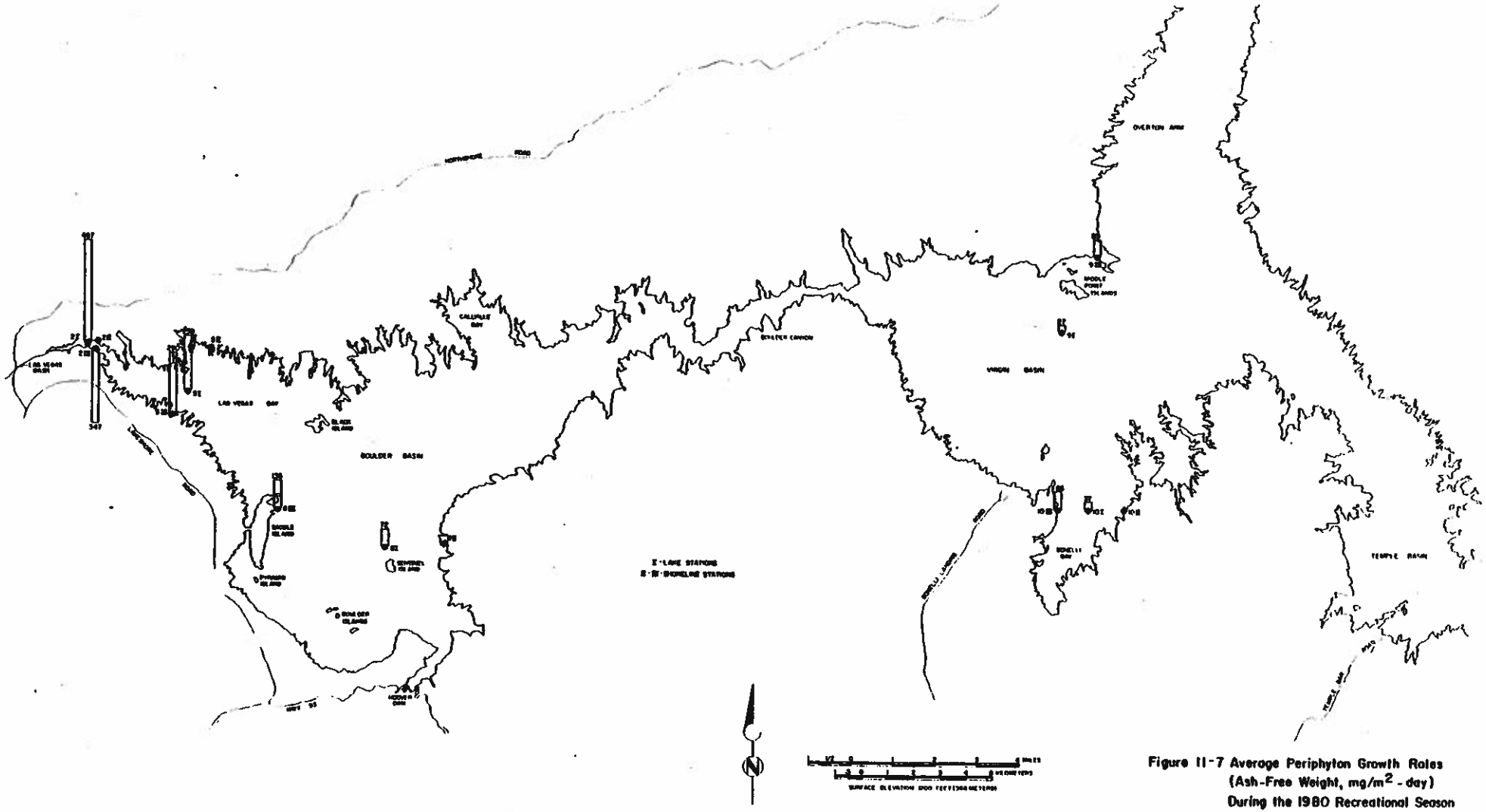


Figure II-7 Average Periphyton Growth Rates (Ash-Free Weight, mg/m^2 - day) During the 1980 Recreational Season (May to September)

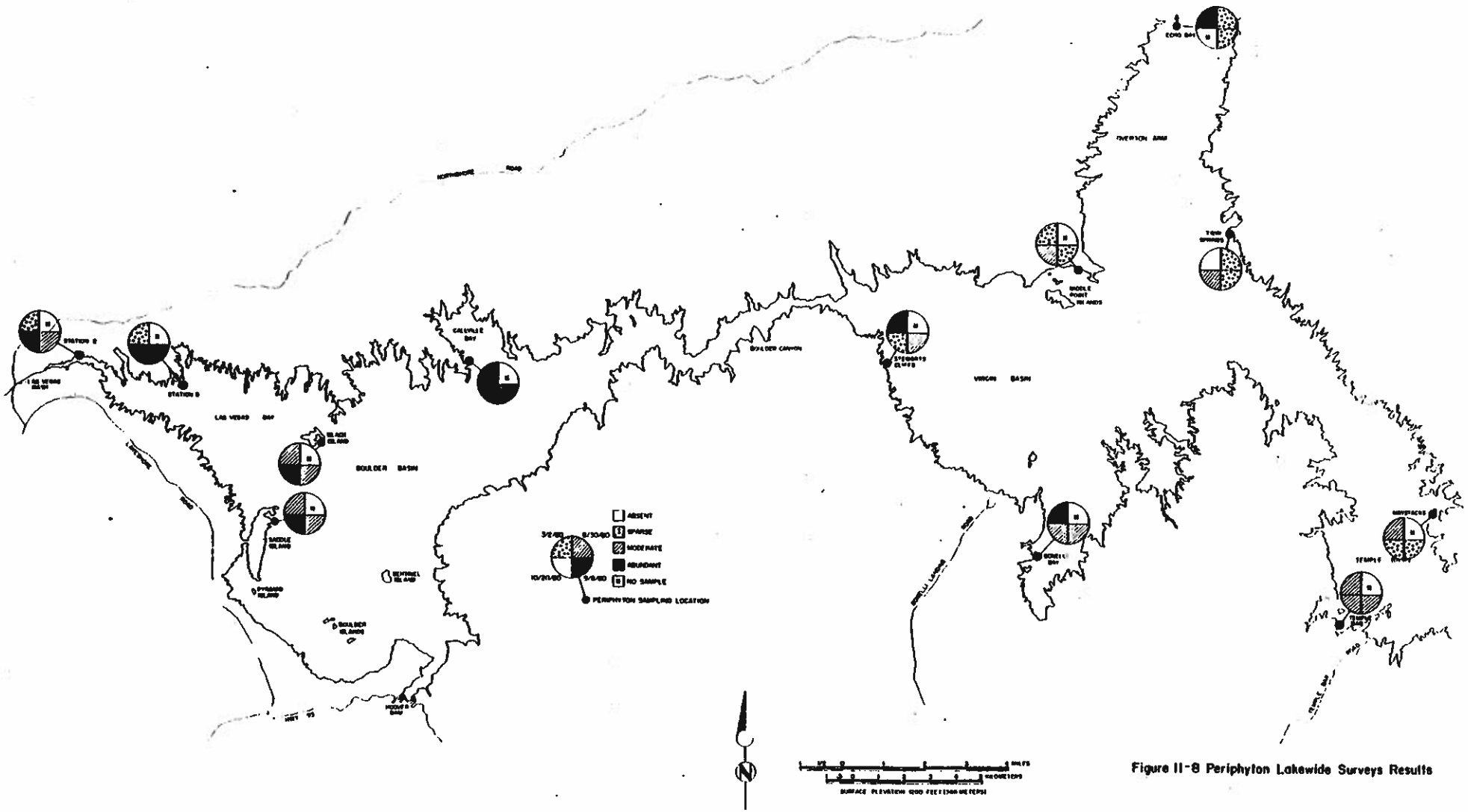


Figure II-8 Periphyton Lakewide Surveys Results

On September 8, 1980, salt cedar in Las Vegas Bay was dominated by Rhizoclonium (green). Diatoms and greens co-dominated communities at Black and Saddle Islands. Blue-greens occurred at every station surveyed and co-dominated with diatoms at all stations in the Upper Basin. Diatoms were also present throughout the lake. Growth was abundant only in outer Las Vegas Bay and Callville Bay, and was sparse at Haystacks, Twin Springs, Middle Point, and Echo Bay. Elsewhere in the lake, growth was moderate.

On November 20, 1980, blue-greens were either common or dominant at all stations surveyed. Green algae were common or co-dominated with blue-greens and diatoms throughout the lake except at Black Island where they were rare. Diatoms occurred at all stations. Growth was abundant throughout Boulder Basin, sparse at Stewart's Cliff and Haystacks, and moderate elsewhere.

Comparison of Routine and Lakewide Surveys

Measurements of periphyton growth rates made in routine sampling of artificial substrates demonstrated a consistent trend of decreased growth rates with increased distance from Las Vegas Wash. This trend was not as clear in the lakewide surveys. On some occasions, the relative abundance observed in Las Vegas Bay was comparable to or less than that observed in other parts of Lake Mead. Measurements of relative abundance in the lakewide surveys were based upon visual inspection. Thus, the differences are not completely surprising, because biomass measurements can differ significantly from visual impressions.

Species identified in the lakewide surveys were comparable to periphyton identified on the artificial substrates. In the

lakewide surveys, species were identified both on rock and salt cedar substrates. Artificial substrate-developed periphyton communities were most like those noted on rock subtrates; however, there were differences. For example, in several locations, matted growths of Oscillatoria were noted during the March 2 lakewide survey, while Oscillatoria were absent on the artificial substrate.

The proper type of artificial substrate for periphyton sampling has been and continues to be the subject of debate among limnologists. Early research utilized glass slides. The smooth surface, however, did not enable holdfast attachment, and significant differences were noted between natural periphyton communities and those on glass slides. Most recently, styrofoam has been used as an artificial substrate. While styrofoam provides a surface which is very similar to natural substrate, the effective surface area cannot be easily determined. Fiberglass, the type of substrate used in WQSS, is something of a compromise; it is rougher than glass, but the surface area can be estimated. However, shoreline periphyton on natural substrate will probably always differ from those on artificial substrate simply because of physical processes. Periphyton along the shoreline are subjected to wave action, which constantly removes growth. Sediment from runoff buries natural periphyton communities. As a result, sampling is highly dependent upon the particular sampling location.

DATA COMPARISONS

Most of the literature regarding periphyton is qualitative in nature, and concerns succession of algal communities in various streams and lakes. The lack of quantitative data is

due, to a large degree, to the difficulty of making consistent measurements. Factors considered in the literature include selection of representative substrate, determination of the effective surface area of rough substrate, suitability of artificial substrate for measurements, and the effect of varying incubation periods on rate of growth measurements. These factors in combination with the lack of standard sampling methods have resulted in a scarcity of comparable periphyton measurements.

WQSS periphyton results and reported measurements which are comparable to the WQSS procedures are summarized in Table 11-7. Comparing the Lake Mead results with measurements made in other areas, it is apparent that conditions at all Lake Mead stations were generally less severe than sampling sites in the Sacramento River in 1977. However, the growth rates in Lake Mead were 1 to 2 orders of magnitude greater than in relatively pristine Lake Tahoe, and were comparable to the other references cited.

Table 11-7. Periphyton Ash-Free Weight Comparisons

Reference	Location	Rate of accumulation mg/m^2-day
WQSS		
Station 2I	Inner Las Vegas Bay--Lake Mead	487[a]
Station 5I	Middle Las Vegas Bay--Lake Mead	258[a]
Station 8I	Boulder Basin--Lake Mead	57[a]
Station 9I	Virgin Basin--Lake Mead	27[a]
Station 10I	Bonelli Bay--Lake Mead	37[a]
King and Ball[2]	Red Cedar River--Lower Peninsula, Michigan	284
Kevern, et. al.[3]	A natural spring	70-150
	Laboratory streams	80-350
Goldman, et.al., 1970[4]	Lake Tahoe	0.09-2.2
Brown and Caldwell, 1977[5]	Sacramento River	140-4,140

[a]May through September 1980.

ANALYSIS

A number of factors affect periphyton growth rates. Temperature, light level, substrate, pH, nutrients, turbulence, and grazing all influence periphyton abundance. These factors have been examined to varying degree for only a few species of periphyton. The combined impact of these factors results in a distinct seasonal cycle of periphyton growth. Typically, growth rates are minimal during the winter due to low temperature and low light intensities. During the spring, as temperature and light increase, growth accelerates. In mid-summer, growth rates again decrease. During the late summer and early fall, there is usually another period of rapid growth. In the late fall, upright parts of the algae become detached, leaving thick-walled basal fragments which begin the cycle again in the spring.

To assess the effect of nutrient concentrations upon periphyton, the effects of the other factors must first be identified. Because of the wide diversity of algal species and their differing ecological requirements, exceptions can be found to any of the factors which affect periphyton growth. However, the following discussion provides a general background for considering conditions in Lake Mead.

Temperature

Periphyton have been reported from a wide range of climatic regions ranging from the Arctic to the tropics; however, a marked decrease in abundance has been noted at temperature extremes. Although exceptions have been documented, typical maximum growth rates occur for temperatures between 15° and

25°C. Decreases in abundance during the coldest and hottest months of the year have been documented in many studies.[6] Average monthly growth rates and water temperatures at Stations 2I, 5I, and 8I during the summer period are shown on Figure 11-9. Although high temperatures during July and August may have some inhibitory effects on periphyton growth rates, there is no clear relationship.

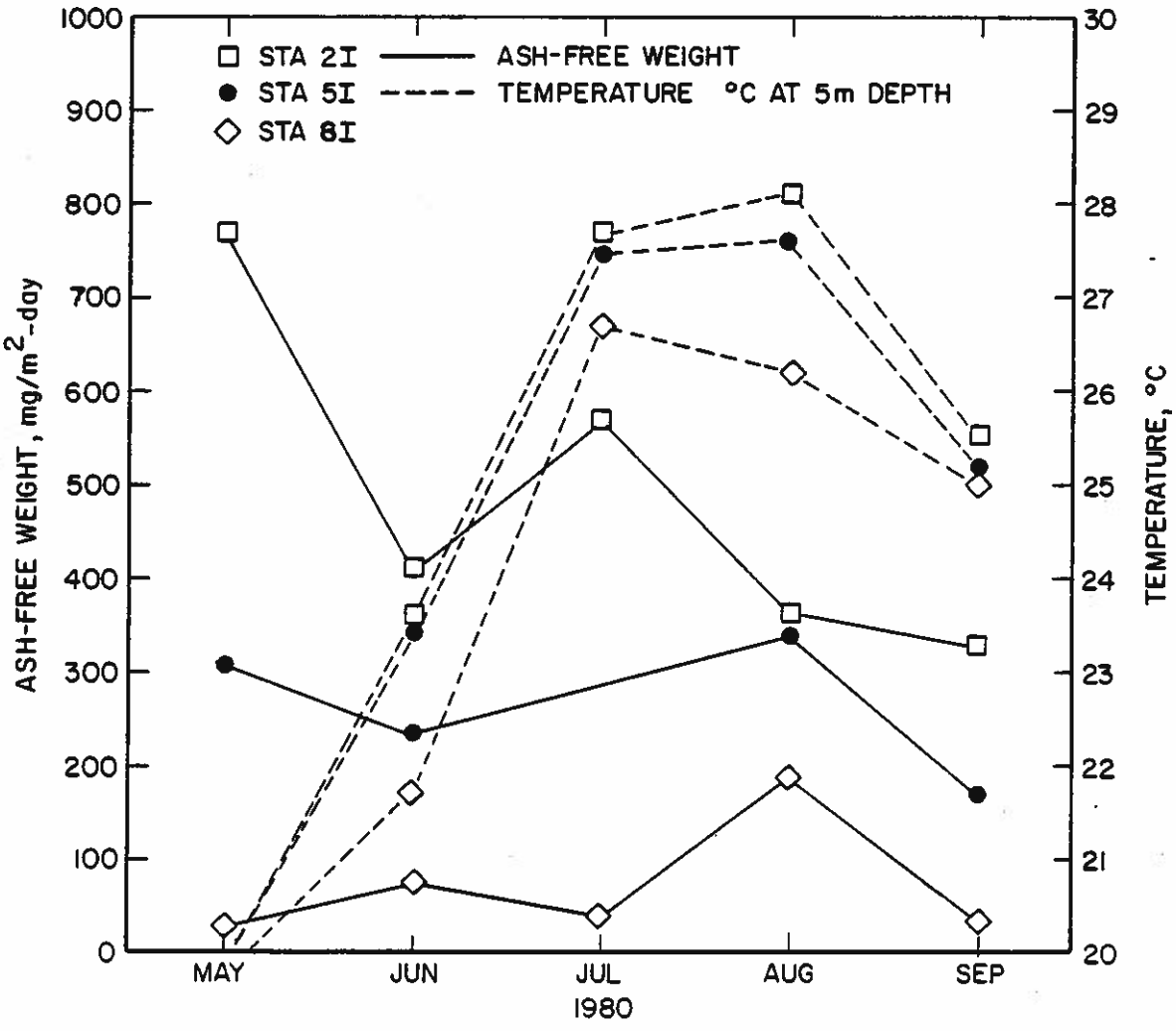


Figure 11-9 Average Monthly Water Temperature and Biomass Growth Rates

Light

Although it has been reported that growth rates are significantly affected by light intensity, previous research is difficult to interpret. Some species favor shade while others are markedly favored by high light intensity.[6] Secchi depth, an indicator of relative light intensity, and ash-free weight measurements are plotted on Figure 11-10. Comparing the stations by month, low light levels in the Las Vegas Bay (i.e., low Secchi depth at Station 2) do not appear to be inhibiting growth. Likewise, higher light levels in mid-Boulder Basin do not appear to significantly stimulate growth. It must be recognized, however, that Secchi depth and, thus, light intensity are influenced by nutrient concentrations as is periphyton growth. Thus, there is potential for autocorrelation.

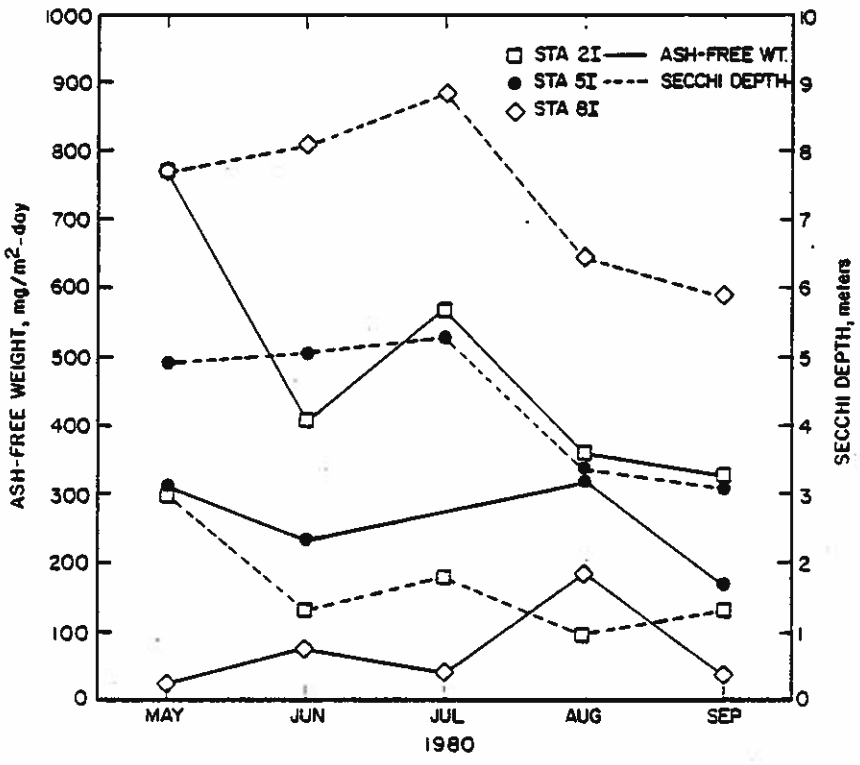


Figure 11-10 Average Monthly Secchi Depth and Biomass Growth Rates

pH

Cladophora species are almost always associated with conditions of relatively high pH. Typically, optimal growth rates occur in the pH range of 7.0 to 10.0 although exceptions have been reported.[6] In Lake Mead, pH averaged about 8.1 and 99 percent of all pH values fell between about 7.2 and 9.1. Thus, typical pH values in Lake Mead do not have an inhibitory affect on periphyton growth.

Within its optimal pH range, *Cladophora* species appear favored by hard or very hard water.[6] Some species of *Cladophora* are unable to survive in calcium-free medium. There is no evidence to indicate that high calcium concentrations are inhibitory. Lake Mead water is quite hard. Six measurements of hardness made in the WQSS averaged 353 mg/l total hardness as calcium carbonate.

Water Movement

Algal growths appear markedly favored by water movements. In fact, *Cladophora* species are generally absent from completely quiet waters.[6] The favorability of moving water is generally attributed to the increase in nutrient availability it affords. In this regard, typical stream environments are markedly different than the Lake Mead environment where there are no significant current patterns. Additionally, the littoral stations in the WQSS may be expected to behave differently than the limnetic stations due to turbulence from wave action. The impact of thermal stratification on mixing regimes, and the mixing of the hypolimnion with surface water during the winter months affects nutrient distributions through the lake. Thus, the seasonal lake mixing pattern affects algal growth rates.

Substrates

A significant degree of algal diversification has resulted from preference for differing substrates. This fact results in differences between the species identified on artificial substrates utilized in the WQSS routine monitoring and species identified along the shoreline in the lakewide surveys. Uniformity of substrates used in the routine monitoring, however, does eliminate one ecological variable which simplifies comparison of the results from different routine stations.

Nutrients

Surprisingly little research has been done to determine the relationship of nutrient concentrations to periphyton growth rates. Additionally, the work that has been done has usually dealt with monocultures under laboratory conditions. Under natural conditions, due to the wide variety of algae and their unique environmental requirements, changes in nutrient concentrations often simply cause one type of algae to replace another.

Average growth rates and concentrations of orthophosphorus and inorganic nitrogen, the nutrients most readily utilized by algae, for May through September 1980, are presented on Figures 11-11 through 11-15. The nutrient measurements are monthly average routine WQSS data for the 5-meter integrated surface sample. Nutrient samples were not taken at the littoral periphyton stations. Phosphorus- and nitrogen-limiting conditions, determined on the basis of inorganic nitrogen: orthophosphorus ratios, are also shown on the figures. Nutrient limitation is based on the analysis for algae and nutrients

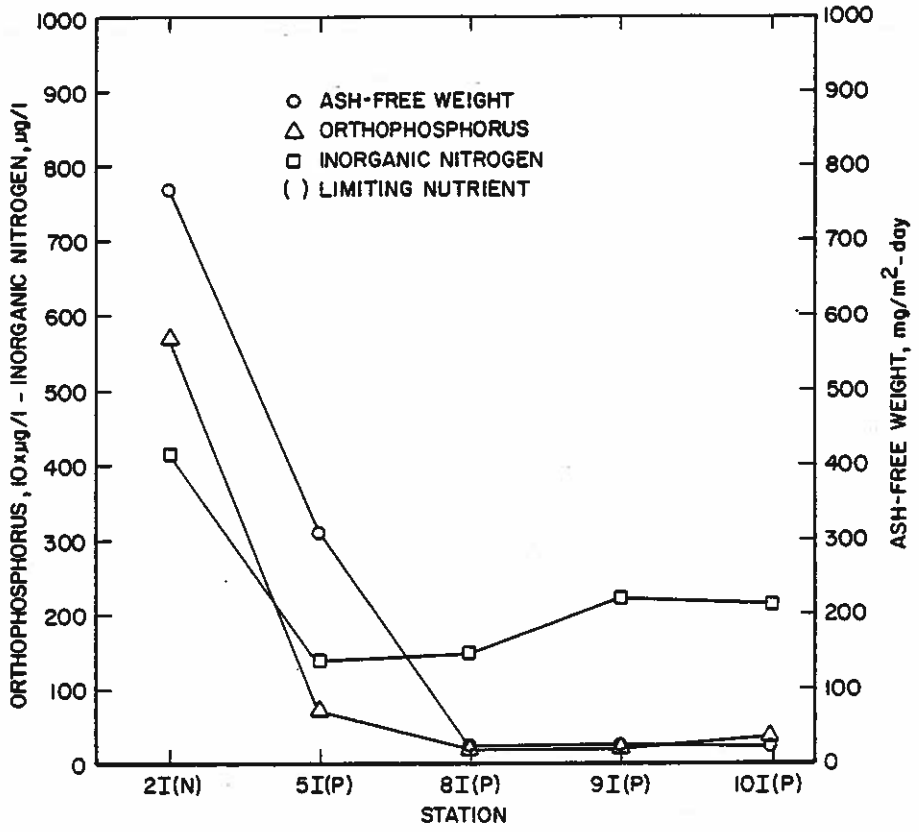


Figure 11-11 Periphyton and Nutrient Data for May 1980

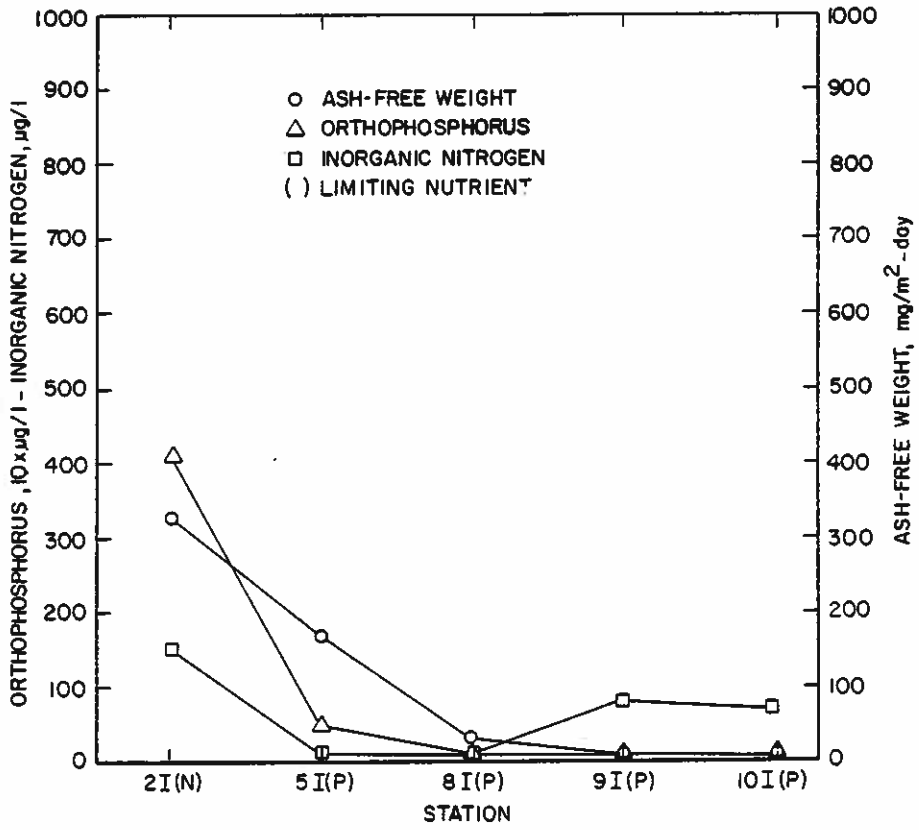


Figure 11-12 Periphyton and Nutrient Data for June 1980

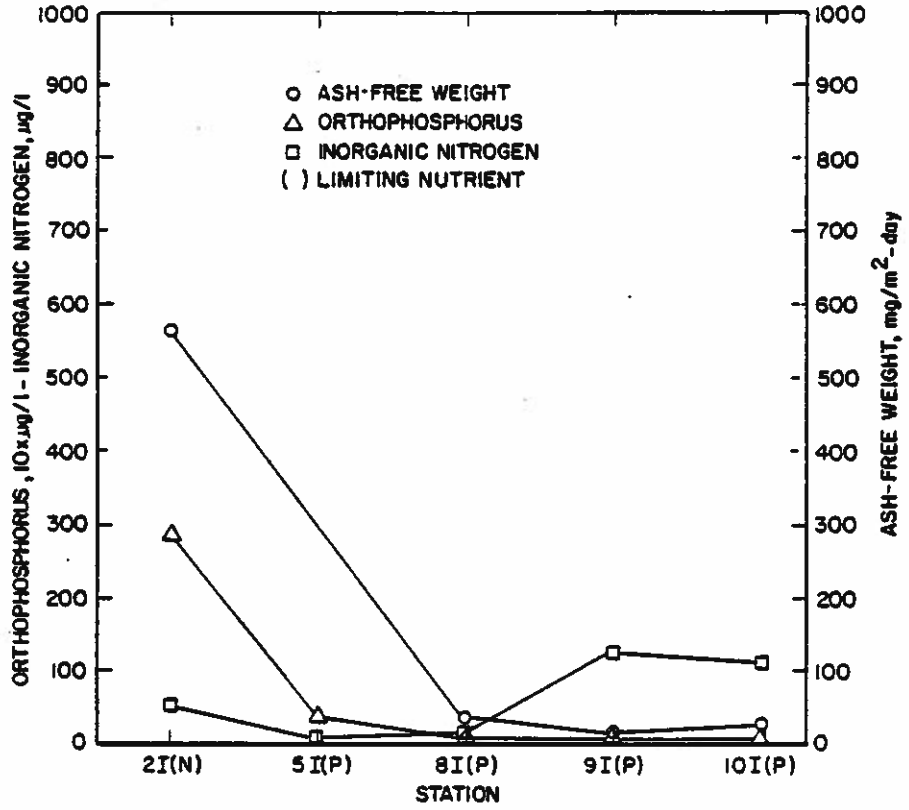


Figure 11-13 Periphyton and Nutrient Data for July 1980

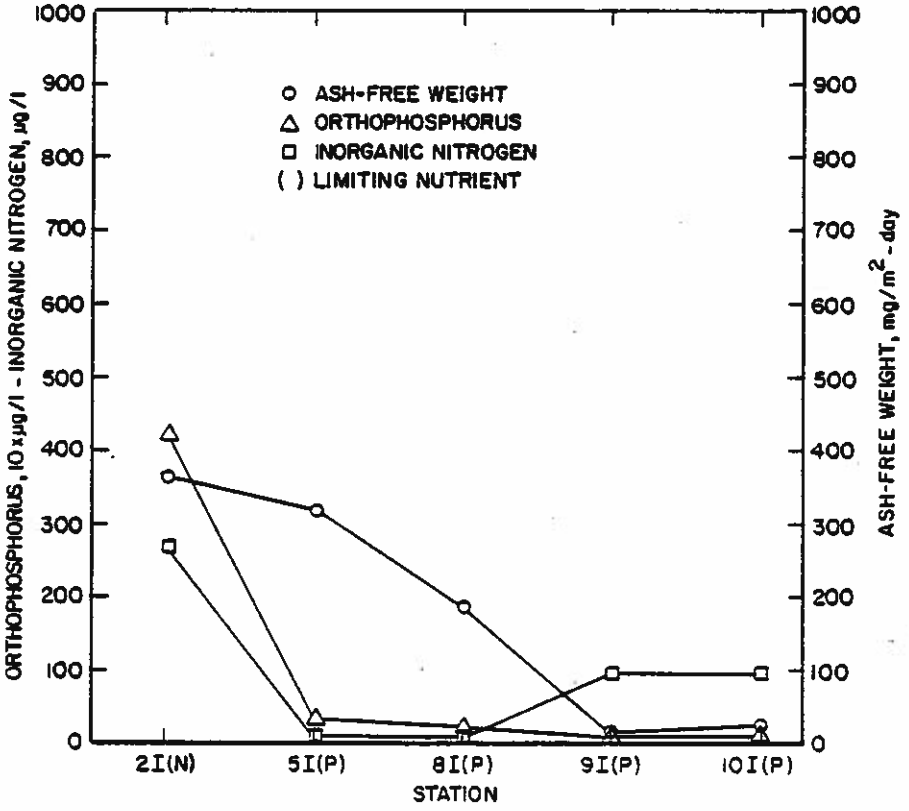


Figure 11-14 Periphyton and Nutrient Data for August 1980

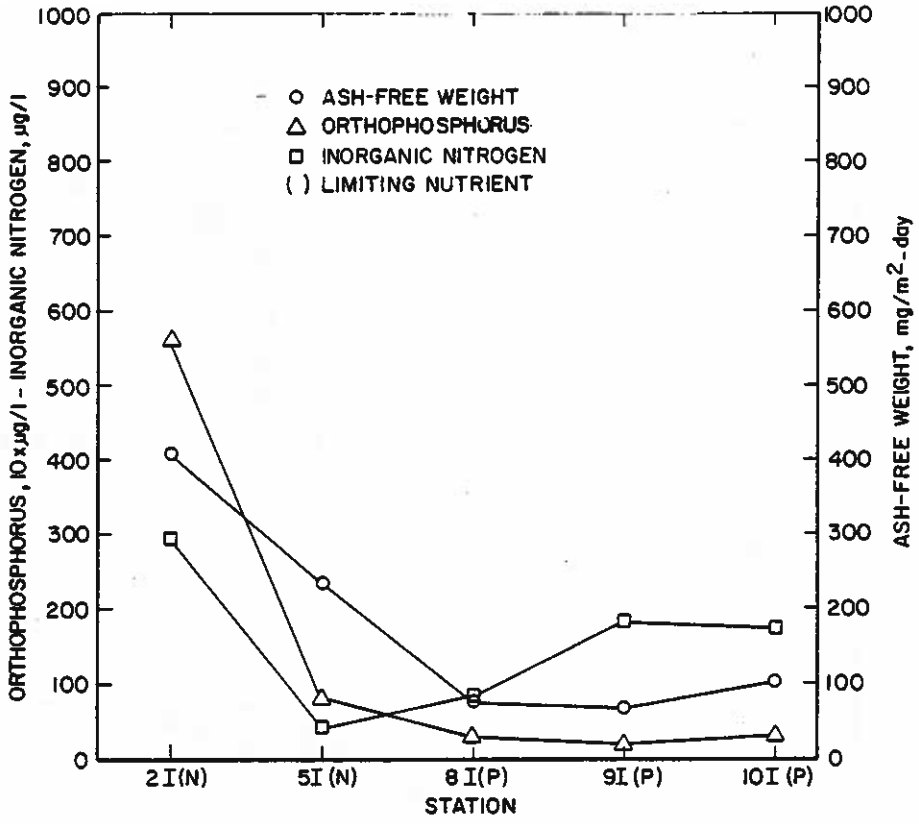


Figure 11-15 Periphyton and Nutrient Data for September 1980

presented in Chapter 8: P-limited conditions when inorganic N/orthoP>10 and N-limited conditions when inorganic N/orthoP<10. Because of the seasonal cycle of growth which results from the previously described factors, it would be best to develop nutrient/growth relationships for individual months. In this way, the effects of other factors could be minimized. However, inspection of Figures 11-11 through 11-15 indicates that there are not enough data points in any month to enable curve-fitting. For this reason, average monthly data are combined on Figures 11-16 and 11-17.

Because the ash-free weight data are rate values, and inorganic nitrogen and orthophosphorus are essentially

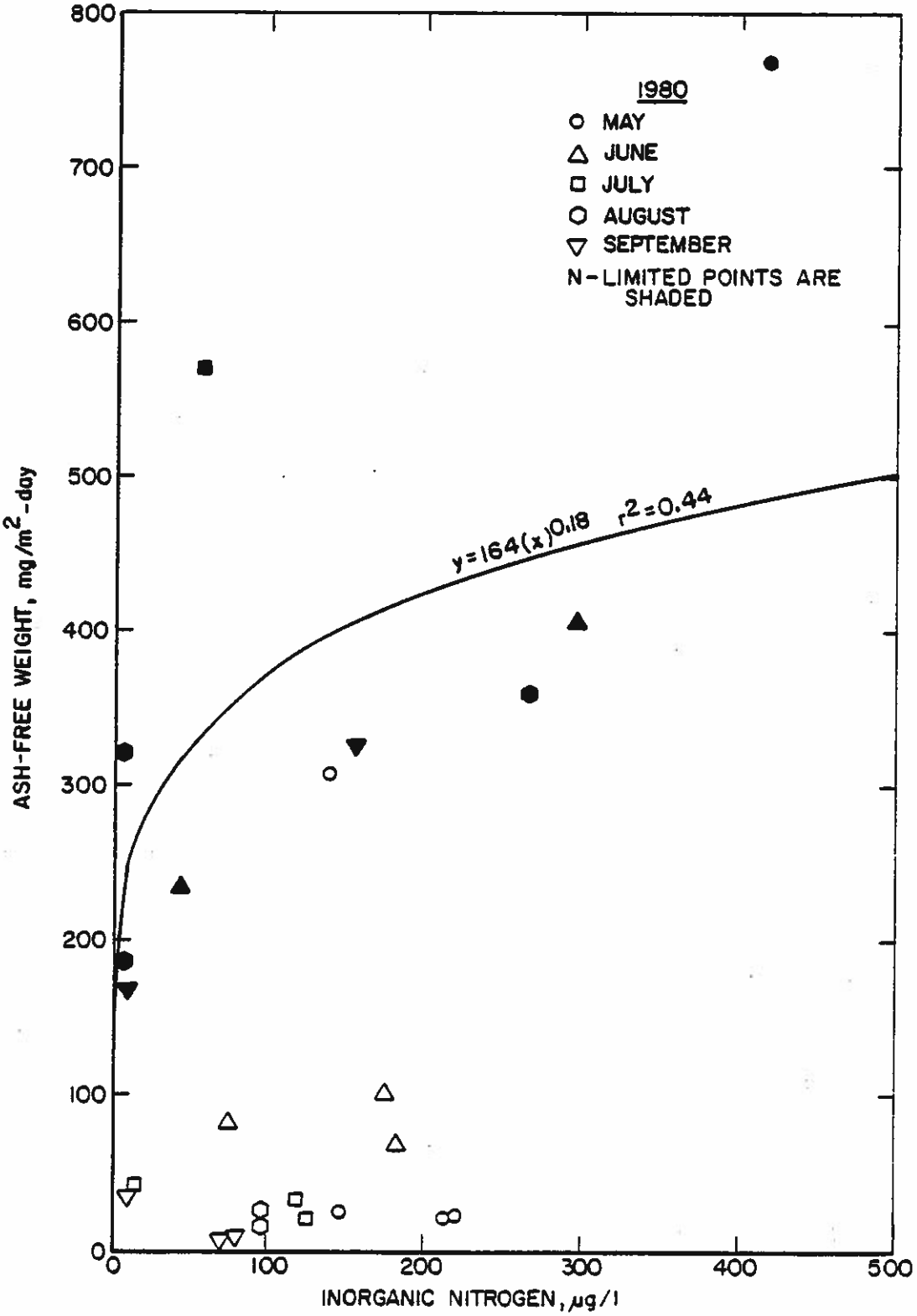


Figure II-16 Relationship Between Periphyton and Inorganic Nitrogen

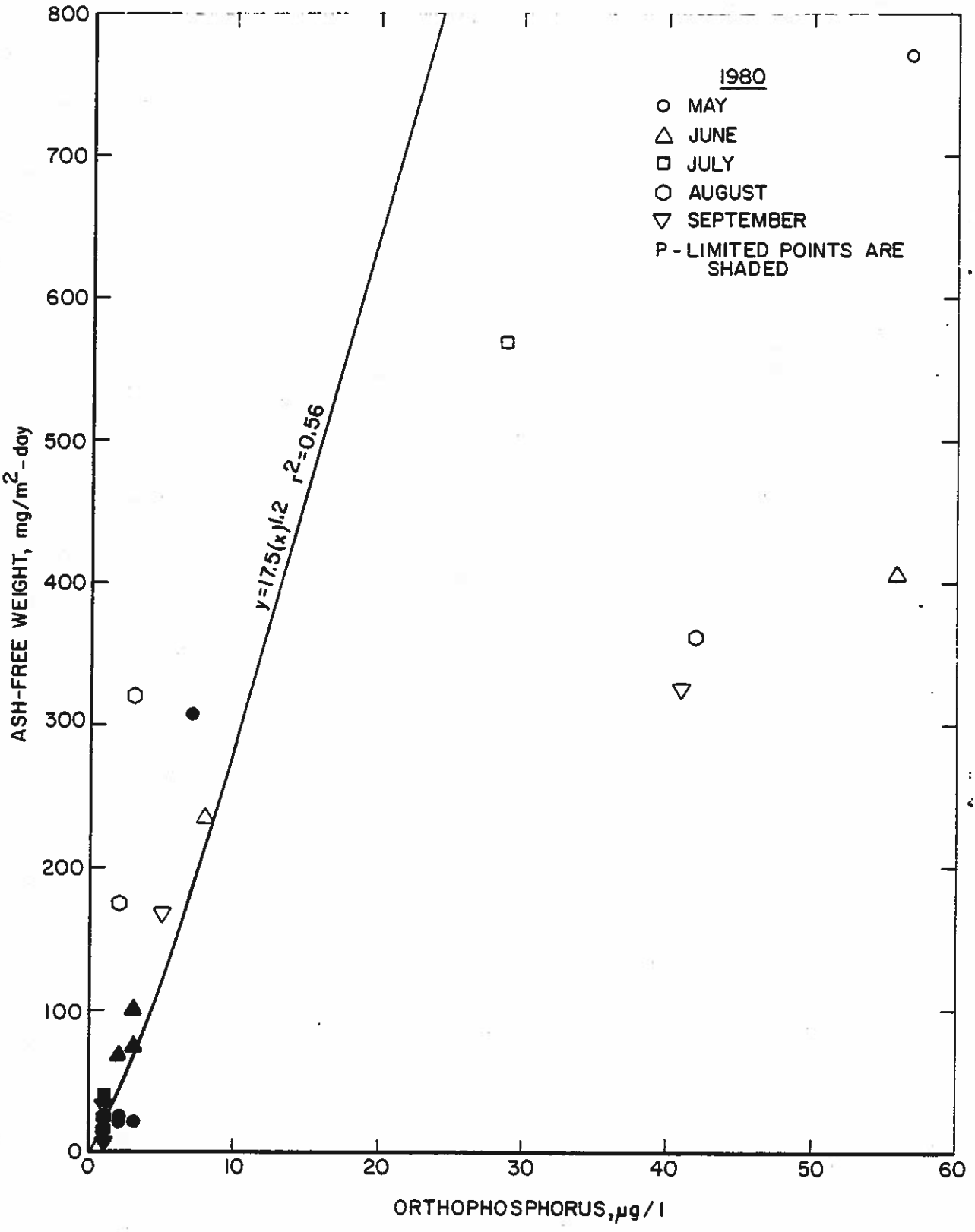


Figure II-17 Relationship Between Periphyton and Orthophosphorus

reactants, it is appropriate to develop Monod-type power functions ($y=x^a$) in relating growth rates to limiting nutrient concentrations. This type of analysis results in the following functions (also shown on Figures 11-16 and 11-17):

For nitrogen-limited data—

Ash-free weight [mg/m^2 -day] = 164 (inorganic nitrogen [ug/l])$^{0.18}$

r^2 = 0.44 N=9

For phosphorus-limited data—

Ash-free weight [mg/m^2 -day] = 17.5 (orthophosphorus [ug/l])$^{1.2}$

r^2 = 0.56 N = 15

As indicated by the r^2 statistic, the significance of these relationships is quite low and they are not suitable for making quantitative predictions of periphyton response to different nutrient levels. However, there is a general trend between decreasing nutrient levels and lower periphyton growth rates in comparing data from inner Las Vegas Bay to data in outer Las Vegas Bay and Virgin Basin.

Relationship of Nearshore Stations to Limnetic Stations

Generally, the nearshore stations exhibited higher growth rates than the limnetic stations. There are several possible reasons for this. Turbulence was greater around the nearshore stations, thus, there would be greater nutrient availability. Runoff also has a greater impact near the shore. The nearshore stations were closer to the lake bottom and natural periphyton communities than the limnetic stations. This fact may have resulted in more rapid colonization.

To further investigate these factors, other WQSS data have been reviewed. The intensive synotic surveys, summarized in

Chapter 8, did not evidence any consistent differences between water quality conditions at nearshore and limnetic stations. Although the Las Vegas Wash Marina has been suggested as a source of nutrients, measurements made in and around the Las Vegas Wash Marina on May 26, 1980, indicate that on that day, nutrient concentrations in the marina were lower than the nearest lake stations (Stations 3 and 4).

EFFECT ON BENEFICIAL USES

Periphyton impacts several of the beneficial uses of Lake Mead. The most apparent impacts include periphyton growths on boat hulls and along shorelines. Although periphyton growths do not directly inhibit boating, they increase maintenance efforts due to the added effort needed to clean the growths from boats. Periphyton growth on rocks along the shoreline can create a slippery surface and pose a hazard to swimmers.

As is the case for phytoplankton or floating algae, periphyton may have a dual impact on fish. Periphyton serve as a food source for fish; at the same time, periphyton that sloughs off substrates will be decomposed, depleting dissolved oxygen. Generally, the lake-wide surveys revealed moderate to abundant levels of periphyton throughout the Las Vegas Bay. All substrates in the bay were subject to some degree of periphyton growth. Black periphyton growth on most boat hulls in the Las Vegas Wash Marina was noted in a water quality sampling run conducted in May 1980.

It is difficult to quantify the impact of periphyton. There are no standards or criteria for periphyton, and studies to determine the costs of cleaning periphyton from boat hulls or

the public perception of the impacts of periphyton on use of the lake were not conducted as part of the WQSS. The analysis of periphyton data collected in WQSS shows that there is a general relationship between nutrient concentrations and periphyton in Las Vegas Bay. It is not possible to quantitatively predict future changes in periphyton, although measures for control of phytoplankton are likely to result in some reduction in periphyton growth. There is a limit as to what extent periphyton growth could be reduced in Las Vegas Bay. Periphyton are able to grow at very low levels of nutrients, as evidenced by the growths observed during the lakewide surveys in other portions of Lake Mead.

CONCLUSIONS

The material presented in this chapter documents periphyton conditions in Lake Mead and enables a number of conclusions to be drawn.

1. Lakewide surveys indicate that periphyton growth occurs throughout Boulder Basin and Virgin Basin.

2. Periphyton biomass growth rates on artificial substrates in Las Vegas Bay were three to five times greater than in central Boulder Basin and five to ten times greater than growth rates in Virgin Basin.

3. At all stations, except the one closest to the Las Vegas Wash, growth rates in the nearshore or littoral zone were greater than at the limnetic stations located in the middle of the lake.

4. Periphyton biomass growth rates in Lake Mead were one to two orders of magnitude greater than in Lake Tahoe and comparable to other references cited.

5. Periphyton growth is affected by a number of factors including temperature, light level, substrate, pH, nutrients, and grazing.

6. Periphyton growth rates can be generally related to inorganic nitrogen or orthophosphorus concentrations using a power function; however, the statistical significance of these relationships is quite low, so the relationships are not suitable for making quantitative predictions of periphyton response to different nutrient levels.

7. Periphyton can impact beneficial uses. Black periphyton growth was noted on boat hulls in Las Vegas Wash Marina during the WQSS. Extensive periphyton growth can reduce aesthetics and interfere with body-contact recreation; however, no surveys were included in WQSS to assess the extent of these impacts in Lake Mead.

8. It is not feasible to establish a quantitative water quality standard for periphyton. Thus, it will be necessary to rely on qualitative estimates of changes in periphyton growth resulting from the nutrient loads associated with the transparency control program.

CHAPTER 12

OTHER ISSUES

Other issues related to the Water Quality Standards Study (WQSS) raised in the Annual Report review process, but not addressed elsewhere in this report, are discussed in this chapter.

INTRODUCTION

This section presents the background, objectives, and organization of this chapter.

Background

Comments on the WQSS Annual Report identified a number of key issues which served to direct the completion of the WQSS. In addition to the key issues, which are discussed in preceding chapters, a number of secondary issues were raised. Secondary issues include:

1. Water supply issues
2. Analysis of bacteriological data
3. Analysis of toxics data

A number of these issues were analyzed in the "Segment I Other Lake Studies Report," February 1980. The Project Management Consultant (PMC) response to comments on the Annual Report indicated that additional work would be required to adequately answer many of the comments on the Annual Report. Most of the additional work, however, was never approved by the Water Quality Study Board (WQSB).

Objectives

This chapter addresses the various secondary issues raised during comments on the Annual Report. Data from the WQSS monitoring program relevant to each issue are presented and analyzed. Other sources of data, including data collected by the U. S. Geological Survey (USGS), the Southern Nevada Water System (SNWS), the University of Nevada at Las Vegas (UNLV), and other organizations, have been reviewed and assessed. To the extent possible, conclusions have been drawn on each issue.

Chapter Organization

This chapter is organized into sections which address each previously identified issue. To a large extent, the organization of each section is dictated by the data available. Where WQSS monitoring relates to the issue, the sections follow the organization of previous chapters, i.e., WQSS monitoring and results, discussion of results and comparison with other data, and conclusions.

WATER SUPPLY ISSUES

Water supply is a designated beneficial use of Lake Mead. Through the SNWS and Basic Management Incorporated (BMI) intake structures, about 120,000 acre-feet of water are withdrawn annually. The use of the lake for water supply is further described in Chapter 4. Water supply issues related to the WQSS include the relationship of the Las Vegas Wash discharge to the water supply intake structures and taste and odor problems in the water supply.

Las Vegas Wash Discharge

The relationship of the Las Vegas Wash discharge to water supply has been analyzed in two ways. The first utilizes results of the hydraulic study to describe behavior of the plume relative to the SNWS intake structure. Because of the relationship between the plume and temperature stratification in the lake, the thermocline is also discussed. The second approach involves comparison of WQSS monitoring results in Las Vegas Bay with conditions in Virgin Basin.

Plume Dynamics and the SNWS Intake. The water supply intake at Saddle Island in Boulder Basin is located approximately 8 miles from the point where Las Vegas Wash flows into Las Vegas Bay. The intake is at an elevation of 1,042 feet, which was about 160 feet (48 meters) below the water surface during the WQSS. During the WQSS, lake elevation averaged about 1,200 feet. As part of the WQSS, a hydraulic study was conducted to describe behavior of the Las Vegas discharge as it enters Lake Mead (report is included as Appendix F). The primary focus of the hydraulic study was the inner and middle bay. The study was not intended to assess circulation in the area near the intake structures. However, some of the data collected in the hydraulic study are relevant to this discussion.

Las Vegas Wash water enters Lake Mead with a salinity about three times greater than the ambient salinity in Lake Mead. This difference is a key to the formation of a subsurface plume in the lake, and it provides a means to distinguish the plume using conductivity measurements. Normally, the inflow is more dense than the lake waters, principally as a result of higher salinity (total dissolved solids). The inflow initially flows downward into the lake along the bottom until it reaches

the ambient lake density through entrainment of the surrounding lake water. At the depth where the density of the plume equals the density of the rest of the lake, the inflow separates from the bottom and continues as a plume farther out into the lake. The point of separation between the plume and lake bottom typically occurs at the thermocline, with the plume flowing out into the bay just under the thermocline. In the vicinity of the SNWS intake, the thermocline develops during the spring near the lake surface. As the summer proceeds, the thermocline becomes deeper, reaching a maximum depth of 30 to 50 meters in the late fall as the thermocline erodes and the lake becomes mixed.

During intensive surveys conducted November 30, 1979, and January 30, 1980, the plume was located toward the center of the bay, several kilometers from the intake at depths ranging from 50 to 80 meters. Dilutions ranged from 58 to 1 in November to about 140 to 1 in January at a station in the plume 3 kilometers northeast of the intake.

The circulation pattern in Boulder Basin is not well understood, so it is difficult to conclude whether or not the plume ever reaches the water supply intake. During the two intensive surveys, the plume was not detected at stations in the immediate vicinity of the intake, indicating dilutions greater than 1,000 to 1 (limit of detection). During the spring and summer, the plume stayed within the upper 20 meters of the lake, well above the intake at current lake level. During the winter and early spring, the plume depth fluctuates widely, dispersing the plume over a large vertical extent. Behavior of the plume is further discussed in Chapter 8 and Appendix F.

The elevation of the plume will vary as the lake level changes. Figure 3-9 shows the likely range of future lake levels. The plume elevation will also change if the temperature

and/or salinity of Las Vegas Wash flow change. The impact of these and other possible future conditions are to be analyzed in the remaining work in the Phase II Treatment Facilities Study.

Comparison of Las Vegas Bay and Virgin Basin. For purposes of comparing water quality conditions in Las Vegas Bay with conditions in Virgin Basin, Station 7 was selected because of its proximity to the SNWS intake. Station 9 was selected in Virgin Basin because the depths of Stations 7 and 9 are comparable. Station 9 has been used to characterize outer Bonelli Bay, just as Station 7 has been used to characterize outer Las Vegas Bay. For purposes of comparing conditions at the depth of the intake, 25- and 75-meter samples have been averaged. Monthly mean nutrient concentrations at Stations 7 and 9 are presented in Table 12-1. Orthophosphorus, total phosphorus, and ammonia concentrations at Station 7 were three to six times higher than at Station 9. The mean concentration of nitrate and nitrite was nearly equal at the two stations. Unfortunately, chlorophyll was only measured in the surface layer, so concentrations at the depth of the intake structure cannot be compared; however, surface layer chlorophyll concentrations at Station 7 were about twice as high as measurements at Station 9. Chronological plots of dissolved oxygen, pH, conductivity, and temperature at the 45-meter depth are shown on Figures 12-1 through 12-4, respectively. As seen on the figures, physical conditions at the two stations were nearly identical.

The State of Nevada Water Pollution Control Regulations[1] include recommended water quality criteria for un-ionized ammonia, nitrate, nitrite, and pH for protection of drinking water supplies. Data at Station 7 are compared to these criteria in Table 12-2. In all cases, conditions measured in the WQSS were well within the criteria.

Table 12-1. Mean Monthly Nutrient Concentrations, Average of 25- and 75-Meter Samples

	Concentrations, mg/l							
	Ortho P as P		Total P as P		Total Ammonia as N		Nitrate plus nitrite as N	
	Stations		Stations		Stations		Stations	
Month	7	9	7	9	7	9	7	9
07/79	0.007	0.001	0.021	0.003	0.004	0.005	0.311	0.270
08/79	0.013	0.002	0.019	0.004	0.006	0.007	0.298	0.252
09/79	0.015	0.001	0.023	0.004	0.004	0.002	0.355	0.354
10/79	0.013	0.001	0.018	0.003	0.005	0.004	0.329	0.300
11/79	0.009	0.002	0.015	0.005	0.008	0.003	0.141	0.258
12/79	0.011	0.002	0.016	0.004	0.010	0.001	0.239	0.317
01/80	0.005	0.002	0.016	0.003	0.040	0.002	0.196	0.244
02/80	0.010	0.002	0.018	0.005	0.038	0.003	0.321	0.258
03/80	0.012	0.002	0.017	0.005	0.012	0.003	0.361	0.289
04/80	0.012	0.002	0.015	0.007	0.004	0.003	0.303	0.274
05/80	0.007	0.002	0.015	0.007	0.005	0.002	0.308	0.264
06/80	0.005	0.002	0.017	0.008	0.015	0.005	0.270	0.248
07/80	0.006	0.001	0.014	0.010	0.015	0.003	0.285	0.330
08/80	0.006	0.001	0.014	0.004	0.003	0.002	0.296	0.327
09/80	0.008	0.001	0.017	0.005	0.002	0.001	0.307	0.340
10/80	0.007	0.001	0.019	0.005	0.002	0.001	0.304	0.346
11/80	0.007	0.001	0.016	0.013	0.005	0.001	0.277	0.292
Mean	0.009	0.002	0.017	0.006	0.017	0.003	0.289	0.292

Table. 12-2. Comparison of Station 7 Data with Criteria for Water Supply

Parameter	Concentration, mg/l		
	Station 7		State of Nevada Criterion[a]
	Mean	Range	
Un-ionized ammonia, as N[b]	<0.001	<0.001-0.001	0.5
Nitrate, as N[b]	0.291	0.261-0.300	10.0
Nitrite, as N[b]	0.002	0.001-0.004	1.0
pH[c]	7.93	5.90 -8.46	5.0-9.0

[a]Reference 1.
[b]Average of 25- and 75-meter samples.
[c]45-meter sample.

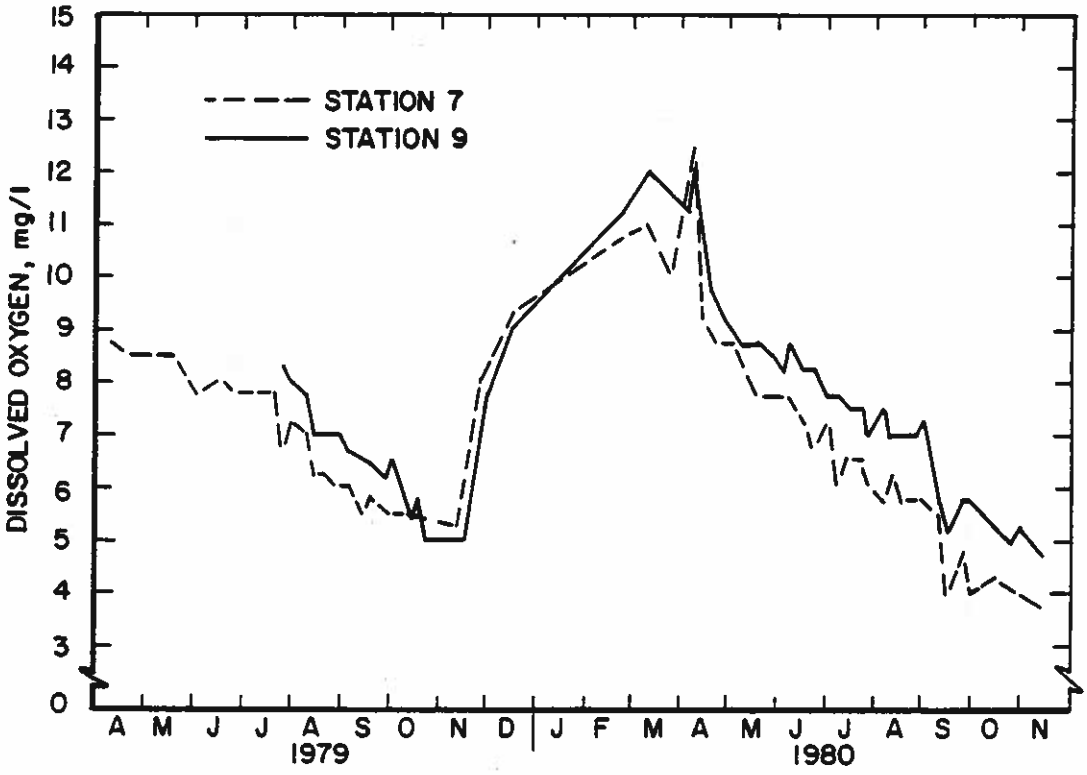


Figure 12-1 Chronological Plot of Dissolved Oxygen at Stations 7 and 9 (45 meter depth)

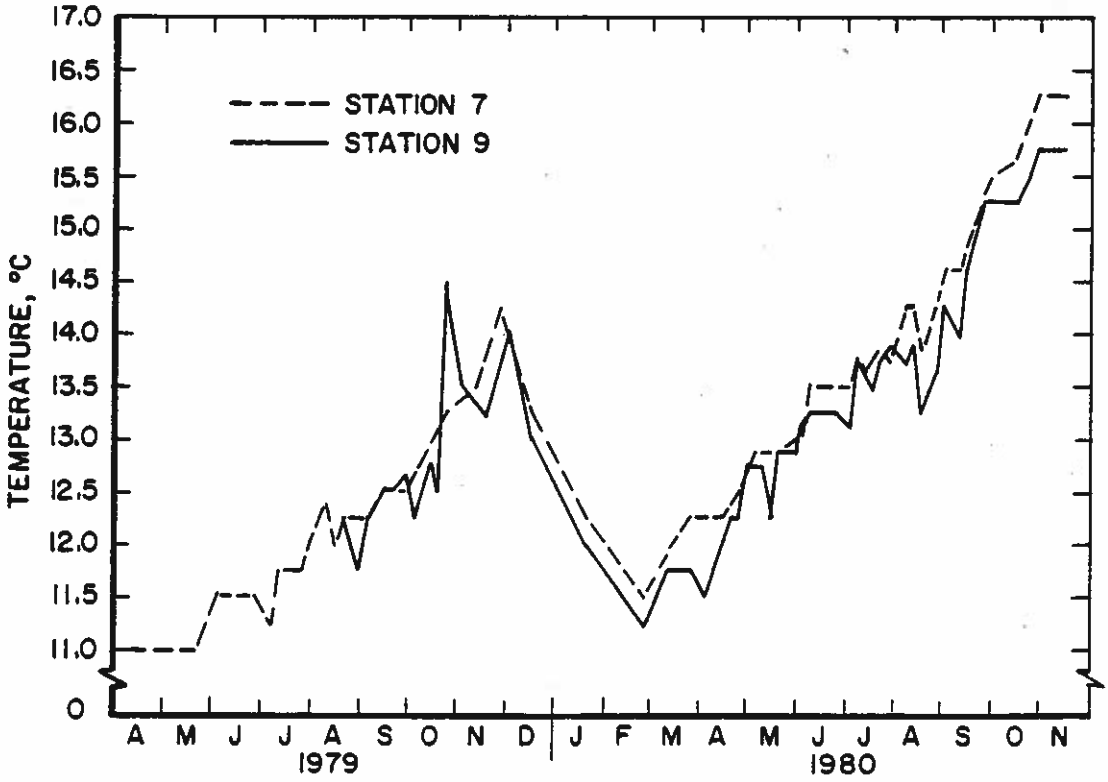


Figure 12-2 Chronological Plot of Temperature at Stations 7 and 9 (45 meter depth)

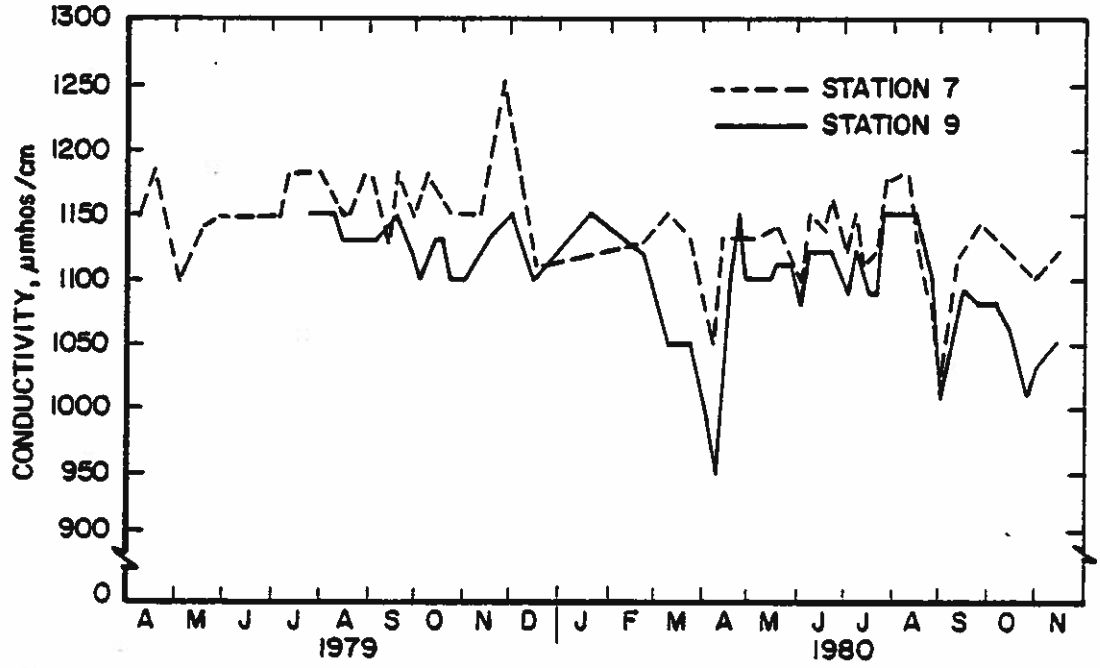


Figure 12-3 Chronological Plot of Conductivity at Stations 7 and 9 (45 meter depth)

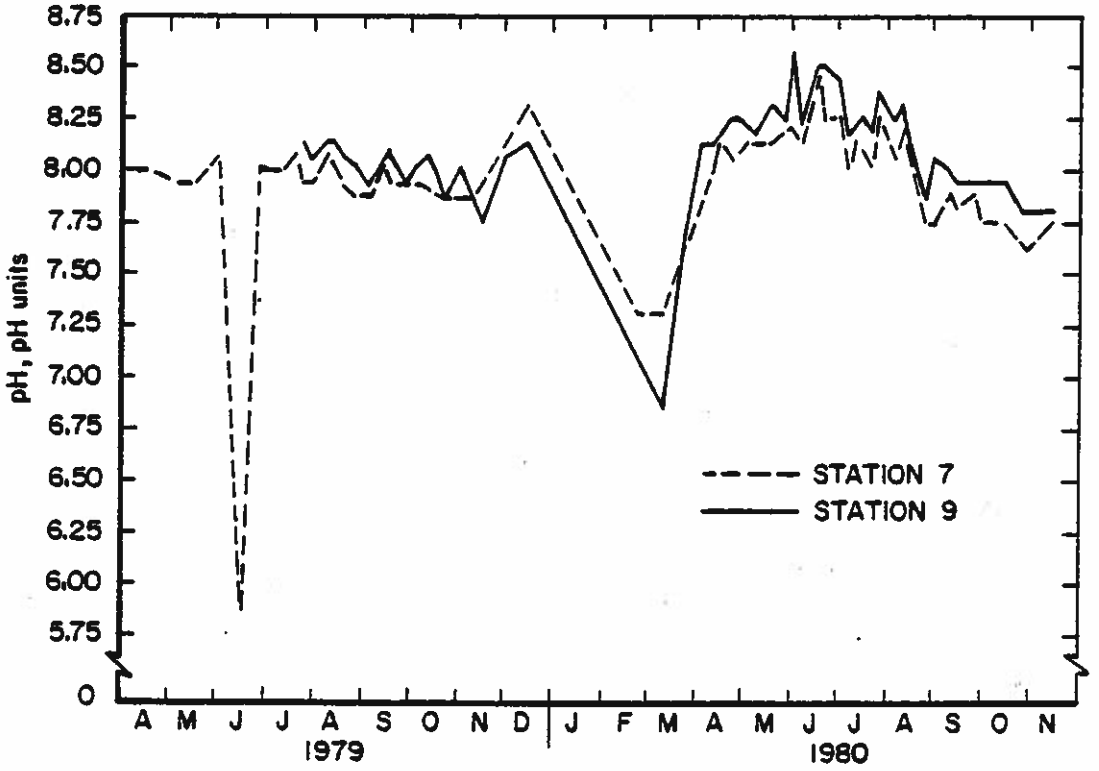


Figure 12-4 Chronological Plot of pH at Stations 7 and 9 (45 meter depth)

Taste and Odors

Since its initial operation in 1971, odors have been recognized as a problem in the SNWS supply.[2] Odors also affect taste, although taste tests have not been performed as rigorously as odor tests. Odor tests are performed on the raw water supply on a daily basis, and treatment strategies to reduce odor require significant quantities of chemicals.

Odors are measured on the basis of the number of dilutions with odor-free water required to produce a sample in which odor can just be perceived by half of the human observers. Dilutions are recorded as a threshold odor number (TON). A TON of "1" indicates that odor can be perceived in a raw water sample, but not in a diluted sample. A TON of "2" indicates that odor can be perceived in a sample of one-half raw water and one-half odor-free water. If no odor is detected, the TON is "no odor detected." Monthly mean and maximum daily odor measurements for the SNWS raw water supply are presented on Figure 12-5. As shown on the figure, some level of odor can always be perceived in the water supply, and a general cycle of odor peaking during October through December has regularly occurred. Peak odor levels have steadily decreased since 1972.

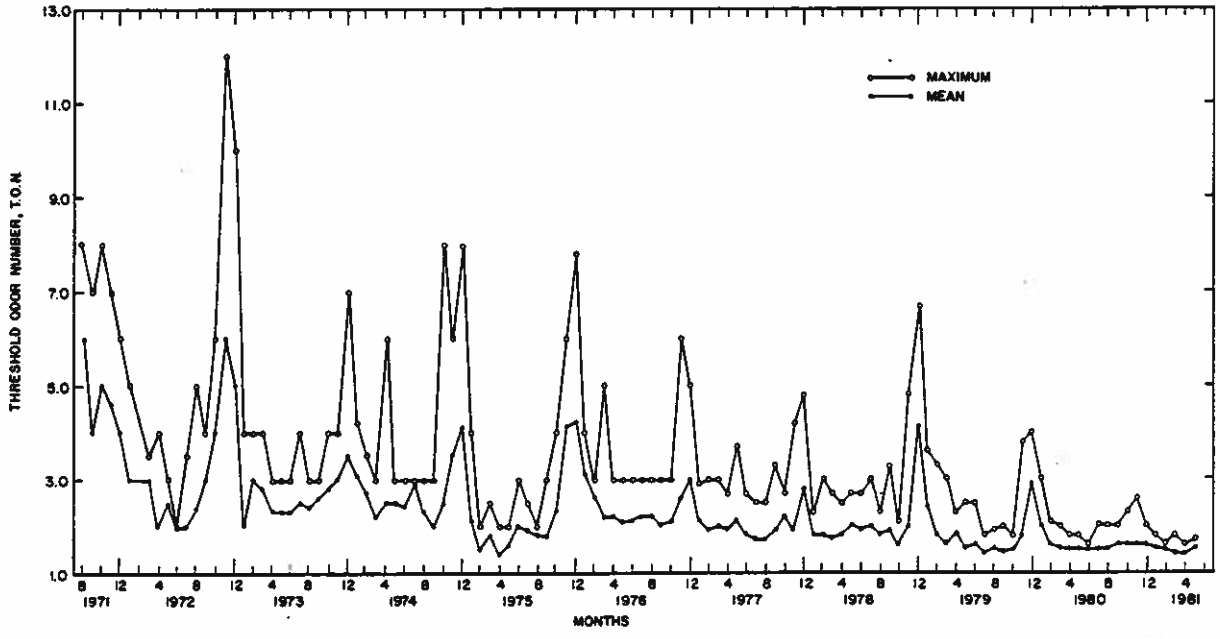


Figure 12-5 Monthly Mean and Maximum Daily Odor Measurements for the SNWS Raw Water Supply

In most reservoirs, odors are associated with low dissolved oxygen conditions. In particular, reduced iron and sulfide have been related to odors in many reservoirs. SNWS has undertaken a number of studies to identify the cause of odors in its supply.[3,4,5] Peak odors occur during the fall period of thermal destratification. The initial hypothesis for the odor conditions was that during destratification, there are uplifts of organic matter from the bottom. Partially decomposed organics, particularly sulfur compounds, were believed to be the primary cause of odors. Studies conducted by SNWS in 1975 and 1979 confirm the presence of sulfate-reducing bacteria throughout the water column.[4,5] However, no correlation was found between sulfate-reducing bacteria and dissolved oxygen. Review of the SNWS reports indicates that the cause of the odor problem has not been clearly identified.

Peak odors in the raw water supply have steadily decreased since 1972. The relationship between peak odor conditions and minimum dissolved oxygen concentrations was investigated (Figure 12-6), but no relationship was evident. A number of pollutants, including iron, manganese, and sulfate affect the taste of water. Table 12-3 compares data at Station 8 (data were not collected at Station 7) with criteria identified in the state of Nevada Water Pollution Control Regulations[1] for manganese and iron and with sulfate criteria proposed by the U.S. Environmental Protection Agency (EPA)[6] and the National Academy of Sciences.[7] Iron and manganese data collected during WQSS in the surface waters were well within the criteria. Sulfate measurements slightly exceeded the criterion.

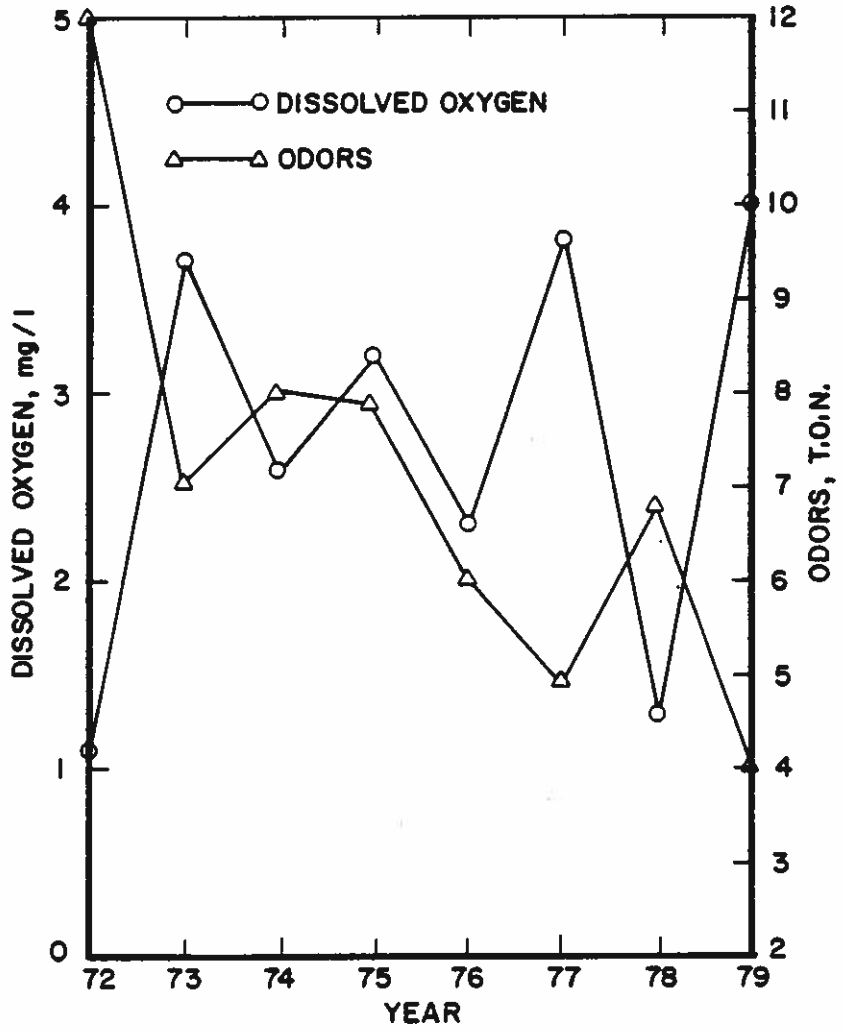


Figure 12-6 Minimum Dissolved Oxygen and Peak Odors at the SNWS Intake During Peak Odor Periods (October to December)

Table 12-3. Comparison of Station 8 Data with Criteria for Water Supply

Parameter	Concentration, mg/l		
	Station 8		State of Nevada Criterion[a]
	Mean	Range	
Iron[b]	0.002	<0.001-0.008	0.3
Manganese[c]	<0.01	<0.01	0.05
Sulfate[c]	303	281-323	250

[a]Reference 1.
[b]Average of 25- and 75-meter samples.
[c]45-meter integrated samples.

One of the strongest relationships identified by SNWS is between lake elevation and odors. As shown on Figure 12-7, during the period 1972 to 1979, lake elevation steadily increased while odors decreased. Another possible explanation for the decrease in odors during the 1970s may be reduced sedimentation rates. A recent U.S. Bureau of Reclamation (USBR) report indicates that sedimentation rates have significantly decreased as a result of construction of Glen Canyon Dam and filling of Lake Powell.[8]

BACTERIOLOGICAL DATA

As a result of excessive fecal coliforms, the inner Las Vegas Bay has been posted as a no swimming area since the mid-1950s. Bacteriological monitoring was conducted as part of the WQSS to document existing bacteriological conditions and to identify sources of bacteria. Results of other monitoring programs have also been reviewed.

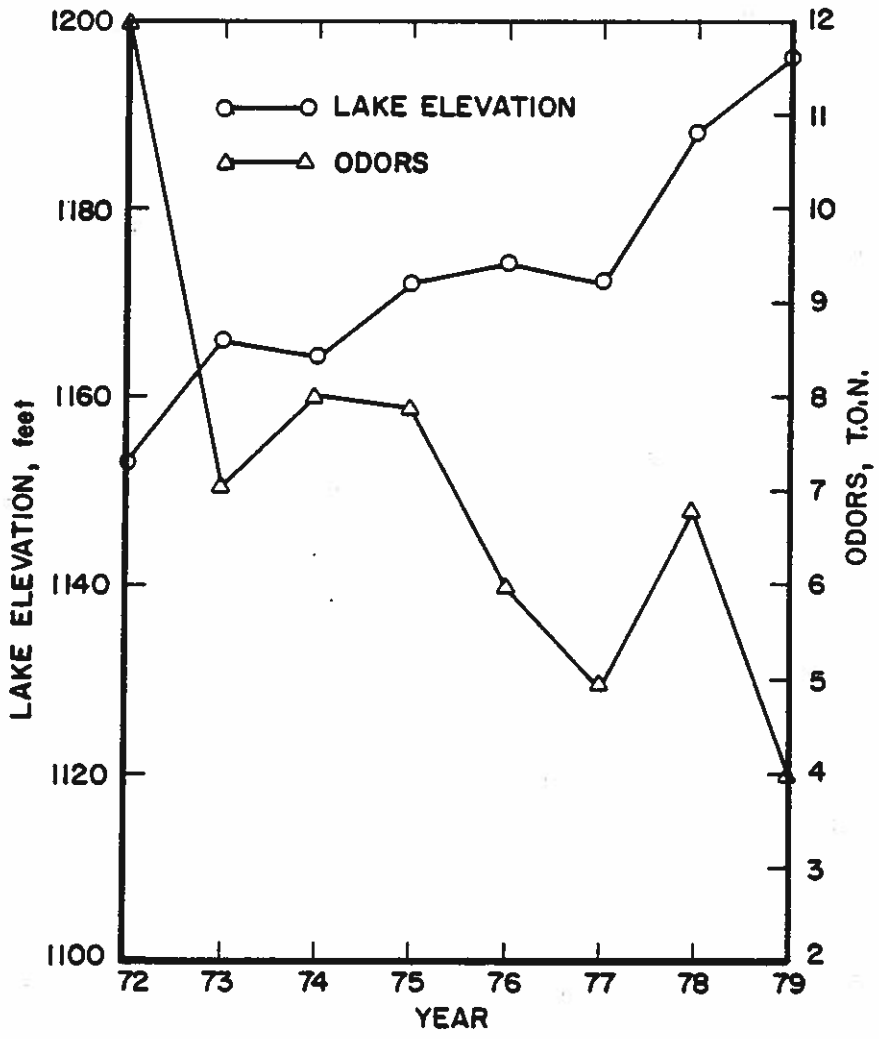


Figure 12-7 Average Lake Elevation and Peak Odors at the SNWS Intake During Peak Odor Periods (October to December)

WQSS Monitoring

Surface samples from Stations 1, 2, 3, 4, and 5 were analyzed for total and fecal coliforms and fecal streptococci on a bimonthly basis from May through September 1980. Analyses consisted of multiple-tube fermentation, results of which are presented in Table 12-4. Of the 50 measurements made, the highest fecal coliform determination was 17/100 ml. Average measurements (arithmetric) were 3/100 ml at Station 1, 4/100 ml at Station 2, 5/100 ml at Station 3, 1/100 ml at Station 4, and 1/100 ml at Station 5.

Other Bacteriological Data

Bacteriological monitoring programs have been conducted by a number of agencies including:

City of Las Vegas
Clark County Health District
Clark County Sanitation District
Southern Nevada Water System
University of Nevada at Las Vegas
U.S. Federal Water Pollution Control Administration
U.S. Geological Survey
U.S. National Park Service

Most of these programs, however, have involved sampling in the Las Vegas Wash or outer portions of Las Vegas Bay. Only two programs have included sampling in the inner Las Vegas Bay.

Samples were taken by the Federal Water Pollution Control Administration in the Las Vegas Bay in May 1966.[9] A total of 12 samples were taken at each of seven stations located

Table 12-4. Results of Las Vegas Bay Bacteriological Monitoring

Station	Date	Total coliform[a]	Fecal coliform[a]	Fecal streptococci[a]	FC/FS[b]
	5/14/80	700	0	24	0
	5/27/80	20	0	2	0
	6/10/80	20	<2	1	<2.00
	6/24/80	400	1	4	0.25
1	7/08/80	20	1	20	0.05
	7/22/80	400	6	6	1.00
	8/05/80	200	12	4	3.00
	8/19/80	400	<2	15	<0.13
	9/02/80	100	<2	2	<1.00
	9/16/80	200	3	1	3.00
	5/14/80	90	0	0	-
	5/27/80	20	2	0	-
	6/10/80	50	10	0	-
	6/24/80	200	2	0	-
2	7/08/80	30	0	3	0
	7/22/80	600	7	2	3.50
	8/05/80	100	12	10	1.20
	8/19/80	300	2	10	0.20
	9/02/80	500	<2	2	<1.00
	9/16/80	50	1	2	0.50
	5/14/80	80	0	2	2.00
	5/27/80	30	4	0	-
	6/10/80	40	<2	0	-
	6/24/80	340	0	1	0
3	7/08/80	100	17	1	17.00
	7/22/80	300	2	4	0.50
	8/05/80	400	7	4	1.75
	8/19/80	400	12	3	4.00
	9/02/80	500	0	0	-
	9/16/80	200	1	1	1.00
	5/14/80	12	0	12	0
	5/27/80	4	0	0	-
	6/10/80	9	<2	2	<1.00
	6/24/80	140	0	0	-
4	7/08/80	150	0	25	0
	7/22/80	100	2	100	0.02
	8/05/80	40	2	<2	>1.00
	8/19/80	50	1	0	-
	9/02/80	10	0	0	-
	9/16/80	10	0	0	-
	5/14/80	4	0	0	-
	5/27/80	4	0	0	-
	6/10/80	2	<2	1	<2.00
	6/24/80	25	0	0	-
5	7/08/80	40	2	10	0.20
	7/22/80	100	0	3	0
	8/05/80	40	1	0	-
	8/19/80	30	0	1	-
	9/02/80	40	0	0	0
	9/16/80	200	1	2	0.5

[a]Number per 100 ml.
[b]Ratio of fecal coliform to fecal streptococci.

in the bay. Fecal coliforms were quite low, not exceeding 13 MPN/100 ml for the innermost station (corresponding to WQSS Station 1).

From 1974 through 1977, a series of monitoring programs were conducted by the UNLV under the direction of Dr. James Deacon.[10,11,12] UNLV sampling stations in Las Vegas Bay and Boulder Basin are shown on Figure 12-8. Samples were taken throughout the water column twice per month during the recreational season and once per month during the winter. Results of the program in the inner bay are presented in Table 12-5. In 1974 and 1975, fecal coliforms were quite low, well within the body-contact recreation standard. In 1976 and 1977, however, fecal coliforms increased dramatically.

Discussion

Results of WQSS monitoring in inner and middle Las Vegas Bay are well within the standard for body-contact recreation (geometric mean of 200/100 ml during any 30-day period with no more than 10 percent of samples exceeding 400/100 ml). However, the plume formed by Las Vegas Wash as it enters the bay flows near the bay bottom, and fecal coliform concentrations may be much higher in the plume. Fortunately, earlier monitoring programs conducted by UNLV involved sampling at multiple depths. While in many cases bottom samples collected by UNLV did have higher coliform concentrations than surface samples, there were cases when just the opposite was true. In addition, the bulk of UNLV data (1974 through mid-1976) were well within body-contact criteria. It is the high fecal coliform levels recorded in 1976 and 1977 that cast some doubt on the quality of the inner bay for body-contact recreation. However, comparison of surface samples taken in 1976 and 1977 (August 26, 1976 to

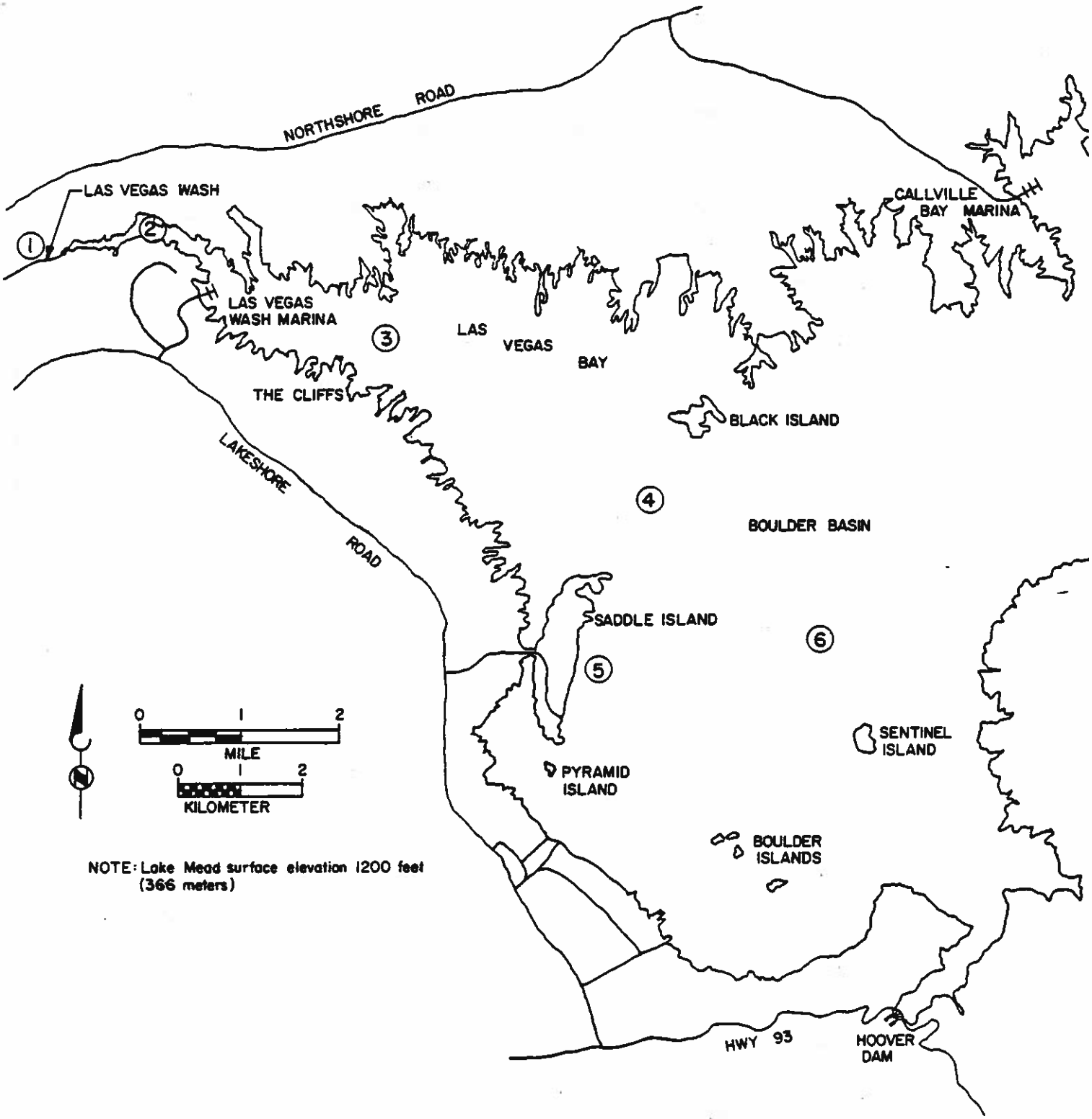


Figure 12-8 Location of UNLV Sampling Stations in Las Vegas Bay and Boulder Basin, 1974 to 1977

Table 12-5. University of Nevada at Las Vegas Bacteriological Monitoring Results

Date	Station 2 depth,[a] meters		Station 3 depth,[a] meters						
	0	10	0	10	20	30	40	40–45	45–50
02/28/74	0	0[c]	8	8	0	0	0	-	2
03/19/74	0	0[c]	0	-	-	-	-	-	-
04/23/74	2	2[c]	3	0	4	11	12	-	22
05/24/74	0	0[c]	0	0	1	1	0	-	-
06/10/74	4	0[c]	0	0	0	0	-	0	-
06/24/74	0	0[c]	0	0	0	0	-	0	-
07/12/74	0	0[c]	0	0	0	0	-	0	-
07/26/74	10	100[c]	70	0	0	100	-	200	
08/14/74	1	0[c]	0	0	0	0	-	0	-
08/28/74	0	0	-	-	-	-	-	-	-
09/13/74	90	50	-	-	-	-	-	-	-
09/29/74	0	0	-	-	-	-	-	-	-
10/11/74	10	0	-	-	-	-	-	-	-
10/25/74	10	20	-	-	-	-	-	-	-
11/15/74	7	30	-	-	-	-	-	-	-
12/27/74	12	50	-	-	-	-	-	-	-
01/23/75	7	10	-	-	-	-	-	-	-
04/28/75	0	40	0	0	0	0	0	-	-
05/16/75	30	0	0	0	0	0	0	-	-
05/28/75	0	10	0	0	0	0	0	-	-
06/18/75	20	11	0	0	0	0	0	-	-
06/28/75	1	10	5	0	1	1	1	-	-
07/22/75	0	8	-	-	-	-	-	-	-
07/31/75	0	70	0	0	0	0	20	-	-
08/19/75	7	7	0	0	0	0	0	-	-
08/28/75	30	10	0	0	0	-	-	-	-
09/17/75	0	0	0	0	0	0	0	-	-
10/16/75	0	0	0	0	0	0	0	-	-
11/24/75	0	2	0	0	12	0	0	-	-
12/22/75	0	0	0	0	0	0	0	-	-
01/30/76	10	1	0	0	0	1	1	-	-
02/19/76	0	0	0	0	0	0	0	-	-
08/26/76	49	790[d]	-	-	-	-	-	-	-
09/26/76	3,500	2,400[d]	-	-	-	-	-	-	-
10/28/76	630	330[d]	-	-	-	-	-	-	-
12/28/76	1,700	1,300[d]	-	-	-	-	-	-	-
01/31/77	490	2,800[d]	-	-	-	-	-	-	-
02/17/77	79	9,200[d]	-	-	-	-	-	-	-
03/31/77	5	140[d]	-	-	-	-	-	-	-
04/25/77	-	790[d]	-	-	-	-	-	-	-
05/31/77	22	14[d]	-	-	-	-	-	-	-
06/23/77	27	24,000[d]	-	-	-	-	-	-	-

[a]Same location as WQSS Station 1.
[b]Same location as WQSS Station 4.
[c]8-meter depth.
[d]Bottom samples.

Source: References 10, 11, and 12.

June 23, 1977) with WQSS surface samples (May 14, 1980 to September 16, 1980) indicates that the two periods were different at the 95 percent significance level.

To determine what may have caused the difference in the two periods, monitoring conducted in the Las Vegas Wash has been reviewed. The UNLV results indicate that both wash and lake coliform concentrations increased during the 1976 to 1977 period; however, the UNLV 1976 to 1977 data are comparable to WQSS measurements at Northshore Road during the period of WQSS lake bacteriological monitoring. Regrettably, there is no continuous record of monitoring by any agency, such as the USGS or U.S. National Park Service which would reveal possible changes in the Las Vegas Wash coliform discharge.

Fecal coliforms are discharged by both man and other warm-blooded animals. Fecal coliforms do not in themselves present a health hazard, rather they serve as an indicator of the possible presence of pathogens resulting from contamination from human sources. Research has indicated that the fecal coliform to fecal streptococci ratio is an indicator of the source of fecal contamination. The ratio of fecal coliforms to fecal streptococci for human waste is about 4.4 and for other warm-blooded animals is 0.6 or less.[13] Data collected in the WQSS cannot be clearly interpreted, both because the fecal coliform concentrations are too low for the ratios to be meaningful and because natural die-off phenomenon may affect the indexes.

TOXICS DATA

The EPA has identified 65 classes of toxic pollutants based upon evidence of carcinogenic, mutagenic, teratogenic, and/or other toxic effects. In November 1980, EPA published final

water quality criteria for 64 of the 65 classes of priority pollutants.[14] The State of Nevada has adopted water quality criteria for some of the priority pollutants and has also established criteria for a number of pesticides and herbicides not included in the EPA list.[1] Although analysis of lake and wash samples for all 65 classes of pollutants was proposed in the WQSS, the work was never authorized. A few of the pollutants (heavy metals) were measured periodically during the WQSS. USGS and SNWS monitoring results have also been reviewed. EPA priority pollutants, pollutants recognized in State regulations, and pollutants measured during the WQSS and by others are listed in Table 12-6.

WQSS Monitoring

Toxics data were collected in Lake Mead as part of surveys to measure cations, anions, and heavy metals. On October 31, 1979, July 16, 1980, and September 27, 1980, 5-meter integrated samples were collected at Stations 2 and 8 and analyzed for the constituents shown in Table 12-7. Results for priority pollutants are presented in Table 12-8.

Other Toxics Data

Southern Nevada Water System has routinely monitored a wide range of pollutants in the water supply since 1972. Results of the SNWS quarterly analyses are presented in Table 12-9. USGS has monitored water quality in the wash and below Hoover Day for many years. USGS data accessed through the STORET data management system are also summarized in Table 12-9. Reported mean values for both SNWS and USGS can be somewhat misleading. Both agencies have reported minimum concentrations as zero, rather than as the detection limits for the analysis technique.

Table 12-6. U.S. Environmental Protection Agency Priority Pollutants

Priority pollutant	EPA regs.[a]	State regs.[b]	WQSS lake monitoring	SNWS monitoring	USGS lake and wash monitoring
Acenaphthene	ID[c]				
Acrolein	X				
Acrylonitrile	X				
Aldrin-Dieldrin					
Aldrin	X	X			X
Dieldrin	X	X			X
Antimony	X				
Arsenic	X	X	X	X	X
Asbestos	X				
Benzene	X				
Benzidine	X				
Beryllium	X	X	X	X	
Cadmium	X	X	X	X	X
Carbon tetrachloride	X				
Chlordane	X	X			
Chlorinated benzenes					
Hexachlorobenzene	X				
1,2,4,5-tetrachlorobenzene	X				
Pentachlorobenzene	X				
Trichlorobenzene	ID				
Monochlorobenzene	X				
Chloronated ethanes					
1,2-dichloroethane	X				
1,1,1-trichloroethane	X				
1,1,2-trichloroethane	X				
1,1,2,2-tetrachloroethane	X				
Hexachloroethane	X				
Monochloroethane	ID				
1,1-dichloroethane	ID				
1,1,1,2-tetrachloroethane	ID				
Pentachloroethane	ID				
Chlorinated naphthalenes	ID				
Chlorinated phenols					
3-monochlorophenol	ID				
4-monochlorophenol	ID				
2,3-dichlorophenol	ID				
2,5-dichlorophenol	ID				
2,6-dichlorophenol	ID				
3,4-dichlorophenol	ID				
2,3,4,6-tetrachlorophenol	ID				
2,4,5-trichlorophenol	X				
2,4,6-trichlorophenol	X				
2--methyl-4-chlorophenol	ID				
3-methyl-4-chlorophenol	ID				
3-methyl-6-chlorophenol	ID				
Chloroalkyl ethers					
Bis (chloromethyl) ether	X				
Bis (2-chloromethyl) ether	X				
Bis (2-chloroisopropyl) ether	X				
Chloroform	X				
2-Chlorophenol	ID				
Chromium		X	X	X	X
Hexavalent	X				
Trivalent	X				
Copper	X	X	X	X	X
Cyanide	X	X			
DDT and metabolites					
DDT	X	X			X
TDE	ID				
DDE	ID				X
Dichlorobenzenes	X				
Dichlorobenzidines	X				
Dichloroethylenes					
1,1-dichloroethylene	X				
1,2-dichloroethylene	ID				
2,4-dichlorophenol	X				
Dichloropropanes	ID				
Dichloropropenes	X				
2,4-dimethylphenol	ID				

Table 12-6. U.S. Environmental Protection Agency Priority Pollutants, continued

Priority pollutant	EPA regs.[a]	State regs.[b]	WQSS lake monitoring	SNWS monitoring	USGS lake and wash monitoring
2,4-dinitrotoluene	x				
1,2-diphenylhydrazine	x				
Endosulfan	x	x			x
Endrin	x	x		x	x
Ethylbenzene	x				
Fluoranthene	x				
Haloethers	ID				
Halomethanes	x				
Heptachlor	x	x			x
Hexachlorobutadiene	x				
Hexachlorocyclohexane					
Alpha-BHC	x				
Beta-BHC	x				
Gamma-BHC (lindane)	x	x		x	x
Delta-BHC	ID				
Epsilon-BHC	ID				
Tech-BHC	x				
Hexachlorocyclopentadiene	x				
Isophorone	x				
Lead	x	x		x	x
Mercury	x	x	x	x	x
Naphthalene	ID				x
Nickel	x	x	x	x	x
Nitrobenzene	x				
Nitrophenols					
2,4-dinitro-o-cresol	x				
Dinitrophenol	x				
Mononitrophenol	ID				
Trinitrophenol	ID				
Nitrosamines					
n-nitrosodimethylamine	x				
n-nitrosodiethylamine	x				
n-nitrosodi-n-butylamine	x				
n-nitrosodiphenylamine	x				
n-nitrosopyrrolidine	x				
Pentachlorophenol	x				
Phenol	x	x			
Phthalate esters		x			
Dimethyl phthalate	x				
Diethyl phthalate	x				
Dibutyl phthalate	x				
Di-2-ethylhexyl phthalate	x				
Polychlorinated biphenyls	x	x			x
Polynuclear aromatic hydrocarbons	x				
Selenium	x	x	x	x	x
Silver	x	x		x	x
Tetrachloroethylene	x				
Thallium	x		x		
Toluene	x				
Toxaphene	x	x		x	x
Trichloroethylene	x				
Vinyl chloride	x				
Zinc	x	x	x	x	x
Miscellaneous pesticides and herbicides					
2,4-D		x		x	x
Demeton		x			
Guthion		x			
Malathion		x			x
Methoxychlor		x		x	
Mirex		x			x
Parathion		x			x
Silvex		x			x

[a]Federal Register, November 28, 1980 (FRL 1623-3).
[b]Amendments to Nevada Water Pollution Control Regulations, adopted August 1980.
[c]ID—Insufficient data to develop criteria.

Table 12-7. Measurements Made as Part of Cation, Anion, and Heavy Metal Surveys

Pollutant	
Arsenic	Magnesium
Beryllium	Magnesium hardness
Bicarbonate	Manganese
Bicarbonate alkalinity	MBAS
Cadmium	Mercury
Calcium	Nickel
Calcium hardness	Nitrate nitrogen
Carbonate	Potassium
Carbonate alkalinity	Selenium
Chloride	Specific conductance
Chromium	Sodium
Copper	Sulfate
Dissolved residue	Total hardness
Hydroxide alkalinity	Thallium
Iron	Zinc

Table 12-8. Water Quality Standards Study Results for Heavy Metals

	Concentrations, ug/l					
	Station 2			Station 8		
Pollutant	10/31/79	7/16/80	9/27/80	10/31/79	7/16/80	9/27/80
Arsenic	3.6	4.1	3.2	3.0	6.5	2.8
Beryllium	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Cadmium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chromium	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0
Copper	1.0	1.0	8.0	6.0	4.0	2.0
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	10.0	<1.0	20.0	5.0	<1.0	13.0
Selenium	<0.5	1.1	<0.5	<0.5	0.8	0.8
Thallium	<100.0	<100.0	<100.0	<100.0	<100.0	<100.0
Zinc	<10.0	<10.0	30.0	30.0	10.0	30.0

Table 12-9. Other Toxics Data

Pollutant	Concentrations, ug/l								
	SNWS[a]			USGS					
				Northshore Road[b]			Below Hoover Dam[c]		
	No. of samples	Range	Mean	No. of samples	Range	Mean[d]	No. of samples	Range	Mean[d]
Aldrin-Dieldrin									
Aldrin		—	—	(18)	0-.010	.001		—	—
Dieldrin		—	—	(18)	0-.010	.001		—	—
Arsenic	(22)	<5-24	10	(55)	16-120	39	(29)	1-6	3.5
Cadmium	(22)	<.5-18	1	(46)	0-29	10	(26)	0-20	10
Chlordane		—	—	(18)	0	0		—	—
Chromium	(23)	0-<5	<5	(54)	0-100	24	(30)	0-20	3.6
Copper	(20)	2-13	4	(54)	5-71	19	(29)	2-440	26
DDT and metabolites									
DDT		—	—	(18)	0	0		—	—
DDE		—	—	(18)	0-.02	.001		—	—
Endosulfans		—	—	(8)	0	0		—	—
Endrin	(2)	<.06-<.1	<.1	(18)	0	0		—	—
Heptachlor		—	—	(18)	0	0		—	—
Hexachlor-cyclohexane Gamma-BHC (lindane)	(2)	<.02	<.02	(18)	0-0.30	.06		—	—
Lead	(22)	<1-13	4	(45)	28-420	123	(26)	0-200	104
Mercury	(21)	<.2-<5	<2	(53)	0-15	.40	(29)	0-1.3	0.3
Napthalene		—	—	(11)	0	0		—	—
Nickel	(4)	<5-<8	<7		—	—	(9)	1-5	3.1
Polychlorinated biphenyls		—	—	(18)	0-2.7	.15		—	—
Selenium	(22)	0-15	5	(53)	0-5	2		—	—
Silver	(9)	0-5	3	(54)	0-40	8	(21)	0-20	1.2
Toxaphene	(2)	<3	<3	(18)	0	0		—	—
Zinc	(13)	<50-<250	<83	(54)	10-270	58	(13)	10-70	32
Miscellaneous pesticides and herbicides									
2,4-D	(2)	<0.3	<.3	(17)	0-.12	.03		—	—
Malathion		—	—	(18)	0	0		—	—
Methoxychlor	(1)	<0.4	<.4		—	—		—	—
Mirex		—	—	(1)	0	0		—	—
Parathion		—	—	(18)	0	0		—	—
Silvex		—	—	(17)	0-.02	002		—	—

[a]1972 through 1980
[b]1974 through 1979
[c]1974 through 1981
[d]Means are from STORET inventory procedure, based on data as recorded in the data management system.

Discussion

The EPA and State criteria for the priority pollutants for which data have been presented are shown in Table 12-10. EPA criteria for human health are presented for maximum protection and a range of risk factors. The risk factors indicate the fraction of the population which would experience deleterious health effects as a result of exposure to priority pollutants at the indicated concentrations. In most cases, the EPA criteria are less than the limits of detection with conventional analytic techniques. In addition, the divergence between EPA and State criteria is noteworthy. In many cases, federal criteria for protection of human health are more stringent than State criteria, while just the opposite is true for fish and wildlife protection.

Comparison of Tables 12-8, 12-9, and 12-10 indicates that violations of human health and/or fish and wildlife criteria were recorded for the pollutants shown in Table 12-11. Of the 28 pollutants measured, there were violations of human health criteria for 10 pollutants and fish and wildlife violations for 12 pollutants. The tabulation of violations shown in Table 12-11 is based on comparing maximum concentration measurements with maximum protection criteria. Mean values were not evaluated because USGS and SNWS have reported values as zero instead of the detection limits when the pollutant could not be detected.

Several factors make it difficult to determine the significance of these violations and whether they are having any effect on the beneficial uses of Las Vegas Wash and Lake Mead. The data base is very limited; there are insufficient data to estimate what the background levels are in Lake Mead or to determine what sources may be contributing toxic pollutants.

Table 12-10. Priority Pollutant Criteria

Pollutant	Concentration, ug/l				
	Human health		Freshwater aquatic life		
	Maximum protection	10^{-7} to 10^{-5} risk factor	Average	Maximum	Wildlife maximum
Aldrin-Dieldrin					
Aldrin					
EPA	0	7.4×10^{-6} to 7.4×10^{-4}	ID[a]	3	
State	1	—	—	.003	1
Dieldrin					
EPA	0	7.1×10^{-6} to 7.1×10^{-4}	.0019	2.5	
State	1	—	—	.003	1
Arsenic					
EPA	0	2.2×10^{-4} to 2.2×10^{-2}	ID	440	
State	50	—	—	50	—
Beryllium					
EPA	0	3.7×10^{-4} to 3.7×10^{-2}	ID	ID	
State	—	—	—	900	—
Cadmium					
EPA	10	—	.017	2	
State	10	—	—	10	50
Chlordane					
EPA	0	4.6×10^{-5} to 4.6×10^{-3}	.0043	2.4	
State	3	—	—	.01	3
Chromium					
EPA	50	—	.29	21	
State	50	—	—	100	1,000
Copper					
EPA	ID	—	5.6	15	
State	1,000	—	—	20	500
DDT					
EPA	0	2.4×10^{-6} to 2.4×10^{-4}	1×10^{-3}	1.1	
State	50	—	—	.001	50
Endosulfane					
EPA	0	4×10^{-3} to 4.22×10^{-1}	.056	.22	
State	DL[b]	—	—	.003	DL
Endrin					
EPA	1	—	.0023	.18	
State	.2	—	—	.004	.2
Heptachlor					
EPA	0	2.8×10^{-5} to 2.8×10^{-3}	.0038	.52	
State	.1	—	—	.001	.1
Hexachlorocyclo-pentadiene					
Gamma-BHC (lindane)	0	1.86×10^{-3} to 1.86×10^{-1}	.08	2.0	
EPA					
State	4		.01	4	
Lead					
EPA	50	—	1.6	108	
State	50	—	—	100	100
Mercury					
EPA	.144	—	.00057	.0017	
State	2	—	—	.05	.05
Nickel					
EPA	13.4	—	71	1,400	
State	—		—	300	—

Table 12-10. Priority Pollutant Criteria, continued

Pollutant	Concentration, ug/l				
	Human health		Freshwater aquatic life		
	Maximum protection	10^{-7} to 10^{-5} risk factor	Average	Maximum	Wildlife maximum
Polychlorinated biphenyls					
EPA	0	$7.9x10^{-6}$ to $7.9x10^{-4}$	.014	ID	
State	—	—	—	.001	—
Selenium					
EPA	10	—	35	260	
State	10	—	—	50	50
Silver					
EPA	50	—	ID	2.1	
State	50	—	—	.2	—
Thallium					
EPA	13	—	ID	ID	
State	—	—	—	—	—
Toxaphene					
EPA	0	$7x10^{-5}$ to $7.1x10^{-3}$	.013	1.6	
State	5	—	—	.005	5
Zinc					
EPA	ID	—	47	233	—
State	5,000	—	—	300	25,000
Miscellaneous					
2,4-D					
EPA	—	—	—	—	
State	100	—	—	—	100
Malathion[b]					
EPA	—	—	—	—	
State	DL	—	—	.1	DL
Methoxychlor					
EPA	—	—	—	—	
State	100	—	—	.03	100
Mirex					
EPA	—	—	—	—	
State	DL	—	—	.001	DL
Parathion					
EPA	—	—	—	—	
State	DL	—	—	.04	DL
Silvex					
EPA	—	—	—	—	
State	10			10	

[a]ID—Insufficient data.
[b]DL—Detection limits.

Table 12-11. Priority Pollutant Criteria Violations

Pollutant	Human Health				Fish and Wildlife			
			USGS				USGS	
	WQSS	SNWS	Wash[a]	River[b]	WQSS	SNWS	Wash[a]	River[b]
Aldrin-Dieldrin								
Aldrin	ND	ND	F		ND	ND	S	
Dieldrin	ND	ND	F		ND	ND	S	
Arsenic	F	F	F,S	F,S			F,S	F,S
Beryllium	FDL	ND	ND	ND	FDL	ND	ND	ND
Cadmium		F,S	F,S	F,S		F,S	F,S	F,S
Chromium			F,S		FDL	FDL	F	
Copper							F,S	F,S
Hexachloro-cyclohexane								
Gamma-BHC (lindane)	ND	FDL	F	ND	ND	SDL	S	ND
Lead	ND		F,S	F,S	ND	S	F,S	F,S
Mercury	FDL	FDL	F,S	F	FDL	FDL, SDL	F,S	F,S
Polychlorinated biphenyls	ND	ND	F	ND	ND	ND	S	ND
Selenium	ND	F,S		ND				ND
Silver	ND				ND	F,S	F,S	F,S
Thallium	FDL	ND	ND	ND		ND	ND	ND
Toxaphene	ND	FDL		ND	ND	FDL, SDL		ND
Zinc							F	
Miscellaneous								
Methoxychlor	ND		ND	ND	ND	SDL	ND	ND

Key: F—Violation of EPA Priority Pollutant criteria.
S—Violation of State criteria.
FDL—EPA criteria below detection limits for analysis.
SDL—State criteria below detection limits for analysis.
ND—No data.

[a]At Northshore Road.
[b]Below Hoover Dam.

For many of the pollutants, criteria are below the limits of detection for even the most sophisticated analytical equipment available. It is difficult to separate the effect of toxics from the effect of other factors. For example, the maximum potential for some water uses, such as a fishery, may be limited, but the limitation may be due to some other environmental factor, such as food availability or dissolved oxygen, despite the fact that certain toxic levels exceed criteria.

CONCLUSIONS

The preceding analyses enable a number of conclusions to be drawn with regard to each issue.

Water Supply Issues

1. During most of the WQSS, the plume formed by the Las Vegas Wash was at an elevation higher than the SNWS intake.

2. During the winter, plume depth fluctuated widely. It may have reached the depth of the SNWS intake; however, the plume was not detected in the immediate vicinity of the SNWS during two surveys conducted in late fall and winter.

3. Comparison of nutrient measurements at the depth of the SNWS intake indicate that orthophosphorus, total phosphorus, and ammonia are several times higher in outer Las Vegas Bay than in outer Bonelli Bay; however, all measurements are within current recommended criteria.

4. Physical conditions including temperature, pH, dissolved oxygen, and conductivity at the depth of the SNWS intake in outer Las Vegas Bay and outer Bonelli Bay are nearly identical.

5. Although odors have been a problem since initial operation of the SNWS, the cause of odors has not been determined.

6. Based on data collected by SNWS, odors have steadily decreased since 1972.

Bacteriological Data

1. With the exception of UNLV data for a period extending from August 1976 through June 1977, all fecal coliform measurements taken in the inner Las Vegas Bay comply with body-contact recreation criteria.

2. The cause of high coliform concentrations during 1976 and 1977 has not been determined; however, concentrations in the lake were higher than those measured in the WQSS monitoring, while concentrations in the wash were comparable in the two studies.

Toxics Data

1. Some constituents violate EPA priority pollutant criteria and State recommended criteria.

2. Due to the very limited existing data base on toxics, it is not possible to estimate what the background levels are in Lake Mead or to determine what sources may be contributing toxic pollutants.

3. Additional sampling would be required to determine if existing pollutant levels affect fish and wildlife.

CHAPTER 13

CONCLUSIONS AND RECOMMENDATIONS

The primary conclusions and recommendations made in the previous chapters of the report are summarized in this chapter. The conclusions and recommendations are presented in a manner that follows the basic objectives of the Water Quality Standards Study (WQSS), rather than on a chapter-by-chapter basis. Thus, this chapter is organized into three key parts:

1. Beneficial uses — ATTAINABILITY
2. Water quality criteria
3. Allowable loads

A concluding section outlines the remaining technical work necessary to fulfill the Consent Decree requirements.

As stated at the outset of this report, the Consent Decree specified that the Phase II Treatment Facilities Study (TFS-II) be conducted in conjunction with WQSS to investigate the technological, economic, and environmental feasibility of a range of alternatives for achieving various water quality criteria. The objective of the combined WQSS/TFS-II process is to provide the basis upon which the Nevada Environmental Commission can make administrative determinations regarding beneficial uses, water quality criteria, allowable waste loads and effluent limitations. Since much of TFS-II has not yet been authorized by the Water Quality Study Board (WQSB), it is not possible to fulfill all of the Consent Decree requirements. The work that has been conducted to date in WQSS

provides an adequate basis to develop many recommendations related to beneficial uses and the water quality criteria necessary to support those uses. However, treatment plant effluent limitations cannot be defined until the remainder of TFS-II is completed.

BENEFICIAL USES

One of the objectives of the combined WQSS/TFS-II process is to make recommendations regarding the beneficial uses of Las Vegas Wash and Lake Mead. The information developed as part of WQSS is adequate for making recommendations for most beneficial uses. There are a few questions regarding the attainability of some uses that cannot be completely answered without TFS-II.

Las Vegas Wash

The currently designated beneficial uses of Las Vegas Wash are aesthetics and recreation, irrigation, stock watering, fish, and wildlife. These uses are described in detail in Chapters 4 and 6. Table 13-1 summarizes the extent of these uses and our recommendations. The basis for our recommendations is described below by use.

Aesthetics and Recreation. Current aesthetic and recreational uses of the wash are birdwatching, hiking and hunting. These uses are expected to increase if the wetlands park is established. Body-contact recreation (swimming) and boating are not current uses of the wash. Water quality conditions and physical constraints make it infeasible for body-contact recreation in the wash. The wash flow consists primarily of treated wastewater with minimal dilution from other

Table 13-1. Beneficial Use Recommendations for Las Vegas Wash

Use	Extent of that use	Recommendation
Aesthetics and recreation	Moderate use for bird-watching, hiking, and hunting presently and is expected to increase if the wetlands park is established. No significant body-contact recreation.	Use should be maintained but should be qualified to exclude body-contact recreation.
Irrigation	No present irrigation use. Irrigation of grass at Stadium Park is proposed.	Use should be maintained.
Stock watering	Present use is minor, but could increase if equestrian trails are expanded as part of wetlands park.	Use should be maintained.
Fish	Mosquito fish are only fish inhabiting wash to any significant degree.	Use should be deleted.
Wildlife	Presently the wash provides a diverse terrestrial animal and bird habitat, which would be expanded if the wetlands park is established	Use should be maintained.

flows and as such is incompatible with body-contact recreation. Boating does not occur because most of the wash is too shallow and fast-flowing; most ponded areas are inaccessible due to heavy marsh vegetation. Because of these physical and water quality constraints, the thrust of the wetlands park is towards enhancement of non-contact uses. ***Thus, it is recommended that the use of aesthetics and recreation be maintained, but it should be qualified to exclude body-contact recreation.***

Irrigation. Irrigation is not presently a use of the wash, although it is planned to use wash water to irrigate grass at the proposed Stadium Park. Use of the wash for irrigation is not significantly constrained by any physical factors and it is generally compatible with existing water quality conditions. ***Thus, it is recommended that irrigation be maintained as a use in the wash.***

Stock Watering. No systematic use of wash water for stock watering is conducted, although there may be some consumption of wash water by horses on equestrian trails. Since equestrian trails are planned as part of the wetlands park, this use may increase in the future. ***It is recommended that stock watering be maintained as a use in the wash.***

Fish. Limited information is available on fish species inhabiting the wash presently or in the past. A review of the few available reports and conversations with fisheries biologists are described in Chapter 4. That information indicates that the wash did not in the past and does not today support a substantial fishery. At present, mosquito fish appear to be the only fish inhabiting the wash in any significant number, although there have been a few random sitings of goldfish and sunfish.

Both water quality conditions and physical limitations preclude the wash from being able to support a significant fishery. Based on the data reported in Chapter 6, a diverse fishery could not survive in the wash under current water quality conditions of low dissolved oxygen, high un-ionized ammonia, high nitrite and high turbidity. The mosquito fish appear to be well adapted to the water quality conditions found in the wash. Unlike most other fish, mosquito fish do not depend on dissolved oxygen in the water as they obtain oxygen directly from the air at the air-water interface. Most of the wash is unsuitable as a habitat for fish since it is too shallow and fast-flowing or is heavily laden with silt. Upstream of the treatment plants, there is insufficient flow to support fish. The only portion of the wash that appears to be suitable as a fish habitat is the ponded area near Pabco Road. Expansion of the current limited fish habitat would require major physical modifications to the wash and alteration of flow patterns.

Since the wash does not contain an appreciable area with suitable habitat to support a diverse fishery, it is recommended that fish be deleted as a beneficial use. Despite the current physical and water quality constraints, it is likely that mosquito fish and small numbers of other fish will continue to inhabit the wash in the ponded areas near Pabco Road.

Wildlife. The wash presently provides a diverse terrestrial animal and bird habitat. This use would be expanded if the proposed wetlands park is established. *Thus, it is recommended that wildlife be maintained as a use in the wash.* However, erosion that has been occurring in the wash for several years is gradually destroying portions of the wildlife habitat. To

maintain adequate wildlife habitat, the wetlands park concept must include steps to control erosion and alter current flow patterns in the wash.

Lake Mead

The current beneficial uses of Lake Mead are water supply, recreation, boating, fish, wildlife, and irrigation. Another current use is hydropower, but it is not discussed here since it does not closely relate to the water quality issues assessed in WQSS. In our presentation of beneficial uses in Chapter 4 and in the summary in this section boating is included under recreation and irrigation is included under water supply.

The beneficial uses of Lake Mead are described in detail in Chapter 4. The relationship of these uses to transparency, dissolved oxygen, un-ionized ammonia, periphyton, and bacteriological quality and toxics are further described in Chapters 8, 9, 10, 11, and 12, respectively. Table 13-2 summarizes the extent of current uses and our recommendations. The basis for our recommendations is described below by use.

Water Supply. Water supply as a beneficial use of Lake Mead has included public water supply, industrial water supply, and agricultural water supply. About 82 percent of the water supply withdrawals from Lake Mead are made through the Southern Nevada Water System (SNWS) which serves the Las Vegas Valley Water District, North Las Vegas, Boulder City, Henderson, and Nellis Air Force Base. Water for the SNWS is withdrawn from Boulder Basin near Saddle Island and is treated by coagulation, filtration, and disinfection. The quality of water delivered by SNWS meets all current finished drinking

Table 13-2. Beneficial Use Recommendations for Lake Mead

Use	Extent of that use	Recommendation
Water supply	Water is presently diverted for public and industrial water supply. About 125,000 acre-feet of water was withdrawn for water supply in 1980. Southern Nevada Water System and Basic Management Incorporated account for about 98 percent of the water supply diversions through their intakes at Saddle Island.	Use should be maintained.
Recreation	Swimming, water skiing, boating, and aesthetic enjoyment are extensive recreational uses. There are over three million visitors per year to Lake Mead.	All present recreational uses should be maintained. A mixing zone should be designated downstream of the wash discharge to the inner bay out to Station 2. The attainability of maintaining adequate transparency for swimming in the remainder of the inner bay should be assessed in TFS-II.
Fish	There presently is a substantial fishery consisting of striped and largemouth bass, shad, catfish, and carp. Economic value of the fishery is estimated to be $68 million per year.	Use should be maintained.
Wildlife	There is a variety of amphibians, birds, and mammals.	Use should be maintained.

water standards. About 16 percent of the Lake Mead water supply withdrawals are made through an intake structure near Saddle Island belonging to Basic Management Incorporated (BMI); this water is used for both public water supply and industrial purposes. Water is provided to the City of Henderson, Nevada Department of Wildlife, National Park Service, and the BMI complex. No agricultural diversions have been made from Lake Mead since 1970.

Lake Mead will continue to be the primary water supply for the Las Vegas Valley in the future. *It is recommended that water supply be maintained as a beneficial use of Lake Mead.*

Recreation. Recreational use in Lake Mead consists of both body-contact and non-contact recreation. Body-contact recreation includes swimming and water skiing. Non-contact recreation includes boating, fishing, and aesthetic enjoyment. In recent years, there have been over three million visitors per year to Lake Mead. National Park Service records indicate that comparable numbers of people engage in the two major uses, fishing, and swimming/water skiing. *It is recommended that both body-contact and non-contact recreation be maintained as uses in Lake Mead.* The area of inner Las Vegas Bay out to Station 2 (approximately the western boundary of the campground) should be designated as a mixing zone. As discussed in Chapter 8, the attainability of maintaining adequate transparency for swimming in the remainder of inner Las Vegas Bay should be assessed in TFS-II.

Fish. The lake presently supports a substantial fishery consisting of striped and largemouth bass, threadfin shad, catfish, and carp. In 1979, the economic value of the Lake Mead

fishery was estimated to be $68 million per year. There have been increases and decreases in some fish species since Lake Mead was formed in 1941; these population cycles are described in Chapter 4.

Fishing is one of the major recreational activities in Lake Mead and is expected to continue to be a major interest in the future. ***Thus, it is recommended that fish be maintained as a beneficial use of Lake Mead.***

Wildlife. The lake presently supports a variety of amphibians, birds, and mammals. ***It is recommended that wildlife be maintained as a use.***

WATER QUALITY CRITERIA

One of the objectives of the combined WQSS/TFS-II process is to identify the appropriate water quality criteria necessary to support the beneficial uses of Las Vegas Wash and Lake Mead. In Chapter 4, the approach used in this study to develop water quality criteria was described. Various methods to develop water quality criteria were considered including user surveys. The approach adopted by the WQSB consisted of scientific evaluation of data collected in WQSS and review of available agency documents and scientific sources on water quality criteria. Our recommendations regarding water quality criteria for Las Vegas Wash and Lake Mead are presented in this section.

Las Vegas Wash

In Chapter 6, various water quality criteria were reviewed, and these criteria were compared with data collected in WQSS to

provide a basis for developing recommendations on water quality criteria. Those recommendations are summarized in Table 13-3 and are based on maintenance of the uses of aesthetics and recreation (excluding body-contact recreation), irrigation, stock watering and wildlife. The parameters in Table 13-3 are shown in the same order as presented in the list of current standards (Table 47, State of Nevada, Water Pollution Control Regulations). A brief assessment of each water quality criterion is presented below. Several additional water quality parameters are discussed which are relevant to the beneficial uses of the wash, but for which criteria are not recommended.

Temperature. The temperature of the wash affects the beneficial use of wildlife. *The current temperature standard is adequate to protect this use, and thus, it should be retained.* Present conditions meet the standard at all stations, although the upper temperature limit may occasionally be exceeded immediately downstream of the treatment plant discharges.

pH. The pH of the wash water affects the use of the water by wildlife as a drinking water source and affects the food supply. For protection of wildlife, the various criteria documents all suggest a pH of 9.0 as the upper limit and a pH between 6.0 and 7.0 as the lower limit. The maximum and minimum pH limits should be based on a single value rather than 90 percent frequency to protect against toxic discharges. *It is recommended that the monthly median pH be maintained within the range 6.5 to 8.5 (same as current standard), but that the minimum/maximum portion of the standard be modified to require that all pH values fall within the range 6.0 to 9.0.* Present conditions meet the recommended standards, except a few measurements less than 6.0 were recorded at Station 4.

Table 13-3. Water Quality Criteria Recommendations for Las Vegas Wash

Parameter/Current Standard[a]	Recommendation
Temperature June to September: Average—not more than 27°C Maximum[b]—not more than 31°C October to May: Monthly Mean—not more than 23°C Maximum[b]—not more than 27°C	Retain current standard.
pH Monthly Median—within range 6.5 to 8.5 Maximum[b]—within range 6.5 to 8.5	Monthly Median—within range 6.5 to 8.5 Single Value—within range 6.0 to 9.0.
Dissolved Oxygen Monthly Mean—not less than 5 mg/l Minimum[c]—not less than 4 mg/l	Aerobic conditions should be maintained.
Biochemical Oxygen Demand Monthly Mean—not more than 10 mg/l Maximum[b]—not less than 15 mg/l	Delete current standard.
Chemical Oxygen Demand Monthly Mean—not more than 40 mg/l Maximum[b]—not more than 50 mg/l	Delete current standard.
Suspended Solids Monthly Mean—not more than 2 mg/l Maximum[b]—not more than 5 mg/l	Delete current standard.
Surfactants (MBAS) Monthly Mean—not more than 0.8 mg/l Maximum[b]—not more than 1.0 mg/l	Retain current standard.
Phosphorus Monthly Mean—not more than 0.5 mg/l Maximum[b]—not more than 1.0 mg/l	Delete current standard.
Turbidity Monthly Mean—not more than 5 JTU	Delete current standard.
Fecal Coliform Monthly Geometric Mean[d]—not more than 200/100 ml Maximum[e]—not more than 400/100 ml	Delete current standard.
Nitrate No standard	Maximum of 25 mg/l.

[a]Table 47—State of Nevada Water Pollution Control Regulations.
[b]Maximum refers to single value in 90 percent of the samples.
[c]Minimum refers to single value in 90 percent of the samples.
[d]Based on a minimum of five samples during any 30-day period.
[e]Based on a minimum of five samples during any 30-day period; not more than 10% of total samples shall exceed 400/100 ml.

Dissolved Oxygen. The current standard of a monthly mean of 5.0 mg/l and a minimum of 4.0 mg/l is related to supporting a diverse fishery. In the beneficial use discussion it was recommended that fish be deleted as a use. The criteria documents reviewed indicate that aerobic conditions should be maintained to support aesthetics and recreation, irrigation, and wildlife. *Thus, it is recommended that aerobic conditions be maintained to protect the recommended beneficial uses of the wash.* Aerobic conditions are generally maintained at all Stations. However, there were several periods during WQSS when the dissolved oxygen level was very low or zero in the marsh at Stations 2 and 3.

Biochemical and Chemical Oxygen Demand. *Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) do not directly affect the uses of the wash and are not appropriate parameters for establishing water quality criteria. Current BOD and COD standards should be deleted.* However, it is appropriate to consider BOD load limits in conjunction with a criterion for dissolved oxygen.

Suspended Solids and Turbidity. *It is recommended that standards for total suspended solids and turbidity be deleted, since these two parameters do not have a significant relationship to the recommended beneficial uses of the wash.*

Surfactants. A criterion for surfactants (MBAS) is necessary to protect wildlife. *It is recommended that the present MBAS standard be retained.* The limited number of MBAS measurements made in the wash indicate that it is likely that the current standard is met, except in a small area downstream of the treatment plant discharges.

Phosphorus. *It is recommended that the standard for total phosphorus be deleted, since it has no significant relationship to the recommended uses of the wash.*

Fecal Coliform. *The current standard for fecal coliform should be deleted since there presently are high levels of fecal coliforms from birds and other warm-blooded animals that cannot be differentiated from coliforms of human origin, using the fecal coliform test alone.* Instead, disinfection at the treatment plants should be relied on as a means of assuring that fecal coliforms are not of human origin.

Nitrate. Nitrate is relevant to the protection of wildlife. *It is recommended that a maximum of 25 mg/l be established as a criterion for nitrate based on non-degradation of existing total nitrogen concentration.* Non-degration of total nitrogen rather than nitrate will allow for beneficial conversion of ammonia to nitrate. The proposed maximum level is well within the recommended 100 mg/l nitrate criterion for protection of wildlife.

Nitrite. The nitrite concentration in the wash affects the beneficial uses of wildlife and irrigation. There is not an existing criterion for nitrite. Criteria documents recommend a maximum concentration of 10 mg/l. The maximum nitrite concentrations in the wash were quite low since nitrite is a temporary product that occurs in the conversion of ammonia to nitrate. Nitrite concentrations were generally less than 1 mg/l and the maximum level recorded was 3.6 mg/l. Since it is unlikely that nitrite will exceed current concentrations, which are well below the suggested level, it is not necessary to establish a water quality criterion for nitrite.

Total Dissolved Solids. Total dissolved solids (TDS) is relevant to protecting existing wash vegetation. No work was conducted in the WQSS upon which to develop a recommendation. As discussed in the following section on water quality criteria for the lake, TDS levels in the wash will be significantly influenced by salinity control planning for the Colorado River Basin.

Toxics. The recommended beneficial uses of the wash, particularly wildlife, should also be protected against toxic substances. No toxics data for the wash were collected as part of WQSS Analysis of wash samples for the 65 priority pollutants was proposed in WQSS, but the work was never authorized Limited toxics data have been collected by the U.S. Geological Survey at Northshore Road and are compared with various water quality criteria in Chapter 12. There appear to be some violations of toxics criteria, but the data base is too limited to make any firm conclusions. It is not possible to make any recommendations related to water quality standards for toxics.

Lake Mead

In Chapters 8 through 12, various water quality criteria were reviewed and compared with the data collected in WQSS to provide a basis for developing recommendations on water quality criteria for Lake Mead. Those recommendations are summarized in Table 13-4. The parameters in Table 13-4 are shown in the same order as presented in the list of current standards (Table 45, State of Nevada, Water Pollution Control Regulations). A brief assessment of each water quality criterion is presented below. Several additional water quality parameters are discussed which are relevant to the beneficial uses of the lake, but for which criteria are not recommended.

Table 13-4. Water Quality Criteria Recommendations for Lake Mead

Parameter/Current Standard[a]	Recommendation
Temperature June to September: Average--not more than 16°C Single Value--not more than 18°C October to May: Single Value--not more than 14°C No temperature increase above natural levels when water temperature is greater than or equal to 14°C and a maximum temperature increase of 1°C when the water temperature is less than 14°C.	Delete average and single value provisions but retain the provisions regarding temperature increase above natural levels.
pH Annual Median--within range 7.5 to 8.2 Single Value--within range 7.0 to 8.5	Annual Median[b]--within range 7.5 to 8.3. 90% of the Time[b]--within range 6.5 to 9.0.
Dissolved Oxygen (DO) June to September: Average--not less than 6 mg/l All Year: Single Value--not less than 5 mg/l	Mean DO over the water column should not be less than 5 mg/l, and monthly mean DO at any point in the water column should not be less than 3 mg/l.
Biochemical Oxygen Demand Single Value--not more than 2 mg/l	Delete current standard.
Phosphates Annual Average--not more than 0.04 mg/l as PO_4 Maximum Value in 90% of Samples--not more than 0.06 mg/l as PO_4	Delete current standard.
Nitrates Single Value--not more than 7 mg/l as NO_3 Annual Average--not more than 4 mg/l as NO_3	Single Value--not more than 10 mg/l as N.
Fecal Coliform Geometric Mean[c]--200/100 ml Maximum[d]--400/100 ml	Retain current standard.
Color Color shall not exceed that characteristic of natural conditions by more than 10 units Platinum Cobalt Scale.	Delete current standard.
Turbidity Turbidity shall not exceed that characteristic of natural conditions by more than 10 JTU.	Delete current standard
Total Dissolved Solids 723 mg/l at Hoover Dam.	No recommendation.
Secchi Depth No standard.	A criterion of 1.2 meters (4 feet) be adopted as the minimum acceptable transparency level for areas of Lake Mead designated for swimming. The criterion should be imposed from May through September only and should be met 90% of the time during that period.[b]
Un-Ionized Ammonia No standard.	Mean over the water column should not be more than 0.02 mg/l as N.[b]

[a]Table 45--Nevada Water Pollution Control Regulations.
[b]Criterion does not apply to portion of Las Vegas Bay upstream of WQSS Station 2.
[c]Based on a minimum of five samples during any 30-day period.
[d]Based on a minimum of five samples during any 30-day period; not more than 10% of total samples shall exceed 400/100 ml.

Temperature. The primary importance of temperature is through its effect on the fishery. Fish species have varying temperature tolerances, so water temperature significantly influences the type of fish that inhabit Lake Mead. Presently, the major types of fish in Lake Mead are striped and largemouth bass, threadfin shad, catfish, and carp. Striped bass favor temperatures below 23°C.

Water temperatures throughout Lake Mead often exceed current standards in both summer and winter. Temperature profiles presented in Chapter 8 show that the period from about December through April is the only time that temperatures are less than current standards. During the summer months, surface water temperature throughout the lake consistently exceeds 25°C and occasionally exceeds 30°C. Lake water temperature is the direct result of air temperature. Winds affect mixing paterns within the lake and influence heat distribution over the water column. The flow from Las Vegas Wash has minimal effect on lake water temperature. Wash temperature is generally less than lake surface temperature except from about February through May when the wash may be equal to or a few degrees higher in temperature. Elevated temperatures only occur in the immediate vicinity of the plume and are indistinguishable from the background temperature by the time the plume reaches Station 3.

Although summer surface water temperatures are greater than the ideal range for some of the fish species inhabiting the lake, there is no practical way to control the water temperature since water temperature is controlled by meteorological factors. *Thus, it is recommended that the temperature standard be based*

on natural conditions. The portion of the current standard specifying maximum allowable temperature increases above natural receiving water temperature should be retained: none when water temperature is greater than or equal to 14°C and 1°C when water temperature is less than or equal to 13°C.

pH. In Lake Mead the pH of the water is relevant to the beneficial uses of water supply, fish and wildlife, and swimming. The pH of the water also influences the formation of un-ionized ammonia which is toxic to fish. The agency documents and scientific sources of water quality criteria that were reviewed during WQSS indicate that the pH range should be maintained as follows:

Use	pH
Water supply	5.0 to 9.0
Freshwater aquatic life	6.5 to 9.0
Swimming	6.5 to 8.3

Swimming is the use that is most sensitive to pH. The lacrimal fluid of the human eye has a normal pH of 7.4 and eye irritation is minimized by maintaining the pH in the range of 6.5 to 8.3. The current standard requires that the annual median pH be in the range of 7.5 to 8.2 and that all measurements be in the range of 7.0 to 8.5. These standards generally fall within the ranges needed to protect the beneficial uses of the lake. The upper limit of 8.5 is adequate to protect the uses of aquatic life and water supply although it is slightly greater than the 8.3 value suggested for swimming. Since pH variations occur due to the biological processes occurring in the lake, it is suggested

that the maximum limit be based on 90 percent probability rather than a single value. This will allow for occasional higher values that may be associated with photosynthetic activity. ***Thus, it is recommended that the annual median pH be maintained within the range of 7.5 to 8.3 and that the pH should be maintained within the range 6.5 to 9.0 90 percent of the time.*** Several pH profiles are presented in Chapter 10 and a statistical analysis of the data is contained in Appendix E. None of the pH measurements were below the lower limit of 6.5. In the area of the lake, excluding the inner bay, the pH was nearly always 9.0 or less. In the inner bay at Stations 1, 2, and 3, median pH in the surface waters in the middle and outer bay were about 8.3. These elevated pH levels are caused by photosynthetic activity of the algae in the surface layer. The wash flow does not directly contribute to the elevated pH; the pH at Northshore Road was almost always less than 8.0. Reduction in nutrient levels to improve transparency will lower pH levels slightly due to the decrease in algae, although it is not possible to quantitatively predict the decrease.

Dissolved Oxygen. The dissolved oxygen concentration affects the beneficial uses of recreation, water supply, and fish. For recreation and water supply, aerobic conditions must be maintained to prevent odor problems that can result from anaerobic decomposition of organic matter or chemical reduction of some substances. Fish is the use most sensitive to dissolved oxygen. Oxygen requirements of fish vary among species and the different life stage of a given species.

The current State of Nevada dissolved oxygen standard for Lake Mead is stated as follows:

For various points in Lake Mead:

Average (June through September)	Not less than 6.0 mg/l
Single value	Not less than 5.0 mg/l

Although not specifically stated, the 5.0 mg/l standard is intended to apply year-round. The primary purpose of this standard is to provide an environment conducive to the development and maintenance of a diverse fishery. A review of agency criteria documents and literature sources was performed to provide a basis for a dissolved oxygen criterion for Lake Mead. The sources generally indicate that 5 mg/l dissolved oxygen is desirable to support a diverse fishery and dissolved oxygen levels less than 3 mg/l adversely affect some fish such as striped bass. A dissolved oxygen criterion for Lake Mead needs to take into account the fact that the lake is stratified in the summer months. Portions of the water column have high levels of oxygen, while the metalimnion is significantly depleted. *On this basis, it is recommended that the mean dissolved oxygen concentration over the water column should not be less than 5 mg/l and that the monthly mean dissolved oxygen concentration at any point in the water column should not be less than 3 mg/l.*

Depletion of dissolved oxygen in the metalimnion (middle water layer) in Lake Mead was first reported in 1944 and has probably occurred since Lake Mead was formed in 1935. Oxygen depletion occurs to some degree throughout Lake Mead during the period when the lake is stratified, approximately from May through October. During the remainder of the year oxygen levels are close to saturation throughout the water column. The extent and duration of oxygen depletion that occurred in Boulder Basin and Bonelli Bay during WQSS is described in detail in

Chapter 9. During 1980, minimum dissolved oxygen levels occurred in September. Minimum dissolved oxygen concentrations were about 1 mg/l in Las Vegas Bay and 3 to 4 mg/l in Bonelli Bay. The oxygen depleted zone occupied a much greater volume of water in Las Vegas Bay. For example, 40 to 50 percent of the volume of Las Vegas Bay and 5 to 10 percent of the volume of Bonelli Bay had dissolved oxygen concentrations less than 5 mg/l during September.

Biochemical Oxygen Demand. Biochemical oxygen demand (BOD) does not directly affect the uses of the lake and is not an appropriate parameter for establishing a water quality criterion. *It is recommended that the current water quality standard for BOD be deleted.* However, it is appropriate to consider BOD load limits (carbonaceous and/or nitrogenous) in conjunction with a criterion for dissolved oxygen.

Phosphates. Phosphorus as phosphate is one of the major nutrients required for plant nutrition. In excessive amounts, phosphorus can cause nuisance algal growth. It is proposed that a criterion be established for Secchi depth which provides a direct measure of the effect of algae on transparency. *Thus, it is recommended that current standards for phosphate be deleted.*

Nitrate. Nitrate is relevant to the beneficial uses of recreation and aesthetics, water supply, and freshwater aquatic life. It is not necessary to establish a nitrate criterion to control the effects of nitrate as a nutrient in stimulating algal growth, since it is proposed that a criterion be established for Secchi depth which provides a direct measure of the effect of algae on transparency. Of the

other two uses, water supply is the use that is most sensitive to nitrate. The current nitrate standard for the lake is an average of 4 mg/l and a maximum of 7 mg/l; these limits are for nitrate expressed as NO_3. If these limits are expressed as N, the concentrations are 0.9 mg/l and 1.6 mg/l, respectively. The agency documents and scientific sources of water quality criteria that were reviewed during WQSS indicate that to adequately protect water supply, the nitrate concentration (expressed as N) should not exceed 10 mg/l. ***Thus, it is recommended that the current nitrate standard be modified to a maximum of 10 mg/l nitrate as N.***

During WQSS, the nitrate concentration averaged 0.15 mg/l. The nitrate concentration exceeded 1.0 mg/l in only several samples.

Fecal Coliform. Fecal coliform bacteria are important because they serve as an indicator of the possible presence of disease causing bacteria and viruses; however, fecal coliform bacteria are not themselves harmful. Fecal coliforms originate in the intestinal tract of warm-blooded animals, and thus their presence indicates fecal contamination from both human and other animal sources. The most stringent criterion for fecal coliforms relates to water contact beneficial use. The standard most commonly used, which is also the current standard for Lake Mead, is a mean of 200 per 100 ml and a maximum of 400 per 100 ml. The current standard specifies that the fecal coliform concentration, based on a minimum of five samples during any 30-day period shall not exceed a geometric mean of 200 per 100 ml, nor shall more than 10 percent of total samples during any 30-day period exceed 400 per 100 ml. ***It is recommended that the current fecal coliform standard be retained.***

As part of WQSS, bacteriological monitoring of the lake surface waters was conducted twice per month between May and September 1980. The results are presented in Chapter 12 and consist of data for total coliform, fecal coliform, and fecal streptococci. All fecal coliform levels were well within the standard. The highest level detected was 17 per 100 ml. During the same period fecal coliform concentration at Northshore Road averaged about 200 per 100 ml. Apparently, considerable dilution and die-off of fecal coliform occur between Northshore Road and the surface waters of the inner bay. Fecal coliform levels are expected to be higher in the plume and in the area below the thermocline.

Data collected in WQSS indicate that the bacteriological quality of the surface waters of Las Vegas Bay, including inner Las Vegas Bay, is suitable for the beneficial use of swimming. Bacteriological monitoring should be continued in Las Vegas Bay and should include depth samples as well as surface samples.

Color and Turbidity. Color and turbidity are both factors influencing the transparency of the water. Decomposition of organic matter is the principal cause of color in water. Turbidity is normally related to organic or inorganic matter suspended in the water. Based on our analysis of all the factors affecting water transparency in Lake Mead, Secchi depth is the best measure of transparency since it is all inclusive and incorporates the effects of chlorophyll, color, turbidity, and suspended solids. *Thus, since it is proposed that a criterion be established for Secchi depth to provide a direct measure of transparency, it is recommended that the current standards for color and turbidity be deleted.*

Total Dissolved Solids. The level of total dissolved solids (TDS) is important to the beneficial uses of water supply and irrigation. Excess TDS is objectionable in drinking water because of the taste it imparts and can limit the use of the water for irrigation of certain crops. The Colorado River Basin Salinity Control Forum has adopted water quality standards for salinity for the Colorado River. The TDS standard for Lake Mead is 723 mg/l measured at Hoover Dam. The work in the WQSS was not oriented towards an analysis of the salinity issue, as this issue is under thorough evaluation by other entities including the Colorado River Basin Salinity Control Forum. Only a few TDS measurements were made during WQSS, although extensive measurements were made of specific conductance which is a measure of dissolved solids. Work is proposed in the remainder of TFS-II to assess the effects of alternative salinity control measures in Las Vegas Wash on the wash plume and water quality conditions in Las Vegas Bay.

Since development of salinity criteria has not been an objective of WQSS, we have no recommendation with regard to a standard for salinity or dissolved solids.

Secchi Depth. Secchi disk transparency is the mean depth of the point where a weighted white disk, 20 cm in diameter, disappears when viewed from the shaded side of a vessel, and the point where it reappears upon raising it after it has been lowered beyond visibility. The transparency or clarity of the recreational waters is important from the point of view of safety as well as aesthetics. Swimmers should be able to see a certain distance below the surface of the water so they can avoid hazardous submerged objects and other swimmers. Clear waters are more appealing to swimmers and divers, thus

enhancing the recreational benefits derived from the water. In Lake Mead, the chlorophyll present in algae is the most significant water quality factor affecting transparency. Thus, algal growth will reduce transparency; but at the same time it can be beneficial to fish, since algae represent the foundation of the food chain on which the fish population exists.

Our review of possible water quality criteria for transparency is presented in Chapter 8. *In summary, we recommend the following with regard to a water quality criterion for transparency necessary to support swimming in Lake Mead:*

1. *Secchi depth be used as the basis for the criterion, since it is an all inclusive indicator of transparency including effects of chlorophyll, color, turbidity, and suspended solids.*

2. *A Secchi depth of 1.2 meters (4 feet) be adopted as the minimum acceptable transparency level for areas of Lake Mead designated for swimming. The 1.2 meter criterion should be imposed from May 1 through September 30, and should be met 90 percent of the time during that period.*

3. *A mixing zone should be allowed extending from the point at which Las Vegas Wash enters Las Vegas Bay downstream to WQSS Station 2.*

4. *The issues of whether Secchi depths greater than 1.2 meters should be required or whether the area of inner Las Vegas Bay not designated for swimming should*

be extended beyond the proposed mixing zone must be decided by local decision matters. Such a decision should include consideration of the likelihood of diving in areas of restricted transparency. The work proposed under TFS-II is intended to provide data on costs, energy, and treatment facilities associated with achieving minimum Secchi depths greater than 1.2 meters.

Data showing the seasonal and spatial variation in Secchi depth that occurred during WQSS are presented in Chapter 8. For the May through September period when most water-contact recreation occurs, Secchi depths inwards of Station 3, were less than 1.2 meters more than 10 percent of the time. In middle and outer Las Vegas Bay, Secchi depths were consistently greater than 2 meters and 5 meters, respectively, during the recreation season.

Un-ionized Ammonia. When ammonia dissolves in water, a chemical equilibrium is established between un-ionized ammonia, ionized ammonia, and hydroxide ions. The un-ionized form of ammonia is toxic. Thus, the level of un-ionized ammonia may affect the fishery, although it does not directly affect the other lake uses. *Based on a review of various agency water quality criteria documents and scientific sources, a criterion of 0.02 mg/l of un-ionized ammonia as N is recommended for the protection of the Lake Mead fishery.*

Calculated values for un-ionized ammonia occurring during WQSS are presented in Chapter 9. Based on the criterion of 0.02 mg/l of un-ionized ammonia, toxic concentrations were confined to Station 1 and the area near the plume at Stations 2 and 3 Occasionally concentrations exceeded 0.02 mg/l N in the plume at Station 4. It is proposed that the 0.02 mg/l criterion be applied as a mean water column criterion to be met at all times.

Periphyton. The term periphyton refers to algae which are attached to a fixed surface. Periphyton impacts several of the beneficial uses of Lake Mead. The most apparent impacts include periphyton growths on boat hulls and along shorelines. Although periphyton growths do not directly inhibit boating, they increase maintenance efforts due to the added effort needed to clean the growths from boats. Periphyton growth on rocks along the shoreline can create a slippery surface and pose a hazard to swimmers.

It is not feasible to establish a quantitative water quality standard for periphyton for two reasons. First, no quantitative criteria are presented in criteria documents and the scientific literature to use for guidance. Secondly, proposed user surveys were not authorized or conducted as part of WQSS to relate actual periphyton growth to the effect on beneficial uses. Thus, it will be necessary to rely on qualitative estimates of changes in periphyton growth resulting from nutrient loads associated with the transparency control program.

Toxics. All the beneficial uses of Lake Mead should be protected against toxic substances. No toxics data for the lake were collected as part of the WQSS, except quarterly samples for heavy metals at Stations 2 and 8. Analysis of lake samples for the 65 priority pollutants was proposed in the WQSS, but the work was never authorized. The Southern Nevada Water System makes regular measurements of some of the priority pollutants at the Saddle Island intake and several other points in Boulder Basin. The U.S. Geological Survey collects some toxics data at Hoover Dam. Available toxics data for the lake are compiled in Chapter 12 and compared with various water quality criteria. There appear to be some violations of the toxics criteria, but

the data base is too limited to make any firm conclusions. No site-specific studies have been conducted in Lake Mead to indicate whether or not present toxics levels constitute a problem. It is not possible to make any recommendations related to water quality standards for toxics as part of the WQSS work. Recently proposed EPA water quality regulations provide guidance to the state regarding application of toxics criteria given consideration to various site-specific factors such as the health of indigenous fish species.

ALLOWABLE LOADS

After water quality criteria are identified, allowable loads or total maximum daily loads (TMDLs) may need to be established to assure that water quality criteria will be met. In some cases, a TMDL is needed. However, in other cases it may be unnecessary to develop a TMDL. The need for TMDLs to maintain recommended water quality criteria for Las Vegas Wash and Lake Mead is discussed in this section

Las Vegas Wash

No TMDLs are recommended for Las Vegas Wash. Recommended water quality criteria for temperature, pH, MBAS, and nitrate are presently met. As stated previously, there may be minor violations of the criteria for temperature and MBAS immediately downstream of the treatment plant discharges, but these violations will be very localized and do not warrant establishment of TMDLs. Although effluent loads from the treatment plants will increase in the future, concentrations in the wash will not change significantly since the effluent discharges constitute most of the flow in the wash. It seems unnecessary to set TMDLs for these four parameters when in all likelihood the criteria will continue to be met in the future.

The recommended aerobic standard may be violated on some days in portions of the marsh area of the wash. Anaerobic conditions could have some adverse effect on the recreation and aesthetic uses of the wash, if these uses are expanded as part of the proposed wetlands park. However, it is unknown what the effect, if any, would be. The establishment of a TMDL for oxygen demanding substances to maintain aerobic conditions would be complicated by two factors. First, dissolved oxygen levels may be altered in the future due to changes in flow patterns and/or the physical configuration of the wash caused by either increasing flows or by specific modifications associated with the proposed wetlands park. Secondly, as discussed in Chapter 6, there is insufficient information to accurately separate the various factors that are contributing to dissolved oxygen depletion and to develop confident load relationships. Thus, there is not an adequate basis upon which to establish a TMDL for oxygen-demanding substances.

Lake Mead

No TMDLs are required to assure maintenance of recommended criteria for temperature, pH, nitrate, and fecal coliform. The wash input has no appreciable effect on temperature. Since lake water temperature is controlled by air temperature, it is unnecessary to set a TMDL for temperature. The wash input has no appreciable direct effect on pH in the lake, although nutrient loads indirectly affect pH through photosynthetic activity. Presently, the proposed pH criteria are not exceeded in the area of Las Vegas Bay outside the proposed mixing zone. Changes in nutrient loads will slightly affect pH levels due to changes in algae, although it is not possible to quantitatively predict the decrease. Since the recommended pH criteria are presently met

and since no quantitative method has been developed for relating algae levels to pH, no TMDLs associated with pH are recommended. Current levels of nitrate in Lake Mead are well under the recommended criterion. It seems unnecessary to establish a TMDL for nitrate when, in all likelihood, the criterion will continue to be met in the future. Fecal coliform levels are well within the recommended criteria. Rather than establishing a TMDL for fecal coliform, it is recommended that effective disinfection at the treatment plants be maintained.

In addition to the four parameters just discussed, criteria are recommended for Secchi depth, un-ionized ammonia and dissolved oxygen. The need for TMDLs to assure that these recommended criteria are met is described below.

Nutrients. One of the major objectives of the WQSS was to develop a transparency-algae-nutrient relationship for Lake Mead that could be used to develop TMDLs for nutrients. The work conducted on this subject is presented in Chapter 8. Quantitative relationships were developed between Secchi depth and chlorophyll and between chlorophyll and phosphorus/ nitrogen. Separate relationships were developed for the spring and summer periods. Transparency can be controlled by controlling either phosphorus or nitrogen. *The TMDL calculations for phosphorus and nitrogen allow for 10 percent of the allowable load from sources to the bay other than the wash. The TMDLs identified in this section are wash loads at Northshore Road. The following TMDLs for total phosphorus are required to meet the recommended criterion for Secchi depth:*

Spring (May to June)--310 kg/day (680 lbs/day)
Summer (July to September--270 kg/day (600 lbs/day)
Winter (October to April)--No TMDL required

The recommended Secchi depth criterion could alternatively be met with the following TMDLs for total nitrogen:

Spring (May to June)--1,900 kg/day (4,200 lbs/day)
Summer (July to September)--1,600 kg/day (3,500 lbs/day)
Winter (October to April)--No TMDL required

Since the Secchi depth criterion is only being recommended for the recreation (swimming) season, May through September, the phosphorus or nitrogen TMDLs are only needed for the same period. The effect of winter nutrient loadings on Spring algae growth was analyzed to determine whether nutrient control needs to be initiated for some length of time prior to the date when the Secchi depth criterion would go into effect. The analysis concluded that nutrient control is not needed in the winter. During the winter months, the plume flows near the lake bottom so wash nutrient loads pass through most of Las Vegas Bay and are dispersed in the deeper waters of the outer bay and Boulder Basin.

The transparency control calculation procedure used is based on existing plume conditions. It is applicable for wash and lake conditions expected to occur over the next several years. When future wastewater management plans are developed in TFS-II, control calculation procedures will have to be adjusted to reflect long-term forecasts of lake level and wash flow, salinity, and temperature. The question of whether it is more cost-effective to meet the transparency criterion by controlling phosphorus or nitrogen is another important matter that should be addressed in TFS-II.

Ammonia. In Chapter 10, a method is presented for relating Northshore Road total ammonia concentration to un-ionized

ammonia concentration in the inner bay. The method is based on the effective dilution of ammonia observed during WQSS and takes into account pH and temperature in determining what portion of the total ammonia is in the un-ionized form. The allowable load at Northshore Road required to meet the recommended un-ionized ammonia criterion at Station 2 (mean over the water column of 0.02 mg/l as N) is 4,000 kg/day (8,800 lbs/day) of ammonia. A safety factor of 25 percent should be provided to allow for some variations in temperature and pH and possible changes in the present rate of nitrification and algal uptake rate in the inner bay. *Thus, it is recommended that the TMDL for ammonia as N be set at 3,000 kg/day (6,600 lbs/day).*

SHOULD STATE CLEARLY THIS IS APPLIED

As in the case of the TMDL for nutrients, the TMDL for ammonia is applicable for wash and lake conditions expected to occur over the next several years. In computing the TMDL, the mean water column concentration has been determined by averaging dilution data for the 5-meter integrated surface sample and the 10-meter sample collected above the plume. Future monitoring should include ammonia profiles to more precisely determine the mean water column dilution.

During 1980, the average annual ammonia load at Northshore Road was 2,100 kg/day (4,600 lbs/day) while the maximum daily load was about 3,630 kg/day (8,000 lbs/day). Prior to recent changes in the wash physical configuration due to the headcut, ammonia loads at Northshore Road were much less than the proposed TMDL.

Biochemical Oxygen Demand. As discussed in Chapter 10, dissolved oxygen levels in the area of Stations 3 through

5 do not currently meet the recommended dissolved oxygen criterion at all times. The combined nitrogenous and carbonaceous BOD load from the wash is the primary factor causing oxygen depletion in this portion of Las Vegas Bay. Thus, a TMDL should be established for oxygen demanding substances, for the period of oxygen depletion (June through September). The data base and associated analysis for the BOD/DO relationship are insufficient for computing a TMDL for BOD, but can be used to approximate the BOD load that would be needed to meet the recommended DO criterion. It is estimated that the ultimate oxygen demand (carbonaceous BOD and nitrogenous BOD) load would have to be limited to about 10,000 kg/day (22,000 lbs/day) to meet the DO criterion. The average annual ultimate oxygen demand load at Northshore Road during 1980 was about 11,700 kg/day (25,800 lbs/day). If it were assumed that the carbonaceous BOD remained constant, the remainder of that oxygen demand load would be equivalent to about 1,680 kg/day (3,700 lbs/day) of ammonia. Thus, the preliminary estimate of the allowable load could be met by reducing the 1980 ammonia load by about 20 percent. Prior to recent changes in the wash physical configuration due to the headcut, ammonia loads at Northshore Road were much less than the preliminary estimate of the allowable load.

The TMDL established for nutrients to meet the recommended transparency criterion will reduce algal concentrations and in turn decrease oxygen depletion associated with microbial respiration. Although respiration is not the major factor causing oxygen depletion in the inner bay, it is an important contributor (at least 20 percent) and reduction in algal respiration will help improve dissolved oxygen levels.

REMAINING WORK

Certain remaining work is needed to fulfill the requirements of the Consent Decree and to provide a continuous water quality monitoring record for Las Vegas Wash and Lake Mead. The following discussion is divided into two parts: (1) facilities planning, and (2) water quality monitoring and analysis.

Facilities Planning

As specified in the Consent Decree and described at the outset of this report, the remaining treatment facilities study (TFS-II) was to have been conducted in conjunction with WQSS to investigate the technological, economic and environmental feasibility of a range of alternatives for achieving various water quality criteria. The work that has been conducted to date in WQSS provides an adequate basis for development of recommendations related to beneficial uses and water quality criteria necessary to support those uses. However, treatment plant effluent limitations cannot be precisely defined until the remainder of TFS-II is completed. Thus, before the Consent Decree objectives can be fulfilled, certain work needs to be conducted under TFS-II, or some comparable study. Such work should address the following issues:

1. Allocation of pollutant loads (TMDLs) set forth in this report so treatment plant effluent limitations can be determined.

2. Evaluation of alternative treatment processes, configurations and discharge locations to meet effluent limitations.

3. The feasibility of utilizing Las Vegas Wash for nitrogen or phosphorus removal in lieu of meeting the transparency criterion by phosphorus removal at the treatment plants.

4. Whether obtaining greater transparency than that recommended (minimum of 4 feet) is desirable and cost-effective.

5. Attainability of the recommended transparency criterion in inner Las Vegas Bay.

6. Effects of long-term changes in lake level and wash flow, salinity, and temperature on Lake Mead water quality conditions.

Analyses for cost-effectiveness and attainability should reflect the approaches set forth in the "Draft Water Quality Standards Regulation" issued by EPA on January 29, 1982. The draft regulation provides for a broad, flexible approach on these matters. The following statements from the draft regulation demonstrate the proposed approach:

> "Section 130.10(b) of the proposed regulation expressly provides State the opportunity to define sub-categories of aquatic protection uses which reflect different levels of protection."
>
> "Utilizing more specific levels of protection will make the public more aware of what environmental impacts can be expected and at what cost. This information may then be considered in public forums to reach decisions that balance costs against levels of protection in

setting stream uses and criteria. By participating in the process of setting standards, the public can influence the trade-offs necessary to balance desirable environmental protection against costs. The information available from water quality management plans, the use attainability analysis, the benefit-cost assessments and EPA's criteria guidance can be used in identifying specific levels of protection."

"The proposed water quality standard regulation also encourages a State to determine, after conducting a use attainability analysis, whether the incremental benefits of attaining the use bear a reasonable relationship to the incremental costs. It is difficult to generalize nationally on the level of precision and detail appropriate for any site-specific, benefit-cost assessment. The analysis should be sufficiently detailed to identify and display all significant tangible and intangible benefits of attaining a designated use, and to establish that there is (or is not) a reasonable relationship between the incremental costs and resulting incremental benefits. The incremental benefits should be evaluated in terms of:

(a) the social and economic value of the use; (b) the public interest in establishing or maintaining these uses; (c) the public benefited; (d) the extent to which another incompatible use is already being made of the water body; (e) the availability of alternative water bodies; and (f) the effect on downstream uses."

Water Quality Monitoring Analysis

Data collected in the 18-month WQSS provide a detailed record of water quality conditions in Lake Mead and Las Vegas Wash during 1979 and 1980. There is a continuing need to monitor water quality conditions to obtain a longer term data base collected under a range of future conditions and to provide additional information related to issues that have been identified through the WQSS analysis.

Water quality monitoring is needed to provide additional data in the following key areas:

1. Phosphorus loadings at Northshore Road to assess the effects of reduction of phosphorus from the treatment plants.

2. Phosphorus and chlorophyll concentrations and transparency levels in Las Vegas Bay to assess the effects of phosphorus load reductions.

3. Ammonia transformations in Las Vegas Wash, ammonia loads at Northshore Road and un-ionized ammonia concentrations in the inner bay to closely monitor the zone of un-ionized ammonia toxicity.

4. Bacteriological quality in Las Vegas Bay (both surface and subsurface waters) to confirm that water quality is suitable for swimming.

5. Microbial respiration rates and carbonaceous and nitrogenous BOD exertion rates to refine the general methodology proposed in this report so it can be used for setting TMDLs for oxygen demanding substances.

6. Effects of water quality parameters on the fishery to better define factors presently influencing the Lake Mead fishery including: diurnal and seasonal fish habits; occurrence of blockage of free movement to feeding and habitat areas caused by high temperature, high un-ionized ammonia or low dissolved oxygen; and effects of lowered algal productivity.

7. Baseline data on toxic substances in Las Vegas Wash and Lake Mead.

Table 13-5 summarizes the principal water quality monitoring needs. Routine lake monitoring should include WQSS Stations 2, 3, 4, 5, and 8. Sampling should be conducted twice per month during April through September and once per month during October through March. Routine Wash monitoring should include a composite sample at Northshore Road collected twice per month. Once a month samples should be collected at Stations 1 and 3 in the wash. Table 13-5 identifies several monitoring needs in addition to the routine lake and Wash monitoring. Some of these needs may be met by current monitoring efforts of the Nevada Department of Wildlife, the Las Vegas Valley Water District, and others and should be coordinated with the routine monitoring program.

Data should be regularly compiled and analyzed. Statistical calculations of the type done during WQSS should be performed annually to quantify changes in water quality relationships and to discern trends.

Table 13-5. Water Quality Monitoring Needs for Las Vegas Wash and Lake Mead

Routine Wash Monitoring

1. Dissolved oxygen, temperature, specific conductance, and pH.
2. BOD_5.
3. Total dissolved solids, total suspended solids.
4. Total phosphorus, dissolved phosphorus, and soluble orthophosphorus.
5. Kjeldahl nitrogen, ammonia, nitrite, and nitrate.

Routine Lake Monitoring

1. Secchi depth, temperature, dissolved oxygen, specific conductance, and pH.
2. Total phosphorus, dissolved phosphorus, and soluble orthophosphorus.
3. Total nitrogen, ammonia, nitrite, and nitrate.
4. Chlorophyll *a* and alkaline phosphatase.

Other Monitoring

1. Periodic sampling for total fecal coliform and fecal streptococci at Northshore Road and in the inner bay.
2. Collection of samples for phytoplankton and zooplankton, so enumeration could be performed if later needed.
3. Monthly surveys during one period of metalimnetic dissolved oxygen depletion (June through September) to measure microbial respiration.
4. Special ammonia survey including profiles and longitudinal transects along the plume.
5. Periodic monitoring of toxic substances in the wash and lake.
6. Special study to better define the effects of water quality conditions on the Lake Mead fishery.
7. Regular nutrient analyses of the treatment plant effluents.

GLOSSARY

AAP--Algal Assay Procedure
APA--Alkaline Phosphatase Activity
AWT--Advanced Wastewater Treatment
BMI--Basic Management Incorporated
BOD--Biochemical Oxygen Demand
CCSD--Clark County Sanitation District
cfs--cubic feet per second
DO--Dissolved oxygen
ERA--Ecological Research Associates
EPA--Environmental Protection Agency
$FC/_{FS}$--the fecal coliform to fecal streptococci ratio
GLM--General Linear Models
JTU--Jackson Turbidity Unit
LMLRC--Lake Mead Limnological Research Center
LVW--Las Vegas Wash
mgd--million gallons per day
mg/l--milligrams per liter
NAS--National Academy of Sciences
NDW--Nevada Department of Wildlife
N/P--Nitrogen to Phosphorus Ratio
NTU--Nephelometric Turbidity Unitds
NVSS--Nonvolatile Suspended Solids
OP--Orthophosphorus
PMC--Project Management Consultant
SAS--Statistical Analysis System
SD--Secchi Depth
SNWS--Southern Nevada Water System
STORET--Storage and Retireval System

GLOSSARY (continued)

TAB--Technical Advisory Board
TDS--Total Dissolved Solids
TFS--Treatment Facilities Study
TMDL--Total Maximum Daily Loads
TN--Total Nitrogen
TON--Threshold Odor Number
TP--Total Phsophorus
TSS--Total Suspended Solids
ug/l--micrograms per liter
UNLV--University of Nevada at Las Vegas
USBR--United States Bureau of Reclamation
USGS--United States Geological Survey
USNPS--United States National Park Service
VSS--Volatile Suspended Solids
WQSB--Water Quality Study Board
WQSS--Water Quality Standards Study

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