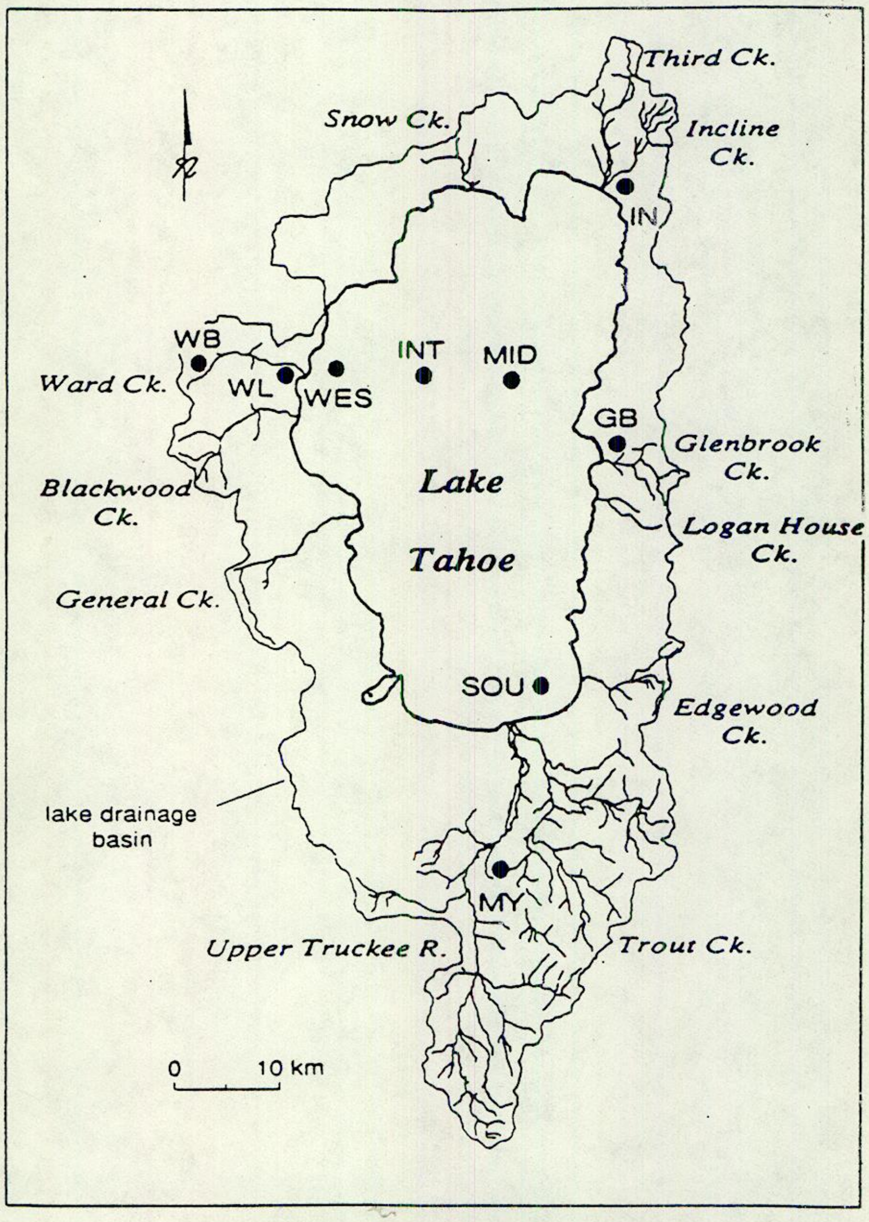
IMPACTS OF MARINA DREDGING ON LAKE TAHOE WATER QUALITY



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Final Report

Impacts of Marina Dredging on Lake Tahoe Water Quality

Submitted to:

Lahontan Region
California Regional Water Quality Control Board

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Recommendations

Physical and Mechanical Measures

1. Use of silt curtains is recommended to control the dispersion of turbidity and nutrients released during dredging. Commercial silt curtains, which are constructed of reinforced PVC or similar material are strong and durable. These curtains should be used when feasible. In very protected areas (i.e. inside protected harbors), lighter-weight commercial curtains or contractor-constructed curtains may be sufficient. When silt curtain use is not feasible, open-lake dredging should only be done using low-sediment-resuspension dredges.
2. Consideration should be given to disposal of dredge-impacted water from silt curtain enclosed areas into the sewer system or other suitable area outside the lake upon completion of dredging. The potential benefits of such pumping (which include removal of suspended nutrients from the lake and more rapid clarification of the dredge area) should be evaluated. Disposal into the sewer system is not feasible in all areas of the lake and is subject to suspended sediment concentration limits in discharge.
3. Consult with the dredge owner or manufacturer to determine whether mechanical modifications may be made to horizontal auger or cutter hydraulic dredges to reduce sediment resuspension.[1] Make use of optional equipment already available (such as a flap valve in the discharge line) to minimize turbidity produced by operations. Consider adding real-time turbidity monitoring equipment.
4. Restrict open-lake dredging to low-sediment-resuspending dredges.
5. Locate spoils dewatering areas within or upgradient of silt curtain enclosed areas. Ideally, intercept and remove water draining from spoils prior to reaching the lake.
6. Dispose of dredged sediments containing high levels of petroleum hydrocarbons, heavy metals or other toxic substances to acceptable disposal areas outside the Lake Tahoe basin.
7. Alum and polymer flocculents are effective in enhancing the settling of particulates and associated nutrients in hydraulic dredging spoils impoundment basins. Until further study can be made of the impacts of alum on lake biota and sediment-nutrient interactions in the lake, agency approval of the use of alum should be made with caution and limited to impoundment basins outside of the lake. Special provisions for monitoring should be placed on projects using alum.

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1 - Note: upon further evaluation of this recommendation in our follow-up report entitled "Cost and Effectiveness Analysis for Implementation of Recommendations in: Impacts of Marina Dredging on Lake Tahoe Water Quality" (Hackley et al., 1996) we no longer recommend that physical alteration of the shroud size on hydraulic dredges to minimize resuspension be attempted. The reader is encouraged to review this follow-up report for further evaluation of costs and benefits associated with many of the recommendations.

Recommendations Cont'd.

8. Encourage the testing of new, environmentally efficient dredging technology during dredging projects at Lake Tahoe.

Operational Control Measures

1. Assure that the operators of mechanical dredges are familiar with and skilled in using operational controls for minimizing turbidity. For bucket dredges these include: keeping the hoist speed below 2 ft. per second and avoiding jerking the bucket, deliberate placement of material at the point of disposal, and not smoothing the bottom at the end of the project.
2. Assure that the operators of hydraulic dredges are familiar with and skilled in using operational controls for minimizing turbidity. These include: careful control of cutter pressure, engine RPM, cutter RPM, and dredge pull speed.
3. Stop open-lake dredging when lake conditions become rough.
4. Avoid dredging of sediments which the dredge cannot easily remove or switch to a low-sediment-resuspending dredge appropriate to the sediments.

Monitoring Measures

1. Increased emphasis should be placed on on-site measurement of turbidity. Maximum TFe and TP levels allowed in permits could be delineated such that compliance with the turbidity standard will also reflect compliance with maximum levels of TFe and TP allowed. On-site measurement of turbidity allows for rapid identification of high sources of turbidity and nutrient release to the lake (i.e. leakage past a silt curtain or resuspension around the dredge). Corrective action may potentially occur rapidly based on on-site turbidity measurement and may help reduce the time period over which such release occurs. Such monitoring might be substituted for extensive water chemistry monitoring on a lesser or greater portion of the days on which a full water chemistry monitoring might have been required in the past.
2. Include an elutriate test in preproject analysis of sediments to be dredged to evaluate the potential for nutrient and contaminant release during dredging.

Suggestions for Future Studies

1. Further study is needed of the magnitude of nutrient depletion which occurs within areas enclosed by silt curtains and magnitude of inorganic and organic nutrients transported to the lake when silt curtains are removed. Such a study should address: (i) to what extent are nutrients removed by processes such as uptake by algae, sorption to settling sediment

particles, and co-precipitation with iron-oxides as pore water oxidizes; (ii) to what extent can the removal and/or settling of algae within the curtains be accelerated; and (iii) to what extent can the material which has settled within a silt curtain enclosed area be expected to be remobilized or transported into the lake upon removal of the silt curtain.

2. More detailed study on the degree of heavy metal and other toxic substances contamination in marina sediments and their potential release during dredging.

3. Testing and selection of a standardized elutriate test which may be used by the regulatory agencies for preproject sediment evaluations.

4. Significance of wave activity and fluctuations in lake level on release of nutrients from nearshore sediments.

Summary of Findings (by Report Section)

Sections 1 and 2: Introduction and Methods (do not have findings)

Section 3. Harbor, Marina, and Nearshore Lake Sediments

1) Considerable variability may exist in the nutrient content of sediments among harbors, among sites at a harbor, and vertically within different layers of harbor sediments.

2) Elutriate tests were used to simulate the nutrient release to the surrounding water which occurs when sediments are disrupted during dredging. Raw sediment total nitrogen (TN) or total phosphorus (TP) content was not a good predictor of the level of soluble or total N or P release in these elutriate tests.

3) A large proportion of the TN released to the supernatant solution in elutriate tests was often organic nitrogen (median level of organic N as % TN was 96%). In a cautious extrapolation of these results to the amount of nitrogen release during dredging, a significant portion of TN released to the water column during dredging will often be organic nitrogen. However, inorganic nitrogen, which is readily available to algae, composed a significant proportion of the TN released from some of the harbor sediments analyzed.

4) The amount of Biologically Available Phosphorus (BAP) released to the elutriate supernatant solution was determined by using an NaOH extraction procedure. BAP usually was from 1-6% (median 3.6%) of TP in the elutriate test supernatant. In a cautious extrapolation of these results to the amount of BAP release during dredging, we would expect approximately 1-6% of the TP resuspended in the water to be BAP.

Section 4. Dredge Area Impacts

1) Monitoring was done around a horizontal cutter hydraulic dredge during operations in the Tahoe Keys East Channel. A plume of elevated turbidity and nutrient levels along the bottom ahead of the horizontal cutter and extending upwards to the surface was detected. Although the surface plumes were detectable quite a distance from the dredge (25-200 ft.), the highest levels of turbidity and nutrients in the plume were localized within 10-20 ft. of the dredge.

2) The mechanical dredging methods monitored in this study (excavator, clamshell, dragline) had relatively high sediment resuspension characteristics. High levels of turbidity developed within the silt curtain enclosed dredge area during excavator dredging at Crystal Shores East. Dragline and clamshell dredging produced high levels of turbidity within the silt curtain enclosed dredge areas at Fleur Du Lac.

Summary of Findings Cont'd.

3) The loading of N and P to the lake from release of dredge area water upon removal or failure of silt curtains, spoils water return to the lake from hydraulic dredging spoils impoundment basins, and plumes produced around the hydraulic dredge was estimated and found to range from less than single kg levels to tens of kg levels. These loads are comparable to other inputs produced by man's activities within the basin which are regulated. For instance, resuspension of 5 kg of TN and TP by dredging is roughly equivalent to the annual TN and TP load in urban runoff from 5 acres of medium-developed residential area or 2-3 acres of tourist-commercial development. The inputs associated with dredging are partially controllable. Management of Lake Tahoe as an Outstanding National Resource Water requires that all practical measures be taken to minimize any allowed short-term degradation associated with projects such as dredging.

Section 5. Dredge Spoils

1) The series of three spoils settling (impoundment) basins used at Tahoe Keys in 1992 were unable to provide the turbidity and nutrient removal necessary to consistently achieve discharge standard limits at inflow rates of approximately 1000 gallons per minute during 7-8 hrs. of operation per day. However, the addition of alum + polymer flocculent to spoils water discharged into the impoundment basins in 1993 proved effective in reducing the levels of turbidity and nutrients (NH_4-N, TRP, TP, TKN, TN) such that discharge standards were more consistently attained.

2) Spoils dewatering on land within an area enclosed by silt curtains or upgradient of the silt-curtain-enclosed area is preferable to dewatering along the shoreline adjacent to the lake. Ideally, a dewatering area will provide for complete capture and removal of the spoils water prior to reaching the lake.

3) Predredging analysis of the levels of heavy metals, Total Petroleum Hydrocarbons (TPH), and other potentially toxic substances in marina sediments, as well as their potential to be mobilized, should be done in order to make decisions on the ultimate fate of dredged spoils. Where levels of toxic substances are high, consideration should be given to disposal outside the Lake Tahoe basin.

Section 6. Bioassays

1) Phytoplankton were co-limited by N and P in the summer when dredging is most likely to occur.

Summary of Findings Cont'd.

2) A majority of the marina sediments were shown to stimulate algal growth when added to Lake Tahoe water as a 1% solution of elutriate test supernatant (lake water containing suspended sediments + soluble nutrients released from the sediments). Lake Tahoe phytoplankton appeared to be sensitive to additions of very small amounts of nutrients (on the order of tenths of μg/l of DIN and BAP) when added in concert with the dredged sediments. In addition to DIN and BAP, these sediments may also contribute other nutrients (e.g. possibly trace metals and other substances) which enhance algal growth.
3) The small amounts of DIN and BAP released in concert with other nutrients during dredging can potentially lead to short-term, localized areas of increased phytoplankton growth in the lake. Such increased phytoplankton growth was observed primarily in protected areas in which the dredge-impacted waters were prevented from dispersing (e.g. in silt curtain enclosed areas at Fleur Du Lac and Tahoe Keys). Outside of silt curtains or in the open lake, phytoplankton and nutrients may disperse so rapidly that localized increased growth was not readily detectable. However, given the low concentration of algal growth nutrients in the lake, all limiting nutrients will eventually be used to fuel algal growth.

Section 7. Nutrient Release from Newly Exposed Sediments Following Dredging

1) Sampling of sediment interstitial water prior to and following hydraulic dredging at a site in the Tahoe Keys indicated that NO_3-N and NH_4-N were released from the newly exposed sediments during dredging and/or in the 16 days following dredging.
2) 0.39 kg NH_4-N/ acre dredged and 0.087 kg NO_3-N/ acre dredged were estimated to have been released from the newly exposed sediments.
3) Dredging may increase the potential for release of NH_4-N from the sediments over a long period. Interstitial NH_4-N concentrations increased in the upper layers of newly exposed sediments at Tahoe Keys during the year following dredging. This increase may have been the result of microbial degradation (ammonification) of available organic matter. The proximity of this NH_4-N to the surface sediments suggested release to the overlying lake water could potentially occur through physical disruption of the sediments and/or possibly through diffusion. Further study would be required to determine the magnitude of such release.

Summary of Findings Cont'd.

Section 8. Selection of Dredging Technology

1) Several factors must be considered in selection of an appropriate dredge, these include: physical and chemical characteristics of the sediments to be dredged, site characteristics, ability to use silt curtains to isolate dredge area, amount of material to be dredged, cost constraints, and dredges available.

2) Mechanical dredges (which include clamshell, dragline, excavator and backhoe types) can remove a variety of sediment types effectively, and produce spoils which are similar in water content and density to the original sediments. These dredges have high sediment resuspension characteristics and should only be used in silt curtain enclosed areas.

3) An environmentally efficient bucket called the Cable Arm Clamshell has been developed which produces sediment resuspension which is about one third that of conventional buckets. The Cable Arm clamshell may have applications in larger harbors at Lake Tahoe which contain finer sediments. It should be considered for future testing.

4) Hydraulic dredges (which include suction, cutterhead, horizontal auger or horizontal cutter types) remove and transport sediments through pipelines as a liquid slurry. Solids are removed from the slurry either through settling in spoils impoundment basins (which require large areas of available land) or through mechanical solids separators. These dredges have low to moderate sediment resuspension characteristics.

5) The Eddy Pump should be considered for testing of its ability to remove sediments while causing low resuspension in Lake Tahoe. This dredge has capability to remove high concentrations of solids (> 70%) while apparently creating very low turbidity.

6) Operational controls are important for minimizing sediment resuspension. For bucket dredges, these include: hoist speed, deliberate placement of material and avoiding smoothing of the bottom. For hydraulic cutter dredges, these may include careful control of: cutter pressure, engine RPM, cutter RPM, and dredge pull speed.

Section 9. Mitigation

1) Dredging should be done during the summer when the lake tends to be calmer

2) Use of silt curtains is recommended to control the dispersion of turbidity and nutrients released during dredging. Commercial silt curtains, which are constructed of reinforced PVC or similar material are strong and durable. These curtains should be used when feasible. In very protected areas (i.e. inside protected harbors), lighter-weight commercial curtains or contractor-constructed curtains may be sufficient. When silt curtain use is not

feasible, open-lake dredging should only be done using low-sediment-resuspension dredges.

3) Pumping of dredge-impacted water from silt curtain enclosed areas to the sewer or other suitable area outside the lake after completion of dredging may be beneficial in reducing the nutrient loading from the project and also help "clear" water in the area rapidly.

4) Alum and polymer flocculents are effective in enhancing settling of particulates and associated nutrients in hydraulic dredging spoils impoundment basins outside the lake. Until further study can be made of the impacts of alum on sediment-nutrient interactions in the lake and on lake biota, agency approval of the use of alum, should be made with caution, and limited to impoundment basins outside of the lake.

5) Spoils dewatering areas should be located such that drainage of nutrient and silt-laden water directly into the lake is prevented. Spoils dewatering on land within the area enclosed by silt curtains, or upgradient of the silt curtain enclosed area can help minimize impacts. Ideally, complete interception and removal of spoils water prior to reaching the lake will minimize potential impacts.

6) Predredging analysis of heavy metals, and TPH in the sediments should be done and will aid in decisions on the ultimate fate of spoils material. Where levels of heavy metals or TPH are high, consideration should be given to disposal outside the basin.

7) Use of optional equipment which may reduce resuspension of sediments during operations should also be considered. Such equipment may include a flap valve in the discharge line of hydraulic dredges, additional shrouds around the cutter and real-time turbidity monitoring equipment.

8) The dredge operator should be familiar with and skilled in use of operational controls to minimize turbidity.

Section 10. Monitoring and Discharge Standards

1) Turbidity was found to be statistically associated with the levels of total or biologically available iron and total phosphorus resuspended during dredging. Same-day measurement of turbidity may provide a rapid means to approximate levels TFe, BAFe and TP. By providing a rapid assessment of the levels of turbidity and these nutrients, sources of excessive levels of resuspension or discharge during dredging can be rapidly identified. Where these sources are controllable, action could be taken to correct them rapidly. Increased focus on turbidity in monitoring programs is recommended.

Summary of Findings Cont'd.

2) TN is not well associated with turbidity. Rapid assessment of whether a project is likely to be in compliance with respect to TN may be made through next day laboratory analysis.

3) Sites selected for monitoring by the regulatory agencies in the past have been well selected. However, it was recommended future monitoring outside silt curtains also include multiple points along the bottom of the curtain. Consideration should also be given to using automated turbidity monitoring equipment during hydraulic dredging to provide real-time turbidity measurements to the dredge operator. The use of a data-logger with such equipment would also provide a continuous record of turbidity generation for the regulatory agencies.

4) Preproject analysis of sediments to be dredged should include an elutriate test to assess potential nutrient and contaminant release from the sediments.

5) Further evaluation of the discharge standard for iron is warranted by Lahontan and TRPA. The linear relationship between turbidity and TFe found in this study predicted that the TFe discharge standard of 500 μg/l would be exceeded when turbidity exceeded 3.7 NTU. The discharge standard for turbidity is 20 NTU however. Projects in compliance with the 20 NTU standard may well exceed the discharge standard for TFe.

Appendix C. Historical Dredging Data 1988-92

1) During dredging, levels of Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), Biologically Available Iron (BAFe), Total Iron (TFe) and turbidity increased within dredged areas in nearly all projects in which they were monitored. TKN, TP, BAFe, and TFe consist of both a soluble and particulate fraction of the nutrient analyzed. Thus as levels of particulates and turbidity increased during dredging, the levels of these nutrients also tended to increase. The magnitude of increase for these parameters varied by project and frequency of sampling.

2) The levels of oxidized nitrogen (NO_2+NO_3-N), ammonium nitrogen (NH_4-N) and ortho-phosphorus increased within dredged areas during dredging in some but not all projects in which they were monitored.

3) Turbidity was found to be statistically associated with BAFe and TFe, but not TP and TKN in the historical data.

4) Increased algal growth as indicated by increased chlorophyll *a* concentration was observed within dredged areas during or following dredging in several projects. This increased growth was likely a result of increased nutrient levels resulting from dredging.

Summary of Findings Cont'd.

5) The silt curtains used to confine water in the dredging areas appeared to be largely effective in isolating dredge area impacted water of high turbidity and nutrient content from the main lake in many of the historical projects. Maximum turbidity and nutrient concentrations outside the turbidity curtains were often near or only slightly higher than background for many projects.

6) Escape of dredge area water into the lake did occur in several historical projects. Projects in which some escape of dredge water occurred during dredging could be divided into three categories: (a) projects in which short-term releases occurred due to minor failures of the turbidity curtains; (b) projects which had ongoing releases due to continued failures of the curtains; (c) projects which had complete failure of curtains and release of much of the dredge area water. Categories (b) and (c) had the greatest potential for impact.

7) Time elapsed between completion of dredging and permission to remove turbidity curtains ranged up to 17 days. Projects which utilized pumping and removal of dredge area water were able to remove silt curtains much sooner.

1. Introduction

1.1. Background

Lake Tahoe is a large, deep subalpine lake renowned for its cobalt blue appearing waters of great clarity. Slow rates of natural input of algal nutrients (nitrogen, phosphorus, and trace metals) to the lake have resulted in an ultraoligotrophic (low algal growth) lake of outstanding clarity. Rapid development within the Tahoe basin since the 1950's, however, has resulted in disturbance within the watershed and degradation of water quality. The lake is currently undergoing a process of "accelerated eutrophication" in which the algal primary productivity is increasing and the lake's outstanding clarity is decreasing.

The potential impact of sediments and nutrients contributed from dredging of marinas in Lake Tahoe has been a source of considerable debate. Mechanical (i.e., excavator, dragline, and clamshell dredging) and hydraulic suction dredging are done in Lake Tahoe to remove accumulated sediments in channels, harbors, and marinas to maintain boat access to mooring, fueling, and service facilities. These dredging methods release sediment and associated nutrients into the water column which may ultimately impact the lake. While it is clear that dredging of bottom sediments releases biologically available nutrients and other compounds to the water column, the extent of this loading has not been quantified. This lack of information, together with sparse information on the most environmentally sensitive and efficient dredging technology and methods, has often resulted in a series of ongoing, emotionally charged debates among marina operators, environmentalists, and regulatory agencies, concerning the contribution of dredging to the decline in lake water quality.

A comprehensive determination of the impacts associated with dredging is particularly important to the regulatory agencies charged with protection of water quality in Lake Tahoe. These agencies include the California Regional Water Quality Control Board Lahontan Region (Lahontan), Tahoe Regional Planning Agency (TRPA), and Nevada Division of Environmental Protection (NDEP). The sponsor of the current study, the California Regional Water Quality Control Board Lahontan Region is charged with establishing and enforcing water quality standards and regulations for the lake in California in order to protect water quality. In 1981, the parent board for Lahontan, the California State Water Resources Control Board designated Lake Tahoe an Outstanding National Resource Water (ONRW). This designation affords Lake Tahoe the Environmental Protection Agency's highest level of protection under antidegradation policy in the EPA's Water Quality Standards Regulations published November 8, 1983 (48 F.R. 51400, 40

CFR 131.12). ONRW status basically means that water quality in Lake Tahoe is required to be maintained and protected. No long-term degradation of water quality is allowed. A thorough determination of the potential impacts of dredging is therefore important for developing policy on dredging consistent with the lake's ONRW status.

In addition to the Lahontan, the TRPA and the NDEP have responsibility for protection of water quality in the lake. TRPA reviews all projects within the shorezone on both the California and Nevada portions of the lake and has adopted a Shorezone Ordinance which governs activities in the shorezone such as dredging. Similar to Lahontan, it has established discharge standards to protect lake water quality. Under TRPA's current dredging policy, maintenance dredging projects may be permitted providing that TRPA finds that there will be no significant impact on the lake. New dredging projects may only be permitted when TRPA finds that the project is "beneficial to existing shorezone conditions, and water quality and clarity." Both Lahontan and TRPA currently require extensive measures be taken to minimize the release of nutrients and sediments resuspended by dredging to the lake. For instance, the use of silt curtains around projects is required where feasible and extensive monitoring is done to assure compliance with discharge standards. However, a more detailed study of impacts of dredging and review of environmentally efficient technology would be useful to TRPA in preproject evaluation of future dredging projects.

The Nevada Division of Environmental Protection is responsible for establishing and enforcing water quality standards and regulations for the Nevada portion of the lake, and has similar needs as Lahontan and TRPA for information on the specific impacts of dredging on the lake.

In an attempt to resolve issues relating to the impacts of dredging on Lake Tahoe, in January 1992, Lahontan set aside moneys to fund a study of water quality impacts associated with dredging, and requested a steering committee be formed to direct the study. In April 1992, the steering committee (which included participants from: Lahontan , TRPA, California Dept. of Fish and Game, State Lands Commission, Lake Tahoe Marina Association, Tahoe Keys Property Owners Association, League to Save Lake Tahoe, University of Nevada Desert Research Institute, and University of California, Davis — Tahoe Research Group) met and determined that the overriding concern of such a study should be centered on pollutant release to the lake (either directly or indirectly) as a function of dredging method, disposal method, depth of dredging, and substrate type. In October 1992, a proposal submitted by the University of California, Davis — Tahoe Research Group (TRG) to study dredging impacts on the lake, was accepted by the Lahontan Board.

1.2. Past Studies of Dredging Impacts at Lake Tahoe

Previous scientific studies have provided some information on the levels of nutrients available in Tahoe sediments which could be released during dredging. In 1977, the TRG performed a limited set of experiments to provide data on the level of nutrients available in marina sediments and their potential impact on Lake Tahoe algae growth. Sediments were collected from within and outside the Boatworks Marina in Tahoe City. These sediments were extracted in distilled water, with the extract then analyzed for ammonia-N, nitrate-N, soluble phosphorus, and soluble reactive iron. A single bioassay was done which tested the impact of these extracts on algal growth in Lake Tahoe. The results of these experiments indicated levels of nutrients in marina sediments were higher than levels from outside the marina, and the sediment extracts were found to be mildly stimulatory to algal growth. While these initial and site-specific experiments did give an estimate of levels of easily solubilized, water-extractable inorganic N and P in the sediments, other forms of N and P were not measured. The organic nitrogen content of the sediments was not determined, yet it may be an important source of inorganic nitrogen through the process of bacterial mineralization. Similarly, various forms of P adsorbed to the sediment and not removed by the water extraction may still have been available for algal utilization, either immediately or over time.

In 1982, a study was done by Ecological Research Associates (ERA) for Fleur Du Lac Estates which looked at the nutrient content of lake sediment interstitial (or pore) water in the area proposed for dredging and in inner harbor sediments. Again, this study only looked at soluble nutrients associated with the material to be dredged and neglected other potentially available forms of nutrients, i.e. organic nitrogen and phosphorus adsorbed to the sediment.

In 1988, the Lahontan Regional Water Quality Control Board laboratory in South Lake Tahoe analyzed the sediment nutrient chemistry of material taken from the mouth of Fleur Du Lac harbor. The difference between total phosphorus (TP) released from sediments in a water extraction procedure (water extractable) and TP released by an acid extraction (acid extractable) was quite large (1.2 mg TP/kg dry sediment and 579.6 mg TP/kg dry sediment, respectively). Studies which have looked at the bioavailability of phosphorus bound to sediment particles have found that 5-30% of the sediment-bound P was available for algae growth (Dorich et al., 1985; Ellis and Stanford, 1988; Engle and Sarnelle, 1990). Researchers have found that a 0.1N NaOH/1.0 N NaCl extraction correlates well with algal available P. Even using an estimate that only 10% of the sediment-bound P (acid extractable P) determined by Lahontan was available for algae growth, the algal available P would have been about 50 times greater than the water-extractable P. Thus a simple water extraction is apparently not adequate to estimate algal available P in sediments.

From 1988-1992, background data has been collected from several marinas which have been allowed to dredge or that were seeking to dredge. Predredging sediment analyses were done for several of the marinas. Analysis of these sediments included total Kjeldahl nitrogen (TKN, which measures ammonia + organic nitrogen), NO_2+NO_3-N, TP (acid-extractable), soluble and biologically available iron, and total iron, oil and grease, and presence or absence of certain toxic and heavy metals. Interstitial water and water column chemistry also was taken at the same time the sediments were sampled. Water quality monitoring was also done during the dredging on a regular basis as part of TRPA and Lahontan permit requirements. This data was compiled and evaluated as part of the current TRG study (see Appendix C).

While there has been some work on potential impacts of dredging and nutrient content in the sediments, the above studies were not comprehensive and were responses to a series of unrelated actions. Questions remain on the extent of nutrient loading during dredging, amounts of bioavailable nutrients relative to "total" amounts, potential impacts on lake algal growth, and potential nutrient release from sediments newly exposed by dredging. The following study addresses these and other questions related to the impacts of dredging on Lake Tahoe.

1.3. Project Goals

The goals of the study were as follows:

[1] Evaluate the impact of different dredges and dredging procedures on lake water quality. Specifically, how much bottom disturbance is associated with different types of dredges and how does this disturbance contribute nutrients to the lake.

[2] Determine concentrations of both soluble and particulate nutrients within selected marina sediments, then:

[a] Relate these concentrations to measured water concentrations during actual dredging operations.

[b] Determine to what extent these nutrients are bioavailable, and the impact of the dredged sediments on Lake Tahoe algal growth.

[c] Evaluate the potential water quality impacts of newly exposed, deeper sediments following dredging.

[3] Study effectiveness and potential impacts of spoils dewatering and disposal methods in use.

[4] Provide agencies with information related to dredging policy i.e.:

[a] Guidelines for selecting most appropriate dredging technology, practices, and possible mitigation measures.

[b] Guidelines for monitoring.

[c] Where feasible, an assessment of whether regulatory agency turbidity and nutrient limits for spoils discharge water and lake water around the dredge were appropriate to keep impacts on the lake to a minimum.

[d] An evaluation of guidelines governing in-lake or land disposal of spoils in dewatering and sedimentation basins.

1.4. Project Approach

The approach applied to meet the project goals was as follows:

[1] <u>Impacts of different dredges and dredging procedures on water quality</u>

To evaluate the effect of different dredges and dredging procedures on lake water quality, we were limited to projects and dredge types which had been permitted during 1992-1993. These included:

- Tahoe Keys East Channel 1992 (hydraulic dredging)
- Tahoe Keys Marina and lagoons 1993 (hydraulic dredging)
- Fleur Du Lac 1993 (dragline and clamshell dredging)
- Crystal Shores East 1993 (excavator dredging)

Extensive water quality monitoring both within the dredging area as well as in the lake outside turbidity curtains was done. This monitoring data was combined with data from regulatory agency (Lahontan and TRPA) required monitoring around the project site to provide a comprehensive picture of water quality changes associated with the different dredging projects. To look at the water quality impact of variables under operator control on a horizontal cutter suction dredge, a test was done in which auger pressure and engine RPM were varied in four combinations of settings.

The amount of disruption of bottom sediments and resuspension to the water column during suction dredging was also documented via underwater video and still photography. Underwater observations of all sites were made prior to and following dredging.

[2] Nutrients present in marina sediments

In determining soluble and particulate nutrients in sediments, we considered the following pools: (i) dissolved interstitial water and loosely adsorbed nutrients removable by leaching with lake water in elutriate tests (i.e. nitrate-nitrogen [NO_3-N], nitrite-nitrogen [NO_2-N], ammonia-nitrogen [NH_4-N], and soluble reactive phosphorus [SRP]; (ii) nutrients more strongly bound to the surface of sediment particles, yet still potentially bioavailable, i.e., Biologically Available Phosphorus [BAP] (defined as aluminum and iron bound P removable by an NaOH extraction); and (iii) a more refractory, particle-bound nutrient pool which is largely unavailable to biota over the short term — these nutrients can be measured in a "total" digestion analysis, i.e. total nitrogen [TN] and total phosphorus [TP].

Marina sediment cores for analysis were collected from at least 3 different sites within the areas to be dredged prior to dredging. Cores were subsectioned based on visual identification of different particle-size layers. Dried sediment was subjected to analysis for total nutrients, while elutriate extractions were done on wet samples. Elutriate extractions simulate the mixing of sediment and water that occurs during dredging and are intended to determine the amounts of pollutants that could be released during dredging. In these tests, one part sediment was agitated with four parts lake water, the solids were allowed to settle for 2 hours, then the overlying supernatant solution was removed and chemically analyzed.

[2 a] Comparison of nutrient concentrations in sediments vs. nutrient concentrations released to dredge area during dredging

This was performed to see whether a relation could be established between nutrients in marina sediments and concentrations released to the dredge area. Specifically, elutriate test supernatant concentrations were compared to maximum water column concentrations observed in the dredge areas.

[2 b] Extent to which sediment nutrients are bioavailable and impact of the sediments on Lake Tahoe algal growth

While the soluble nutrients NO_2-N, NO_3-N, NH_4-N, SRP are assumed to be readily bioavailable, only a portion of the particulate associated TN and TP may be bioavailable. Nitrogen may be bound largely in organic compounds, which must further undergo biological degradation to inorganic forms to become available for algal utilization.

Total Kjeldahl nitrogen was analyzed and provided an indicator of the amount of organic nitrogen present. The organic P fraction of TP is thought to be largely unavailable to algal growth, however, aluminum and iron bound P fraction of TP is bioavailable. The amount of BAP in raw sediments and elutriate were analyzed using an NaOH extraction. This value was then contrasted with the TP value to come up with a range for percent of TP which is bioavailable.

The potential impact of sediment nutrients released by dredging on algal growth was tested using standard bioassay procedures. In these bioassays, small quantities of marina sediment or sediment elutriate test supernatant were added to Lake Tahoe water containing natural phytoplankton assemblages and growth response of the algae monitored. The growth response of treated cultures was statistically compared to controls. Dredge area chlorophyll levels were also analyzed and provide evidence of the stimulatory nature of the dredge material.

[2 c] Potential water quality impact of newly exposed, deeper sediments following dredging

The potential water quality impact of newly exposed, deeper sediments following dredging was investigated. Samples of sediment interstitial (or pore) water were collected at regular depths within the sediments at a site within the Tahoe Keys lagoons to obtain a predredging profile of NO_3-N, NH_4-N, and SRP. We then returned to collect 4 interstitial water profiles over the course of the year following dredging. Through observing changes in nutrient concentrations within the profile, we hoped to draw conclusions on the movement of nutrients within the sediments and release to the overlying water.

[3] Effectiveness and potential impacts of spoils dewatering and disposal methods in use

Dredged sediments typically contain significant amounts of water, with the magnitude dependent on porosity and dredging methodology. Sediments are usually piled at an onshore location and allowed to drain prior to transport to a final disposal site. During dewatering, nutrients can return to the lake via surface runoff and percolation of spoils water into subsurface water. At Crystal Shores East, dewatering was done on a section of beach away from the dredge area, adjacent to the lake. We measured concentrations of nutrients in very shallow surface water adjacent to the site in order to detect whether spoils water was percolating through the sands into the lake.

During the 1992 and 1993 dredging projects at Tahoe Keys, a series of settling ponds was used for solids separation and nutrient removal from the dredge slurry, with the settled water returned to the lagoon system. During dredging at Tahoe Keys in 1993, a sand classification system was used to remove coarse materials and sands from the slurry prior to discharge to the settling ponds. Alum and synthetic polymer flocculant was then added to the remaining slurry of silts and water and discharged to the settling pond system. We monitored the changes in turbidity and nutrients as spoils water passed through the settling pond system at Tahoe Keys both in 1992 and 1993. This monitoring provided information on effectiveness of the pond system in removing turbidity and nutrients prior to discharge into Tahoe Keys, as well as information on the impact of the addition of the sand classification system and flocculent treatment to the effectiveness of the settling ponds.

[4 a] Guidelines for selecting most appropriate dredging technology, practices, and possible mitigation measures

Information on the environmental soundness of dredging practices from studies of the four projects at Tahoe was combined with information gained from researchers studying the environmental efficiency of dredges in the United States (US Army Corps of Engineers Waterways Experiment Station) and in Canada (Environment Canada). Information was also obtained from dredge operators with experience in dredging at Tahoe, dredge manufacturers, and the literature. All information was combined to compile general guidelines for selecting most appropriate dredging technology, practices, and possible mitigation measures for use at Lake Tahoe.

[4 b] Guidelines for monitoring

After reviewing historical monitoring which had been done during dredging projects, and reviewing monitoring done during this project, we made some recommendations on guidelines for future monitoring and on parameters which should be included in monitoring.

[4 c,d] Assessment of water quality objectives and discharge standards and their effect on maintaining minimal impacts during dredging

A comparison was made of concentrations measured during monitoring of the dredging projects, with water quality objectives and discharge standards for the lake. Where levels of the monitored parameter were typically well below the standards, this provided evidence that the standards might be too high and, therefore, allow more impact than the minimum level achievable. The levels of turbidity, TN, TP, TFe measured within silt curtain enclosed areas, outside silt curtains, and near the hydraulic dredge cutter, were compared with discharge standards and water quality objectives.

2. Methods

2.1. Sediment Cores

2.1.1. Site Selection

Appendix figures (B-1 to B-8) present maps of the sediment coring sites, as well as interstitial water quality monitoring sites and water quality sampling sites for all TRG study sites. At least 3 sediment cores were collected from different areas within the harbor or marina prior to dredging. Core sites were chosen to be representative of the different types of sediments in the primary areas to be dredged. At Tahoe Boat Co. Marina (which was not dredged), sites were located in an access channel outside the marina as well as within the marina. At Fleur Du Lac, Tahoe Keys Lagoons, and Crystal Shores East, we returned to selected core sites, approximately 10 months after the dredging to take postdredging cores.

2.1.2. Coring Methods

Sediment cores were collected by driving acid and deionized water-cleaned, Schedule 40 ABS pipe (2-3 inch diameter) as deep as possible into the sediments. The pipe was capped at the top to provide suction. Following removal the cores were capped at the bottom. Cores were stored at 4°C until analyzed. Core lengths ranged from 22 cm to 89 cm. Where sediments were highly consolidated or consisted of very coarse material (e.g. Fleur Du Lac core sites 2, 3a, 3b), it was possible to sample only the uppermost layers of sediments to be dredged. The cores usually encompassed a significant proportion of the total depth of sediment to be dredged.

2.1.3. Core Processing Procedure

Sediments were extruded from the corer and different layers of sediments measured and visually identified based on apparent predominant grain size (e.g. clay, silt, sand, coarse sand, gravel, cobble) and color. From 1-6 distinct layers within each core were then separated temporarily to plastic Ziploc® bags from which subsamples were taken for:

- wet weight, dry weight, and weight Loss On Ignition (LOI) at 550°C.
- BAP
- TP and TN
- elutriate tests
- size fractionation
- archiving

Determination of raw sediment BAP, TP, and TN was done using dried sediments less than 2 mm in diameter (sand and smaller grain sizes). Elutriate tests were done using original unsieved wet sediments and included all particle sizes. A summary of methods used for chemical analysis of sediments, elutriate test supernatant, and water samples are included in Table 2-2.

2.1.3.1. Elutriate Test

An elutriate test was used to simulate the nutrients which might be released to the surrounding lake water during dredging. Elutriate tests were originally developed by the U.S. Environmental Protection Agency and U.S. Army Corps of Engineers to estimate the levels of contaminants which might be released to the surrounding water from spoils at disposal sites (EPA/ACE, 1972). The TRG elutriate test was patterned after earlier versions of these tests.

In the TRG elutriate test, 1 part (by vol.) wet sediment was added to 4 parts (by vol.) (0.45 μm filtered) Lake Tahoe surface water in a 1 or 2 liter Rubbermaid® plastic container and capped. Some air space was left at the top of the container to allow physical mixing. The container was then vigorously shaken on a shaker table at 3000 RPM for 20 minutes. The mixture was allowed to settle for a period of 2 hours, then the overlying supernatant was drawn off for chemical analysis. A portion of the supernatant was filtered through a 0.45 μm HA Millipore filter and analyzed for nutrients leached from the sediments (NO_2NO_3-N, NH_4-N, and SRP). The remaining unfiltered solution was analyzed for BAP, TRP, TP, TKN and suspended sediment, and tested for potential to stimulate Lake Tahoe algal growth in algal bioassays.

2.1.3.2. Size Fractionation of Sediments

Selected samples of sediments were dry sieved to determine the proportions of the major size classes of particles (i.e. gravel/cobble, sand, and silt/clay). The resulting size-fractionated material was saved for later potential TN and TP analysis. We were limited to analysis of small (usually between 3-25 g) quantities of material. Standard dry sieving procedures usually require a larger amount of material (100-200 g or more to obtain a representative sample of many size classes) for sieving through a series of up to 11 sieves. We used a maximum of 3 sieves to correspond to the following size classes of material: > 2 mm (gravel); < 2 mm > 250 μm (medium to coarse sand); < 250 μm > 63 μm (fine sand); < 63 μm (silt/clay). The results should be considered to be approximations subject to some error due to the small sample size.

Samples of sediments were oven-dried at 55°C and then dry sieved through a series of 2-3 stainless steel U.S.A. Standard Testing Sieves. A known weight of sediment was loaded into the top 2-mm sieve, and sieves of progressively smaller mesh sizes were stacked underneath with a collection pan at the bottom. The sieves were then shaken at mid-range speed on a CSC Scientific Sieve Shaker for 10 minutes. The weight of sediment remaining in each sieve relative to the total amount of material sieved indicated the proportion of material in each size class.

2.1.3.3. Sediment Archiving

Small quantities (5-50 g) of core subsection sediments were dried at 55°C and stored for potential later analysis.

2.2. Interstitial Water Sampling

At Tahoe Keys and Fleur Du Lac, samples for analysis of nutrient content in sediment interstitial (or pore) water were collected using minipiezometers similar to those described by Lee and Cherry (1978). The minipiezometer consisted of an 0.5 - 1.5 meter length of 0.4 cm I.D. polyethylene tubing attached to a 8 cm section of 0.7 cm I.D. tubing which was perforated in the sides near the end and wrapped with fiberglass screening. The minipiezometers were placed into the sediments by driving an appropriate length of 1.59 cm I.D. steel pipe fitted with a loosely fitting lag bolt at the sediment end to the desired sampling depth in the sediments, then inserting the minipiezometer, screen section first, into the pipe until it contacted the lag bolt. The minipiezometer was held in place against the lag bolt as the metal pipe was slowly removed from the sediments (the bottom lag bolt prevents sediment from entering the metal pipe while being driven into the sediments, and remains in the sediments near the piezometer tip when the pipe is removed). A length of the minipiezometer tubing remains free in the lake water and is labeled to indicate depth of minipiezometer tip in sediments. Individual minipiezometers were placed to each depth for which a sample was required.

To sample the interstitial water, two 60 ml syringes were attached with Tygon tubing to two ends of a "T" shaped tubing connector, a small length of surgical rubber tubing (0.55 cm I.D.) was used to attach the remaining free end of the "T" connector to the minipiezometer. The plunger of one syringe was then withdrawn sufficiently to flush about 30 ml of water from the minipiezometer, the surgical rubber connector was temporarily clamped, and the water in the syringe was discarded. After reattaching the syringe, the plungers of both syringes were withdrawn and held in place (when necessary by short lengths of wooden blocks) to draw the sample. A total of 100 ml of interstitial water was collected.

At Crystal Shores East, shallow interstitial water was collected by inserting a short length of 1 mm I.D. glass tubing from 3-5 cm into the sediments. Interstitial water was then removed through the tubing into a 60 ml syringe. This method was less reliable than the minipiezometers, as the glass tubing was subject to breakage and plugging with sand.

2.3. Dredge Area Monitoring

2.3.1. Dredge Area and Spoils Area Monitoring

Table 2-1 presents a summary of sampling methods, parameters monitored, and brief description of sampling strategy for each of the dredging projects.

2.3.2. Special Project Monitoring

2.3.2.1. Boat Operation in Tahoe Keys East Channel Prior to Dredging

Information on the impact of boat operation on turbidity and nutrient resuspension in the shallow East Channel prior to dredging was obtained as follows. On 7/14/92, water samples were collected by a diver as the TRG's research boat, R/V Ted Frantz (25 ft. hull length, 9 ft. beam, approximately 3 ft. draft to bottom of outdrive, with a 454 cu. in. Mercruiser Bravo II Inboard/Outboard engine) made passes through the metal bulkhead-lined section of the Tahoe Keys East Channel at speeds of 3 mph, 5-6 mph, and 10 mph. Sampling stations were situated at different locations within this section of channel for each pass. (The bottom substrate was assumed to be relatively uniform within this section of channel consisting of sands and silts with some macrophytes, and maximum depths ranged from about 5-6 ft.) "Grab" water samples were collected at the surface 30 seconds before each pass, near the bottom 10 seconds after the boat passed, and again at the surface 30 seconds after the boat pass. An additional boat pass was made at 6 mph just outside (north of) the metal bulkhead-lined channel. For this pass, an additional water sample was collected at the surface 13 minutes after the boat pass. Changes in the amount of particulates in the water column were recorded on video tape with the TRG's remotely operated underwater vehicle camera (ROV).

2.3.2.2. Turbidity and Nutrient Resuspension During Operation of VMI 612 Horizontal Cutter Suction Dredge at Varied Auger Pressures and Engine RPM

On 9/30/93, we investigated the amount turbidity and nutrient resuspension produced by the VMI 612 horizontal cutter suction dredge at four different combinations of

Table 2-1. Summary of TRG monitoring done during dredging projects 1992-94.

Monit. Type	Location	# Days Sampled	Method	Sampling Strategy	Parameter and (# of samples collected)
Dredge Area	T. Keys East Channel 1992 (VMI 612 Suction Dredging)	5 (1992)	Grab[1] at specific depth	Samples collected along transects primarily in front of and behind VMI 612 suction dredge, at regular depths & distances to determine range and distribution of impact.	Turb.(62), SRP(28), DP(24), TRP(40), TP(62), TKN(23), NO_2NO_3-N(28), NH_4-N(62), BAFe (24), dBAFe(24)
Dredge Spoils Area	T. Keys Spoils Discharge Pond System 1992	10 (1992)	Surface Dip[2] samples	Sampling at sites from inflow area to outflow area along series of 3 settling ponds to determine effectiveness of impoundments in reducing turbidity, and nutrient levels.	Turb.(64), SRP(64), DP(64), TRP(64), TP(64), TKN(64), NO_2NO_3-N(63), NH_4-N(64), BAFe (62), dBAFe(63)
Dredge Area	T. Keys East Lagoons 1993 (VMI 612 Suction Dredging)	6 (1993) 4 (1994)	Surface Grab and Dip samples	Sampling at specific sites within lagoon system and at mouth to determine distribution of impact and potential lake impact. Follow-up samples in '94 for potential long-term impacts	Turb.(36), SRP(11), TRP(33), TP(35), NH_4-N(36), TKN(35) NO_2NO_3-N(36) Chlorophyll a(31) Pheophytin(31)
Dredge Spoils Area	T. Keys Spoils Discharge Pond System and Sand Classification System 1993	6 (1993)	Surface Dip samples	Sampling at sites from inflow area to outflow area along pond system to determine treatment effectiveness in combination with the sand classification system and the addition of alum and polymer flocculant.	Turb.(33), SRP(5), TRP(30), TP(30), NH_4-N(30), TKN(30) NO_2NO_3-N(30) Chlorophyll a(5) Pheophytin(5)
Dredge Area	Fleur Du Lac 1993 (Dragline & Clamshell Dredging)	16 (1993) 3 (1994)	Surface Grab and Dip samples	Sampling within and outside screened dredge area to determine levels of turbidity and nutrients released within the dredge area and effectiveness of the silt curtain. Follow-up samples were collected in 1994 for determination of long-term impacts.	Turb.(63), SRP(54), TRP(46), TP(79), NH_4-N(78), TKN(64) NO_2NO_3-N(79) Chlorophyll a(48) Pheophytin(47)
Dredge Spoils Area	Fleur Du Lac Conveyor System 1993	1 (1993)	Deposition into 28.7 cm diameter bucket	Place deposition buckets underneath conveyor belt during transport of spoils, weigh amount of spoils spilled from conveyor during known duration of time.	Dry wt.(3)
Dredge Area	Crystal Shores East 1993 (Excavator Dredging)	7 (1993) 2 (1994)	Surface Grab and Dip samples	Sampling within and outside screened dredge area to determine levels of turbidity and nutrients released within the dredge area and effectiveness of the silt curtain. Follow-up samples in 1994 for determination of long-term impacts.	Turb.(55), SRP(37), TRP(24), TP(37), NH_4-N(37), TKN(37) NO_2NO_3-N(37) Chlorophyll a(22) Pheophytin(22)
Dredge Spoils Area	Crystal Shores East Backshore Dewatering 1993	2 (1993)	Surface Dip samples	Sample nearshore surface water adjacent to dewatering area to detect possible impacts of spoils water on lake water.	Turb.(3), SRP(3), TRP(3), TP(3), NH_4-N(3), TKN(3), NO_2NO_3-N(3), Chlorophyll a(1), Pheophytin(1)
Dredge Spoils Area	Crystal Shores East Backshore Dewatering 1993	1 (1993)	Use syringe to collect shallow water at shore/lake interface and shallow interstitial water	Sample shallow surface water at lake-land interface using syringe and sample shallow interstitial water to detect possible percolation of spoils water into nearshore lake water.	NO_2NO_3-N(9), NH_4-N(9), SRP(8)

Notes: 1- "Grab" samples were collected directly into 500 ml narrow-mouth Nalgene® sample bottles.
2- "Dip" samples were collected using a wide mouth 1 quart sampling bottle affixed to a 10 ft. pole and then transferred to a 500 ml sampling bottle.

auger pressure (downward pressure forcing the cutter into the sediments) and engine RPM (which supplies overall power to the cutter). During this test, the dredge made a single pass (150 ft. long) down a 7-8 ft deep section of channel near the Tahoe Keys marina gas dock. Engine RPM and auger pressure were varied in four combinations of settings (1300 RPM/400 PSI auger pressure; 1700 RPM/400 PSI; 1300 RPM/700 PSI; 1700 RPM/700 PSI). For each combination of engine RPM and auger pressure, the dredge was allowed to operate for 1-2 minutes at this setting, then a full set of water samples were collected 10 ft. away from the cutterhead, ahead of the right and left edges of the cutter, as well as perpendicular to the cutter at a distance of 10 ft. (as the dredge continued to operate). Three sample depths were collected at each site using a Van Dorn bottle: surface, 3 ft. deep and near the bottom (4-6 ft. deep). After collection of all samples for one set of RPM and auger pressure, the dredge was stopped and sampling boat repositioned, then dredging commenced again under a new set of operational settings. An additional set of samples 20 ft. away from the dredge at depths of 0 ft., 3 ft., 6 ft. were collected at the start of the test run at 1300 RPM and 400 PSI.

2.4. Water Quality Analysis

Table 2-2 presents a summary of methods used in analysis of water samples obtained from project monitoring and sediment elutriate tests. The table also presents methods used for analysis of lake sediments. Detailed procedures for a majority of the analyses are included in an updated manual summarizing TRG analytical methods (Hunter et al., in press [a]). Water samples were stored at 4°C until analyzed. Water samples for determination of soluble constituents were filtered through deionized-water rinsed 0.45 μm HA Millipore® filters. The NO_3-N analysis included both the NO_2-N + NO_3-N fractions, however, we will refer to NO_2-N + NO_3-N throughout this report as NO_3-N. Sediments samples for TP and TN analyses were pre-sieved through 2 mm sieves to remove particles larger than sand size. Samples for BAP analysis were confined to the smaller sand and silt/clay size particles by excluding larger particles when taking a subsample.

2.5. Water Quality Analysis Quality Assurance Program

The Tahoe Research Group laboratories at Lake Tahoe and in Davis adhere to a quality assurance program outlined in detail in Hunter et al. (in press [b]). Many of the methods for analysis of dredging samples are sensitive to the extremely low levels of analyte typically found in Lake Tahoe water. For all samples, meticulous laboratory techniques were used to prevent sample contamination and assure precision. Quality control charts are maintained to monitor the slope of the standard regressions for each

Table 2-2. Summary of analytical methods and method limit of detection.

Parameter	Method	Limit of Detection	References
Chlorophyll a and Pheophytin	A modification of the fluorometric method of Strickland and Parsons (1972). Samples are extracted overnight in basic (1 ml 1N NaOH/1L) methanol. Fluorescence of sample was then determined prior to and following acidification with dilute HCl.	Approx. .02 μg/l	Strickland and Parsons (1972) Holm-Hansen (1978)
Iron -Biologically Available (BAFe)*	Modification of ferrozine method described by Stookey (1970). Preliminary treatment with hydrochloric acid releases iron likely to be available to phytoplankton from variously bound, complexed and colloidal sources.	1 μg/l	Stookey (1970)
Iron -Dissolved Biologically Available (dBAFe)*	Same as BAFe except sample is pre-filtered through a 0.45 μm HA Millipore filter.	1 μg/l	Stookey (1970)
Nitrogen -Ammonium (NH_4-N)*	Sample is pre-filtered through a 0.45 μm HA Millipore filter. Modification of method reported by Liddicoat et al. (1975) and Solorzano (1969). Indophenol method.	5 μg/l	Liddicoat et al. (1975) Solorzano (1969)
Nitrogen -Nitrate + Nitrite (NO_3-N)*	Sample is pre-filtered through a 0.45 μm HA Millipore filter. Hydrazine reduction of nitrate to nitrite, followed by color development using a diazotization-coupling reaction.	1-2 μg/l	Kamphake et al. (1967) Strickland and Parsons (1972)
Nitrogen -Total Kjeldahl Nitrogen (TKN)*	Organic nitrogen is reduced to ammonium ions by digestion with sulfuric acid in the presence of mercuric sulfate and potassium sulfate, then ammonium analyzed. TKN = organic + ammonium nitrogen.	35 μg/l	Liddicoat et al. (1975) Fishman and Friedman (1989) Solorzano (1969) Calif. State Water Resources Control Board (1986)
Nitrogen -Total Nitrogen (TN) (DANR Lab)	Procedure for soil. Total reduced nitrogen by the wet oxidation of soil organic matter using standard Kjeldahl procedure with sulfuric acid and digestion catalyst. Phenyl acetate is added to include NO3 in analysis.	5 μg/g	Issac and Johnson (1976) Carlson (1978)
Phosphorus -Biologically Available (BAP)*	Aluminum (Al) and iron (Fe) bound phosphorus are extracted using 0.1N NaOH. The sample is centrifuged, then analyzed for SRP using the phosphomolybdate method.	1 μg/l	Dorich et al. (1985) Sharpley et al. (1991)
Phosphorus -Dissolved (DP)*	Sample is pre-filtered through a 0.45 μm HA Millipore filter. Organic and other labile forms of phosphorus are converted to orthophosphate by an acid-persulfate digestion. The orthophosphate released is then analyzed using a phosphomolybdate method.	2 μg/l	Goldman (1974) Strickland and Parsons (1972)
Phosphorus -Soluble Reactive (SRP)*	Sample is pre-filtered through a 0.45 μm HA Millipore filter. Soluble orthophosphate is analyzed using a phosphomolybdate method.	1 μg/l	Goldman (1974) Strickland and Parsons (1972)
Phosphorus -Total (TP)*	Same as for DP except analysis is done on unfiltered water sample. Sediment Total Phosphorus was determined on small amounts of dried sediment added to 20 ml of deionized water.	2 μg/l	Goldman (1974) Fishman and Friedman (1989) Strickland and Parsons (1972)
Phosphorus -Total Reactive (TRP)*	Same as SRP except the analysis is done on an unfiltered water sample.	1 μg/l	Goldman (1974) Strickland and Parsons (1972)

Table 2-2. Cont'd.

Parameter	Method	Limit of Detection	References
Suspended Sediment (SS) (Nonfiltrable Residue)	For determination of elutriate SS an modification of the A.P.H.A. method was used (which substituted a 0.45 μm HA Millipore filter for glass fiber filter and used a reduced drying temperature). A small volume of elutriate supernatent was filtered onto a pre-dried (55°C overnight), tared 0.45 μm HA Millipore filter. The filter was then dried overnight at 55°C and re-weighed. Wt. Sed. on filter/Vol. filtered= SS. For determination of the SS : turbidity relationship a pre-dried (105°C overnight), tared glass fiber GF/C filter was used, and samples were dried at 105°C overnight. Wt. Sed. on filter/Vol. filtered= SS.	Approx. 1 mg/l for 0.1 L filtered	A.P.H.A. (1971)
Turbidity	Unfiltered sample water is thoroughly shaken then approx. 30 ml transferred to a cuvette and turbidity determined using a HACH model 2100 Turbidimeter. The turbidimeter is pre-calibrated for the appropriate range using HACH stds.	Approx. 0.1 NTU	A.P.H.A. (1971)
Loss on Ignition (Volatile Residue)	Estimates the amount of volatile organic matter present. Sediment is dried overnight at 105°C. The dried sample is weighed then combusted at 550°C for 1 hr, and reweighed following cooling. LOI = (Wt. 105°C -Wt. 550°C)/Wt. 105°C)	Approx. 0.1 mg/ g sed.	A.P.H.A. (1971)

* Indicates colorimetric method using a spectrophotometer.

individual analysis. Warning limits are established at 1.5 times — and control limits at 3 times — the standard deviations plus or minus the mean slope of the standard regression lines. Laboratory duplicates make up approximately 5% of the total samples analyzed. The TRG laboratories are included in a quality assurance audit program administered by the U.S. Geological Survey, Denver Analytical Laboratory. Periodic audit/reference samples are received from the Denver Lab for determination of the unknown sample concentration. TRG results for these samples are audited by USGS to assure accuracy of analyses.

2.6. Bioassays

A composite sample of 0,3,5,7,11,15 m Lake Tahoe water containing natural phytoplankton assemblages was collected at the TRG's Index Station near Homewood, CA. using Van Dorn bottles, and pre-filtered through 80 μm mesh netting to remove the larger zooplankton. The sample was returned to the laboratory and the bioassay initiated. For elutriate bioassay treatments, 4.5 ml of unfiltered elutriate test supernatant water was added to 445.5 ml of lake water composite water in a 500 ml Erlenmeyer flask. The control for these treatments consisted of 4.5 ml of 0.45 μm filtered lake water added to 445.5 ml of lake composite water. For N and P treatments, an appropriate volume (typically < 1ml) of NH_4NO_3 or Na_2HPO_4 stock solution was added to 450 ml of lake composite water to give the appropriate final N or P treatment concentration; a 450 ml sample of untreated composite water was left as a control. Control and all treatments were triplicated. Cultures were incubated in a Percival incubator under cool-white fluorescent lighting for 6 days at the *in situ* temperature and daylength. *In vivo* fluorescence (live phytoplankton chlorophyll a fluorescence) of cultures was monitored during the bioassay to track changes in algal biomass. *In vivo* fluorescence was measured using a Turner 111 fluorometer fitted with a CS 2-64 filter on the emission side and a CS 5-60 filter over the excitation light (F4T5/CW). Change in *in vivo* fluorescence "d Fluorescence" equated to the fluorescence measured on a particular day minus the fluorescence of the culture at the start of the bioassay (Day 0 fluorescence). The chlorophyll a concentration of each culture was measured at the end of the bioassay using a methanol extraction procedure (see Table 2-2) to estimate biomass. The change in chlorophyll a "d Chlorophyll a" equated to the Day 6 chlorophyll a minus the chlorophyll a in the culture at the start of the bioassay (Day 0 chlorophyll a). The change in pheophytin (a degradation product of chlorophyll) concentration was also determined on Day 6. A treatment was determined to be "stimulatory" if the treatment mean "d Fluorescence" or mean "d Chlorophyll a" was greater than the control mean "d Fluorescence" or mean "d Chlorophyll a" at the $p \leq 0.05$ level of significance.

2.7. Underwater Documentation of Impacts

Characteristics of sediment resuspension produced by the VMI 612 horizontal cutter suction dredge were recorded on video using the TRG's Remotely Operated Vehicle (ROV) underwater camera, and a hand-held video camera. U/W still photos of the VMI 612 were also taken using a 35 mm Nikonos V camera. Post-dredging still photos of all dredge areas were taken using the Nikonos V.

3. Harbor, Marina, and Nearshore Lake Sediments

3.1 General Characteristics of Harbor, Marina and Nearshore Lake Sediments

Embayments, marinas, and harbors present conditions which favor the development of different sediment associations than found in the more exposed nearshore. Natural nearshore sediments typically consist of varied proportions sand, gravel, cobble, and boulders. In some areas, fine-grained sediments, i.e. layers of silts or clay, may underlie these surface sediments. However, few areas of fine-grained surface sediments are found as these materials tend to be transported offshore in Lake Tahoe by wave activity and currents (Osborne et al., 1985). Since harbors and marinas are largely protected from wave activity and turbulence by physical structures, fine as well as coarse particles contained in surface runoff inputs may settle and accumulate on the bottom within a harbor. Bulkheads and other structures may interrupt the movement of currents and sediments along shore and these sediments may also accumulate in the harbor or near the harbor mouth. Organic matter produced by phytoplankton, periphyton, and aquatic plants within harbors also accumulates within the sediments as these organisms die. Further, the addition of nutrients and other contaminants associated either with natural stream inputs or with man's concentrated activities in and around marinas, i.e. boating, fueling, launching, as well as urban runoff, may increase the level of these substances in harbor sediments.

Of concern in this study was the potential impact that disruption of these sediments during dredging would have on lake water quality. Resuspension of sediments by dredging may not only impact lake clarity, but nutrients and contaminants associated with and released from the suspended sediment particles, as well as released from the sediment interstitial (pore) water, may impact lake algal growth. To assess the potential impact of sediment resuspension during dredging, we studied both the levels of total nitrogen and phosphorus in the sediments and the levels of different fractions of nitrogen and phosphorus released during elutriate tests (which simulated the mixing of sediments which occurs during dredging). These analyses included forms thought to be immediately bioavailable to algae and forms which may become available to the algae over time. The effect of the nutrients released on algal growth was later directly tested using algal bioassays. The levels of oil and grease and certain heavy metal contaminants in sediments was also assessed using sediment data provided by Lahontan and TRPA.

3.2 Visual Characterization of Sediments at Study Sites

Several sediment cores were collected from each project site prior to dredging. A general visual characterization of the sediments was first made based on predominant grain size, color, and organic content. The cores were then divided into subsections based on these visual characteristics and chemically analyzed. Grain size distribution of selected core sections was also analyzed. The results for visual classification of the sediment cores are included with the results of chemical analyses in Table 3-1. Some general trends were apparent for the different project sites:

(1) Fleur Du Lac - A large proportion of these sediments consisted of gravel and cobble, while sands and silts were interspersed in smaller proportions throughout the different layers.

(2) Tahoe Keys Lagoons - These sediments consisted primarily of coarse and fine-grained sands. Some distinct layers of organic mud, very compacted sands, and what appeared to be clays were encountered in some but not all cores. Pockets of surface mud and organics occurred in some areas of the lagoons, while in others, surface layers of organics and sand were found. A localized area of very compacted sands was found in the core 2a area. A deep clay layer was found in core 2b. The dredger's logs indicated that layers of clay were encountered while dredging in the area that core 2b was collected as well as in other areas. This layer was found at a depth ranging from 6219-6220 ft. and may have been representative of a fairly uniform layer of clay near the marina as it was encountered frequently as the dredge moved toward the inner marina.

(3) Crystal Shores East - These sediments consisted largely of muddy sands with varying amounts of silt, organic matter, and mica in the layers. A distinct layer of mud with organic debris found at the bottom of cores may represent the mud flow which entered the harbor during flooding in the 1960's. (During the late 1960's, a large mud flow moved across Highway 28 and into the harbor during flooding [Jack Stapleton, Crystal Shores East Association, personal communication].)

(4) Tahoe Boat Co. - Areas of gravel and cobble (2 mm - 256 mm) overlying chunky gray clays were found in the vicinity of some of the floating docks. In deeper portions of the harbor, a fluid ooze (unconsolidated, fine sediments with high water content) of organic and silty material rested over a fluid, gray-colored mud. Gray clay was found at the base of this material.

(5) Tahoe Keys East Channel - Although we did not chemically analyze sediments in these cores (chemical analysis for these sediments was done by Chemax Laboratories, Sparks, NV.), we did visually characterize cores from the East Channel. These sediments tended to

Table 3-1. Results of chemical analysis of dried "raw sediments" and elutriate test supernatant water (both concentration in supernatant, and weight in supernatant per gram sed. shaken are shown). Sediments were collected from (a) Tahoe Keys marina lagoons, (b) Tahoe Boat Co. Marina, (c) Fleur Du Lac, (d) Crystal Shores East harbor, and (e) natural nearshore sites. "Core" indicates the core site designation; "Length" is length of core; "Sect. # & (% of core per sect.)" indicate subsection of core analyzed and percentage of total core length comprising the subsection; "Location in core" is position of subsection where "top" is sediment surface and bottom is deepest section; "pd" is postdredging sample from core site approx. 10 months after dredging; "Visual Charac." is a visual characterization of core where: "g" is gravel, "o" is organic, "sd" is sand, "m" is mud, "cl" is clay, and capitalized letters indicate predominant sediment type; "% < 2 mm" is percent of sediment which passed through a 2mm sieve; "LOI" is Loss On Ignition (an estimate of the organic matter present); "Core Mean" is volume-weighted mean for core. "*" is not measured.

(a) Tahoe Keys lagoons

						RAW SEDIMENT				ELUT. SUPERNAT. CONC.		
Core	Length (cm)	Sect # & (% of core per sect.)	Location in core	Visual Charac.	% <2mm	TN μg/g sed	TP μg/g sed	BAP μg/g sed	LOI mg/g sed	S. Sed. g/l	N03 μg/l	NH4 μg/l
1	89 cm	1-1(5%)	top	goSd	78	300	257	38	4.34	0.36	39	69
		1-2(10%)	upper	oSd	90	280	373	49	11.08	1.56	18	249
		1-3(80%)	mid	gSd	78	100	119	100	6.52	1.48	10	80
		1-4(5%)	bottom	clSd	72	260	296	62	30.50	11.40	82	54
		Core Mean (100%)				136	160	90	8.07	1.93	16	95
2a	25 cm	2a(100%)		oSd	*	130	435	15	6.63	3.29	4	12
2b	53 cm	2b-1(3%)	top	oM	88	850	347	73	34.33	0.40	38	299
		2b-2(15%)	upper	oM	99	815	461	75	34.23	31.75	6	21
		2b-3(72%)	mid	gmSd	70	160	205	77	8.10	5.44	17	74
		2b-4(10%)	bottom	Cl	*	150	419	138	13.43	2.90	9	7
		Core Mean (100%)				278	269	82	13.34	8.98	15	66
3	60 cm	3-1(10%)	upper	oSd	*	290	259	51	14.89	0.35	13	28
		3-2(20%)	upper	Sd	*	180	147	48	6.50	0.30	9	2
		3-4(52%)	bottom	Sd	82	190	64	31	4.39	0.30	8	2
		Core Mean (82%)				200	108	38	6.18	0.31	9	5
pd 1	33 cm	pd1-1 (11%)	top	omSd	98	150	160	21	5.62	0.24	5	3
		pd1-2 (17%)	upper	gSd	*	50	157	10	2.91	0.11	3	0
		pd1-3 (36%)	mid	cgSd	*	90	127	14	2.39	0.22	6	26
		pd1-4 (36%)	bottom	cgSd	*	80	69	22	2.65	0.22	6	81
		Core Mean (100%)				86	115	17	2.92	0.20	5	39
pd 2b	28 cm	pd1-1 (11%)	top	oM	*	310	*	36	11.73	*	*	*
		pd1-2 (44%)	upper	gmSd	*	190	*	53	5.46	*	*	*
		pd1-3 (15%)	lower	omSd	*	310	*	34	13.32	*	*	*
		pd1-4 (15%)	lower	gSd	*	110	*	14	3.04	*	*	*
		pd1-5 (15%)	bottom	Sd	*	100	*	16	6.36	*	*	*
		Core Mean (100%)				196	*	37	7.10	*	*	*

Table 3-1. cont'd. Results of analysis of Tahoe Keys lagoons sediments and elutriate test supernatant.

ELUTRIATE SUPERNATANT CONC. cont'd					AMOUNT IN ELUTRIATE SUPERNATANT PER WT. SED. SHAKEN (wt/wt sed.)								
TKN µg/l	SRP µg/l	BAP µg/l	TRP µg/l	TP µg/l	S.Sed. mg/g	N03 µg/g	NH4 µg/g	TKN µg/g	TN µg/g	SRP µg/g	BAP µg/g	TRP µg/g	TP µg/g
2362	13	73	69	1096	0.98	0.11	0.19	6.45	6.56	0.04	0.20	0.19	2.99
7484	9	67	48	1626	5.15	0.06	0.82	24.72	24.78	0.03	0.22	0.16	5.37
4413	24	261	270	4511	3.77	0.03	0.20	11.23	11.26	0.06	0.66	0.69	11.48
12965	134	684	5930	16561	42.62	0.31	0.20	48.47	48.77	0.50	2.56	22.17	61.91
5045	27	253	521	4654	5.71	0.05	0.26	14.20	14.25	0.08	0.69	1.68	12.97
1749	24	103	406	5175	9.59	0.01	0.03	5.10	5.11	0.07	0.30	1.18	15.08
4711	3	55	25	1069	1.39	0.13	1.04	16.33	16.46	0.01	0.19	0.09	3.71
16966	24	215	866	4520	119.91	0.02	0.08	64.07	64.10	0.09	0.81	3.27	17.07
12495	42	259	573	5757	13.52	0.04	0.18	31.05	31.09	0.10	0.64	1.42	14.31
7090	41	339	1408	6982	11.57	0.04	0.03	28.29	28.33	0.16	1.35	5.62	27.86
12392	38	254	684	5553	28.92	0.04	0.18	35.29	35.33	0.11	0.73	2.08	15.76
1531	13	48	106	1053	1.32	0.05	0.11	5.83	5.88	0.05	0.18	0.40	4.01
1153	9	57	78	721	0.78	0.02	0.01	3.01	3.04	0.02	0.15	0.20	1.88
2392	5	46	37	658	0.68	0.02	0.00	5.35	5.37	0.01	0.10	0.08	1.47
1985	7	49	55	722	0.78	0.02	0.02	4.84	4.86	0.02	0.12	0.15	1.88
744	5	25	134	566	0.64	0.01	0.01	1.99	2.00	0.01	0.07	0.36	1.51
386	8	27	142	422	0.30	0.01	0.00	1.04	1.05	0.02	0.07	0.38	1.13
349	10	34	281	756	0.65	0.02	0.08	1.03	1.05	0.03	0.10	0.83	2.23
445	8	38	294	717	0.70	0.02	0.26	1.41	1.43	0.03	0.12	0.93	2.28
433	8	33	246	664	0.61	0.02	0.12	1.27	1.29	0.02	0.10	0.74	1.98
*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 3-1 cont'd. Results of chemical analysis of Tahoe Boat Co. marina sediments and elutriate test supernatant.

(b) Tahoe Boat Co. Collected 6/28/94

Core	Length (cm)	Sect # & (% of core per sect.)	Location in core	Visual Charac.	% <2mm	RAW SEDIMENT TN µg/g sed	TP µg/g sed	BAP µg/g sed	LOI mg/g sed	ELUT. SUPERNAT. CONC. S. Sed. g/l	NO3 µg/l	NH4 µg/l
1	15 cm	1-1(50%)	top	gcsd	*	230	540	67	17.32	0.40	7	140
		1-2(50%)	bottom	Cl	*	170	857	60	31.72	NES	11	433
		Core Mean (100%)				200	699	64	24.52	*	9	287
2	7.5cm	2-1(100%)	top	gcCl	*	180	1122	39	31.34	NES	7	1
3a	34 cm	3a-1(63%)	top	oM	100	2140	848	242	69.45	1.29	8	2344
		3a-2(22%)	mid	M	100	670	973	127	41.36	1.41	12	3177
		3a-3(15%)	bottom	Cl	100	270	974	50	34.27	0.21	6	1762
		Core Mean (100%)				1536	894	188	57.99	1.15	9	2440

Table 3-1. Results of chemical analysis of Fleur Du Lac sediments and elutriate test supernatent.

(c) Fleur Du Lac

Core	Length (cm)	Sect # & (% of core per sect.)	Location in core	Visual Charac.	% <2mm	RAW SEDIMENT TN µg/g sed	TP µg/g sed	BAP µg/g sed	LOI mg/g sed	ELUT. SUPERNAT. CONC. S. Sed. g/l	NO3 µg/l	NH4 µg/l
1	46 cm	1-1(17%)	top	oG	17	230	677	149	9.27	0.17	410	6
		1-2(17%)	upper	sdG	31	130	1058	59	8.65	0.06	352	3
		1-3(17%)	mid	mCG	12	160	849	113	7.29	0.05	42	22
		1-4(17%)	mid	mCG	10	230	2040	128	12.38	0.18	37	0
		1-5(17%)	lower	sdG	28	140	760	111	6.25	0.11	74	0
		1-6(17%)	bottom	msdG	29	160	580	92	11.89	0.20	25	9
		Core Mean (100%)				175	996	109	9.31	0.13	157	7
2	25 cm	2-1(50%)	top	CG	1	*	580	65	7.79	0.00	11	5
		2-2(50%)	bottom	sdG	15	70	436	25	9.51	0.07	3	1
		Core Mean (100%)				*	508	45	8.65	0.04	7	3
3a	22 cm	3a-1(29%)	top	omgSd	64	110	687	54	9.54	0.14	8	5
		3a-2(71%)	bottom	sdG	35	90	870	57	6.90	0.09	10	1
		Core Mean (100%)				96	817	56	7.66	0.10	9	2
3b	23 cm	3b-1(33%)	top	osdG	41	110	843	65	7.77	0.07	57	0
		3b-2(67%)	bottom	gSd	53	70	844	54	11.37	0.11	4	1
		Core Mean (100%)				83	844	58	10.18	0.10	21	1
pd1a	36 cm	pd1a-1(25%)	top	omSd	*	1380	553	188	100.47	0.92	10	248
		pd1a-2(25%)	upper	omSd	*	1240	574	240	60.36	3.24	9	514
		pd1a-3(25%)	lower	osdM	*	970	840	203	50.88	2.19	10	804
		pd1a-4(25%)	bottom	oM	*	580	590	149	36.72	5.88	23	968
		Core Mean (100%)				1043	639	195	62.10	3.06	13	634
pd1b	34 cm	pd1b-1(55%)	top	osdM	95	1530	560	217	97.56	1.08	8	510
		pd1b-2(45%)	bottom	M	100	760	747	161	42.14	5.45	19	856
		Core Mean (100%)				1184	644	192	72.62	3.05	13	666
pd2	9 cm	pd2-1(100%)	top	sdCG	*	150	*	33	15.08	0.00	4	6

Table 3-1. cont'd. Results of chemical analysis of Tahoe Boat Co. marina sediments and elutriate test supernatant.

ELUTRIATE SUPERNATANT CONC. cont'd					AMOUNT IN ELUTRIATE SUPERNATANT PER WT. SED. SHAKEN (wt/wt sed.)								
TKN µg/l	SRP µg/l	BAP µg/l	TRP µg/l	TP µg/l	S.Sed. mg/g	N03 µg/g	NH4 µg/g	TKN µg/g	TN µg/g	SRP µg/g	BAP µg/g	TRP µg/g	TP µg/g
873	8	36	*	1040	1.17	0.02	0.41	2.55	2.57	0.02	0.11	*	3.04
711	*	*	*	574	*	0.05	1.89	3.10	3.15	*	*	*	2.50
792	*	*	*	807	*	0	1	3	2.86	*	*	*	3
285	33	*	*	367	*	0.03	0.00	1.13	1.16	0.13	*	*	1.45
19310	4	57	688	5005	12.39	0.08	22.51	185.46	185.53	0.04	0.55	6.61	48.07
5242	7	36	1500	4057	10.51	0.09	23.69	39.09	39.18	0.05	0.27	11.18	30.25
2123	5	15	146	358	1.03	0.03	8.67	10.45	10.48	0.02	0.07	0.72	1.76
13637	5	46	785	4099	10.27	0.07	20.70	127.00	127.08	0.04	0.42	6.73	37.20

Table 3-1. cont'd. Results of chemical analysis of Fleur Du Lac sediments and elutriate test supernatant.

ELUTRIATE SUPERNATANT CONC. cont'd					AMOUNT IN ELUTRIATE SUPERNATANT PER WT. SED. SHAKEN (wt/wt sed.)								
TKN µg/l	SRP µg/l	BAP µg/l	TRP µg/l	TP µg/l	S.Sed. mg/g	N03 µg/g	NH4 µg/g	TKN µg/g	TN µg/g	SRP µg/g	BAP µg/g	TRP µg/g	TP µg/g
1368	2	19	32	611	0.47	1.16	0.02	3.85	5.01	0.01	0.05	0.09	1.72
686	1	19	11	261	0.16	0.97	0.01	1.90	2.87	0.00	0.05	0.03	0.72
638	2	14	44	537	0.13	0.11	0.06	1.68	1.79	0.01	0.04	0.12	1.42
822	2	32	119	882	0.32	0.07	0.00	1.47	1.54	0.00	0.06	0.21	1.58
631	3	19	48	579	0.25	0.17	0.00	1.42	1.59	0.01	0.04	0.11	1.31
990	5	41	96	1140	0.23	0.03	0.01	1.15	1.18	0.01	0.05	0.11	1.33
858	3	24	58	670	0.26	0.42	0.02	1.92	2.34	0.00	0.05	0.11	1.35
110	1	0	5	67	0.00	0.03	0.01	0.29	0.32	0.00	0.00	0.01	0.18
263	5	5	39	216	0.18	0.01	0.00	0.68	0.69	0.01	0.01	0.10	0.56
187	3	3	22	142	0.09	0.02	0.01	0.49	0.50	0.01	0.01	0.06	0.37
901	9	21	68	794	0.30	0.02	0.01	1.95	1.97	0.02	0.05	0.15	1.72
317	6	7	55	429	0.24	0.03	0.00	0.87	0.89	0.02	0.02	0.15	1.17
486	7	11	59	535	0.25	0.02	0.01	1.18	1.21	0.02	0.03	0.15	1.33
539	15	14	65	386	0.19	0.15	0.00	1.43	1.58	0.04	0.04	0.17	1.03
1297	8	12	35	330	0.31	0.01	0.00	3.65	3.66	0.02	0.03	0.10	0.93
1047	10	12	45	348	0.27	0.06	0.00	2.92	2.97	0.03	0.03	0.12	0.96
7859	18	108	803	1918	4.80	0.05	1.29	40.98	41.03	0.09	0.56	4.19	10.00
24134	24	397	3375	13703	13.36	0.04	2.12	99.51	99.54	0.10	1.64	13.92	56.50
10458	8	171	2053	4455	9.55	0.04	3.50	45.58	45.63	0.03	0.75	8.95	19.42
17386	26	379	6330	18977	21.40	0.08	3.52	63.27	63.35	0.09	1.38	23.03	69.05
14959	19	264	3140	9763	12.27	0.05	2.61	62.33	62.39	0.08	1.08	12.52	38.74
6335	66	115	694	2052	5.88	0.04	2.78	34.50	34.55	0.36	0.63	3.78	11.18
19012	54	418	5862	17859	20.06	0.07	3.15	69.96	70.03	0.20	1.54	21.57	65.72
12040	61	251	3020	9165	12.26	0.06	2.95	50.46	50.52	0.29	1.04	11.79	35.72
390	*	13	27	1109	0.00	0.01	0.01	0.62	0.63	*	0.02	0.04	1.77

Table 3-1 cont'd. Results of chemical analysis of Crystal Shores East sediments and elutriate test supernatant.

(d) Crystal Shores East

Core	Length (cm)	Sect # & (% of core per sect.)	Location in core	Visual Charac.	% <2mm	RAW SEDIMENT TN µg/g sed	TP µg/g sed	BAP µg/g sed	LOI mg/g sed	ELUT. SUPERNAT. CONC. S. Sed. g/l	NO3 µg/l	NH4 µg/l
1	72 cm	1-1 (17%)	top	osdM	*	570	326	22	30.39	0.44	64	174
		1-2 (13%)	upper	oM	*	690	675	55	62.56	0.95	636	745
		1-3 (13%)	mid	oM	*	840	1209	176	76.87	5.42	16	525
		1-4 (38%)	bottom	gmSd	81	290	247	100	19.10	6.54	38	317
		Core Mean (81%)				501	487	88	37.72	4.18	136	389
2	45 cm	2-1 (11%)	top	gmSd	88	210	423	36	7.12	0.12	55	171
		2-2 (26%)	upper	sdM	100	375	326	23	19.67	0.59	14	3047
		2-3 (26%)	lower	osdM	*	760	608	54	42.82	0.10	10	2073
		2-4 (26%)	bottom	M	99	645	584	118	49.23	4.81	39	762
		Core Mean (89%)				546	496	61	33.52	1.62	25	1739
3	50 cm	3-1 (37%)	top	gmSd	88	130	291	32	8.98	0.30	11	406
		3-2 (28%)	mid	mSd	*	200	349	44	22.77	0.36	14	669
		3-3 (22%)	lower	mSd	*	165	319	39	23.47	0.16	7	707
		3-4 (8%)	bottom	osdM	*	270	607	72	34.75	0.64	11	622
		Core Mean (95%)				171	341	41	18.57	0.31	11	571
pd1b	5 cm	1b-1 (100%)	top	mSd	96	280	440	67	19.44	2.97	38	4
pd2	5 cm	2-1 (100%)	top	sdM	97	300	411	85	21.50	1.40	27	87

Table 3-1 cont'd. Results of chemical analysis of natural nearshore surface sediments and elutriate test supernatant. Where "Hwd" is Homewood Beach; "KgB" is Kings Beach; "RgB" is Regan Beach; "VaB" is Valhalla Beach.

(e) Natural Nearshore Sediments Collected 7/18/94

Core	Length (cm)	Sect # & (% of core per sect.)	Location in core	Visual Charac.	% <2mm	RAW SEDIMENT TN µg/g sed	TP µg/g sed	BAP µg/g sed	LOI mg/g sed	ELUT. SUPERNAT. CONC. S. Sed. g/l	NO3 µg/l	NH4 µg/l
Hwd	7.5cm	Hwd (100%)	top	csdG	5	230	663	51	5.95	0.07	6	79
KgB	3.8cm	KgB (100%)	top	Sd	*	100	294	0	2.82	0.01	8	25
RgB	5cm	RgB (100%)	top	Sd	*	160	48	0	4.74	0.39	12	75
VaB	7.5cm	VaB (100%)	top	gSd	*	150	94	4	5.74	0.08	8	15

Table 3-1 cont'd. Results of chemical analysis of Crystal Shores East sediments and elutriate test supernatant.

ELUTRIATE SUPERNATANT CONC. cont'd					AMOUNT IN ELUTRIATE SUPERNATANT PER WT. SED. SHAKEN (wt/wt sed.)								
TKN µg/l	SRP µg/l	BAP µg/l	TRP µg/l	TP µg/l	S.Sed. mg/g	N03 µg/g	NH4 µg/g	TKN µg/g	TN µg/g	SRP µg/g	BAP µg/g	TRP µg/g	TP µg/g
2833	*	9	29	794	1.46	0.21	0.58	9.47	9.69	*	0.03	0.10	2.66
7766	46	50	74	1813	4.30	2.89	3.38	35.25	38.14	0.21	0.23	0.34	8.23
23488	44	507	1913	10624	29.91	0.09	2.90	129.63	129.72	0.24	2.80	10.56	58.64
22282	57	610	3163	12187	22.06	0.13	1.07	75.17	75.30	0.19	2.06	10.67	41.11
16064	*	378	1809	7880	16.15	0.58	1.63	63.71	64.30	*	1.46	6.77	30.58
1547	*	0	8	362	0.38	0.17	0.54	4.91	5.09	*	0.00	0.03	1.15
8647	4	10	11	1233	2.26	0.05	11.65	33.06	33.11	0.02	0.04	0.04	4.71
3015	2	11	16	191	0.46	0.05	9.60	13.96	14.01	0.01	0.05	0.07	0.88
19025	64	420	1625	8975	17.71	0.14	2.81	70.04	70.18	0.24	1.55	5.98	33.04
9156	*	129	484	3083	6.02	0.09	7.09	34.81	34.90	*	0.48	1.78	11.43
2637	4	9	51	638	0.96	0.04	1.31	8.50	8.53	0.01	0.03	0.16	2.06
1309	16	21	48	769	1.43	0.06	2.64	5.16	5.21	0.06	0.08	0.19	3.03
571	3	9	68	325	0.56	0.02	2.49	2.01	2.03	0.01	0.03	0.24	1.14
3498	2	57	126	1389	2.18	0.04	2.13	11.99	12.02	0.01	0.20	0.43	4.76
1840	7	17	60	667	1.11	0.04	2.04	6.30	6.34	0.03	0.06	0.21	2.36
5909	23	218		5736	9.01	0.12	0.01	17.92	18.03	0.07	0.66	*	17.39
4116	24	101		2511	4.36	0.08	0.27	12.80	12.89	0.07	0.31	*	7.81

Table 3-1 cont'd. Results of chemical analysis of natural nearshore surface sediments and elutriate test supernatant.

ELUTRIATE SUPERNATANT CONC. cont'd					AMOUNT IN ELUTRIATE SUPERNATANT PER WT. SED. SHAKEN (wt/wt sed.)								
TKN µg/l	SRP µg/l	BAP µg/l	TRP µg/l	TP µg/l	S.Sed. mg/g	N03 µg/g	NH4 µg/g	TKN µg/g	TN µg/g	SRP µg/g	BAP µg/g	TRP µg/g	TP µg/g
323	4	0	*	169	0.15	0.01	0.17	0.71	0.73	0.01	0.00	*	0.37
365	3	65	*	70	0.03	0.02	0.07	0.98	1.00	0.01	0.17	*	0.19
5501	4	0	*	1209	*	*	*	*		*	*	*	*
1097	8	0	*	448	0.20	0.02	0.04	2.75	2.77	0.02	0.00	*	1.12

be sandy with some areas enriched in silt/clay-size particles. Within the section of channel confined by bulkheads (the channel is confined by metal bulkheads between the Tahoe Keys lagoons and the backshore of Lake Tahoe near the high water mark, outside of these bulkheads the channel is cut into Lake Tahoe lake sediments), an area high in fine-particle-size fractions and organic material in addition to sands was found. Some distinct layers enriched in mica, or material that appeared to be clay were also found.

Grain size analysis prior to dredging was required by the regulatory agencies for core samples from Tahoe Keys East Channel and Tahoe Keys lagoons. This data was made available to us by Lahontan (Appendix A-14). We also performed some size separations on selected sub-samples from Tahoe Keys Lagoons, Crystal Shores East, Fleur Du Lac, and Tahoe Boat Co. (Appendix A-13). Representative examples of grain size analysis from the data are presented in Table 3-2. In general, a wide range of sediment types were detected in the marina and harbor cores. Fleur Du Lac Core Section 1-6, which was fairly representative of Fleur Du Lac harbor dredge sediments was the most different from the other marina sites with a large proportion (71%) of gravel and cobble particles, only a moderate to low amount of sand (28%), and almost no silt and clay (1%). Tahoe Keys outer channel and lagoon sediments tended to have large proportions of sand, 84% and 86%, respectively. Marina sediments at the Tahoe Boat Co. and Tahoe Keys channel in the bulkhead area had significant portions of silt and clay size particles, 44% and 35%, respectively. Grain size distribution may also vary vertically within the sediments. Crystal Shores East Core Section 2-4 was located deeper within the same core as Section 2-2, and had a higher proportion of silt and clay sediments (20%) compared to Section 2-2 (2%).

The predominant particle sizes present at a site and the degree of consolidation are important factors in determining appropriate dredging methods. Of critical concern in this study were the levels of nutrients associated with these varied sediments, which could potentially be released to the water column during dredging. Certain sediment types such as clays and organics have the potential to bind significant amounts of certain nutrients and other contaminants. Clays, once resuspended, may remain in the water column for long periods of time, and nutrients attached to the clay particles may be subject to physico-chemical changes and/or biological utilization. Section 3.3 briefly reviews factors which may affect nutrient adsorption and release from the sediments. This is followed by a discussion of the nutrient and contaminant content of sediments from the Lake Tahoe study sites.

Table 3-2. Examples of grain size percentages found in selected marina, harbor, and channel sediments. The cobble and gravel fraction was sediment retained on a 2 mm sieve; the sand fraction was sediment passing a 2 mm sieve and retained on either a 63 μm sieve (TRG data) or a 70 μm sieve (Chemax data); the silt and clay fraction was sediment passing either a 63 μm sieve (TRG data) or a 70 μm sieve (Chemax data). "Chemax data" was collected and analyzed by Chemax Laboratories, Sparks, Nev., as part of predredging substrate analyses required by Lahontan and TRPA.

Core Sample	Sampling Date	Site-Sect	% Cobble + Gravel	% Sand	% Silt+Clay
T. Keys E. Channel Inside Bulkhead [1]	7/8/92	#1	1%	64%	35%
T. Keys E. Channel Outside Bulkhead[1]	7/8/92	#4	1%	84%	15%
T. Keys Lagoons [1]	6/25/92	#1	8%	86%	6%
Fleur Du Lac Inside Harbor [2]	8/9/93	#1-6	71%	28%	1%
Crystal Shores East Harbor [2]	9/29/93	#2-2	0%	98%	2%
Crystal Shores East Harbor [2]	9/29/93	#2-4	1%	79%	20%
T. Boat Co. Inside Harbor [2]	6/28/94	#3b,c	0%	56%	44%

1 Collection and analysis by Chemax Labs, Sparks, NV.
2 Collection and analysis by TRG.

3.3 Properties of Aquatic Sediments Which Influence Nutrient Adsorption and Release

Several important factors influence the ability of sediments to bind nutrients. These include sorption properties, pH, redox potential, clay and humic content, and presence of hydrous oxides and sulfides.

Nutrients may become attached to sediment particles through the processes of adsorption and chemosorption. Adsorption is a reversible physical binding of soluble substances on particle surfaces in constant equilibrium with solute concentration. As solute concentration in the aqueous medium increases, the amount of substance adsorbed to particle surfaces increases. Chemosorption is chemical binding (e.g. ionic bonding) of substances to the particles which is not reversible at constant pH and redox potential (Boström et al.,1982).

The redox potential is a measure of the oxidation-reduction status of a system. It is measured in millivolts, with redox potentials of +500 mv or greater representing oxidizing conditions and redox potentials of -250 mv or lower representing extreme reducing conditions. This is an important property of sediments which plays a role in regulating the behavior of contaminants in the sediments. For instance, metal cations will be tightly bound to some clay minerals when the redox is low and the pH is high, whereas they will be released from the sediments when the redox is high and the pH is low. When sediments of low redox potential are disrupted in Lake Tahoe during dredging, they may become oxidized as they are mixed into the highly oxygenated waters of Lake Tahoe. Soluble and chemically reduced forms of iron released by the dredging may oxidize to insoluble iron oxides which precipitate out of solution. Soluble phosphorus present in the reduced sediments may also coprecipitate out of solution with iron oxides as conditions become oxidizing. The eventual disposal of dredged material at land disposal sites may cause changes in the redox potential of the sediments and affect nutrient and contaminant release to the surrounding land. For instance, sediments removed by dredging and disposed of at a landfill site may gradually oxidize as they dry out. If the pH drops below about 6.5 in these sediments, metal cations may begin to be released to the surrounding land. This may pose a problem where there are high levels of heavy metals in the sediments. (However, heavy metal levels in Tahoe sediments are usually very low, see Section 3.5.1).

The pH of sediments or surrounding water also plays an important role in adsorption of charged particles to sediments. Low pH tends to cause desorption of metals from mineral surfaces and humus. High pH promotes adsorption to these substances. The sorptive behavior of phosphorus with changing pH is somewhat more complicated. High pH may increase phosphate coprecipitation with calcium carbonate, but increase the solubility of certain metal phosphate complexes. Lowered pH levels (ca. 5-6) favor high adsorption of phosphate by clays and decreased solubilities of certain metal phosphate complexes (Wetzel, 1975).

The amount of clay and humus present in the sediment are important to the nutrient binding capacity of the sediment. Clay particles are extremely small (0.01-2 μm), which means that there are large numbers of particles per unit weight and that individual particles have large external surface areas. Certain clays also have large internal surface areas available for binding substances. Table 3-3 demonstrates the large surface area of clays relative to other sediment types. Clay particles are highly chemically reactive. Negative charges associated with the surfaces of clays attract and hold large numbers of positive ions such as ammonia (NH_4^+) and heavy metal cations. Phosphate (PO_4^{-3}) anions, which are negatively charged, may bind to the edges of the clay or substitute for silicate in the clay structure (Wetzel, 1975).

Due to their small size, clay particles can remain suspended in the water column for long periods of time. This is important for dispersal to different areas of the lake and potential for utilization of nutrients bound on the clay by algae and bacteria.

Humus is a heterogeneous organic mixture in sediments composed largely of products resulting from microbial and chemical transformations of organic matter. It is a very active agent in the binding of pollutants and metal cations. Humic substances may form complex compounds with clays and hydrous oxides that have enhanced binding capabilities for toxic metals and toxic organics (Cullinane et al., 1990).

Sediments also contain colloidal minerals known as hydrous oxides of iron and manganese. The iron oxides occur in almost all sediments where they can cause some distinctive red or yellow coloration. The iron oxides have adsorption sites for various cations and anions including trace metals and phosphate. Under reducing (anoxic) conditions, a significant fraction of iron oxides become reduced and soluble, resulting in desorption of trace metals and phosphorus. In oxidizing conditions, hydrates of iron are formed which may bind trace metals and phosphate by coprecipitation or sorption.

Under reduced conditions, forms of sulfur known as sulfides combine with metals to form relatively stable insoluble complexes, e.g. FeS. Metal sulfides are exceedingly insoluble at neutral or alkaline pH. Oxidation of FeS produces (Fe^{+2}) which itself can be oxidized and form insoluble (Fe^{+3}) oxide which complexes with metals and phosphate. Under some conditions, oxidation of sulfides to sulfate may result in the formation of weak sulfuric acid and acidic soil conditions. Such conditions may develop as dredge spoils are disposed of on land, dry out and oxidize (Cullinane et al., 1990). Under these acidic conditions, metals may be mobilized. When significant levels of metal contaminants are in the sediments, this may pose a contamination problem.

Table 3-3. Total surface areas (m^2) per gram of different grain-sized sediments.

Sediment Type	Surface Area (m^2/dry gram of material)		
	External	Internal	Total
Coarse Sand	0.0023	0	0.0023
Fine Sand	0.0091	0	0.0091
Silt	0.0454	0	0.0454
Clay	47	753	800

(Table from Cullinane et al., 1990)

Temperature can also be an important factor influencing the rate at which chemical and biologically mediated reactions occur. As temperature increases, the rates of chemical and biological reactions also increase.

3.4. Nutrient Concentrations in Marina and Harbor Area Sediments

Table 3.1 presents the results for all chemical analyses done on predredging core sections collected from all sites, as well as follow-up samples collected from dredged areas approximately 10 months later. Also included are some nearshore sediment samples from areas located well away from marinas and harbors.

3.4.1. Total Nitrogen, Phosphorus, and Organic Content of Raw Sediments

Dried, 2 mm-sieved core sections were analyzed for total, raw sediment constituents including Total Nitrogen "TN" (NO_3-N + TKN), Total Phosphorus "TP" (persulfate extractable), and Biologically Available Phosphorus "BAP". Organic matter in unsieved-sediment samples was determined by measuring the weight loss upon ignition "LOI" at 550°C. The results are presented in Table 3-1. A portion of these constituents may be released to the water column during dredging — both as soluble and particulate forms of N and P. The magnitude of release will not necessarily be proportional to the total concentration present in the sediments. Factors including dredge type, dredging methods, proportions of fine-grained particles, water turbulence at or near the bottom, and the physico-chemical factors which are described in Section 3.3 all may have an impact on ultimate levels released to the water column.

Considerable variability was observed in sediment TN, TP, BAP, and organic matter among harbors, among sites at a harbor, and vertically within cores. The following presents a summary of observations from the data for each raw sediment constituent.

3.4.1.1. Total Nitrogen in Raw Sediments

Individual core section TN values ranged from 70 $\mu g/g$ sed. dry wt. for the particles < 2 mm in the largely gravel and cobble sediments outside Fleur Du Lac harbor to 2140 $\mu g/g$ in organic mud within the Tahoe Boat Co. harbor. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for TN were: median = 210 $\mu g/g$; 10th percentile = 106 $\mu g/g$; 90th percentile = 782 $\mu g/g$; n=41. Within individual cores, distinct layers high in TN were occasionally found, and these high TN layers were often visually characterized as having a large organic mud component (where mud describes sediments of predominantly silt and clay size particles). For instance, the upper layers of organic mud in Tahoe Keys Core 2b - (Sections 1 and 2), had high TN (850 μg/g and 815 μg/g, respectively), while the lower layers of gravel-sand and clay, Core 2b - (Sections 3 and 4), had low TN (160 μg/g and 150 μg/g, respectively). High TN levels were also found in organic muddy layers at Crystal Shores East (Core Section 1-1 [570 μg/g], Section 1-2 [690 μg/g], Section 1-3 [840 μg/g], Section 2-3 [760 μg/g]). TN was associated with organic matter as estimated by LOI (r^2=0.57)[1] in the sediments reflecting an often high proportion of organic nitrogen. However, TN was not associated with BAP (r^2=0.06) or TP (r^2=0.003) in the raw sediments.

3.4.1.2. Total Phosphorus in Raw Sediments

Individual core section TP values ranged from 64 μg/g in a bottom layer of sand from Tahoe Keys lagoons to 2040 μg/g in mud found associated with gravel and cobble within the Fleur Du Lac harbor. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for TP were: median = 560 μg/g; 10th percentile = 234 μg/g; 90th percentile = 999 μg/g; n=42. Distinct layers of high TP were found in some core sections. Sediment layers characterized as having a clay fraction often had a high TP concentration. For instance, high TP levels were found in Tahoe Boat Co. Core Section 1-2 [857 μg/g], Section 2-1 [1122 μg/g], Section 3-3 [974 μg/g], and Tahoe Keys lagoons Core Section 2b-4 [419 μg/g]. High TP was also associated with some muddy sediments. This is consistent with our findings that the smallest grain size particles, e.g. silt and clay size particles, have greater amounts of TP associated with them than larger sand size particles. TP showed some association to organic matter LOI (r^2=0.43) reflecting the presence of organic P. TP showed little association with raw sediment BAP (r^2=0.17) and TN (r^2=0.003).

3.4.1.3. Biologically Available Phosphorus in Raw Sediments

Individual core section BAP values ranged from 15 μg/g for particles less than 2 mm in the largely gravel and cobble sediments outside Fleur Du Lac harbor to 242 μg/g in

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1- The degree of association between various chemical constituents in the raw sediments and among chemicals in the elutriate test supernatant solution was evaluated using correlation analysis. All predredging sediment data was used for testing the association among raw sediment TN (single high outlier excluded), TP, and BAP; and for testing associations among chemicals in the elutriate test supernatant (a single high suspended sediment outlier excluded). Since gravel and cobble were not included in analysis of raw sediment TN, TP, and BAP (but were included in elutriate and LOI tests), tests for the degree of correlation between raw sediment TN, TP, and BAP and either raw sediment LOI or elutriate supernatant nutrients were limited to samples which were predominantly less than 2 mm in diameter (e.g. samples with greater than 80% sand + silt + clay, or if not sieved, visually identified as consisting predominantly of sand and smaller particles).

organic mud within the Tahoe Boat Co. harbor. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for BAP were: median = 60 μg/g; 10th percentile = 29 μg/g; 90th percentile = 131 μg/g; n=42. Some distinct layers high in BAP were found, however, there was no obvious association of high BAP with any one type of sediments based on visual classification. High BAP was found associated with some clays, mud, or gravel-sand associations. Surprisingly, BAP showed little relationship to TP in the <u>raw sediments</u> (r^2=0.17). BAP ranged from 3-84% of sediment TP (median = 12.5%; 10th percentile = 5.7%; 90th percentile = 34.3%; n = 42). Research done on other lake systems has also found BAP to be a variable proportion of TP in the sediments. For instance, Williams et al. (1980) found the BAP portion of TP to range from 8-50% in soil or sediment samples from Lakes Ontario and Erie and their tributary streams. Ellis and Stanford (1988) found NaOH extractable BAP to range from 2-14% of TP in stream bank and fluvial sediments of streams entering Flathead Lake, Montana.

3.4.1.4. Organic Matter in Raw Sediments

The amount of organic matter in the sediments was estimated by combusting dried sediments at 550°C and measuring the weight loss on ignition "LOI". LOI values ranged from 4.34 mg/g sediment (or 0.4%) in sandy sediments at Tahoe Keys Lagoons to 76.87 mg/g sediment (or 7.7%) in sandy mud at Crystal Shores East. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for LOI were: median = 12.91 mg/g or 1.3%; 10th percentile = 6.51 mg/g or 0.7%; 90th percentile = 44.74 mg/g or 4.5%; n=42. Distinct layers of high organic matter were found in some sediments. Layers visually identified as being muddy often tended to have highest concentrations of organic matter. As indicated above, LOI was associated with TN (r^2=0.57) and TP (r^2=0.43), reflecting the presence of organic N and P. LOI also showed some association with BAP (r^2=0.48), perhaps reflecting an association of hydrous-oxide-bound-P to humic material in the sediments.

The amount of organic matter in sediments is of significance because high levels of organics may increase the abilities of sediment to bind metals and other environmental pollutants. Humic organic compounds are very active agents in the binding of pollutants and metal cations. Humic substances may form complex compounds with clays and hydrous oxides that have enhanced binding capabilities for toxic metals and toxic organics (Cullinane et al., 1990). It appears from our studies that Tahoe sediments with higher LOI may bind more BAP.

3.4.1.5. Particle Size vs. Sediment Nutrient Content

Smaller particles, particularly clays, have a large potential to bind nutrients, metals, and other contaminants due to their large surface areas relative to mass. We evaluated the levels of TN and TP associated with various-sized fractions of core sediments. Raw sediment TP and TN in the medium to coarse sand fraction (< 2 mm and > 250 μm), the fine to very fine sand fraction (< 250 μm and > 63 μm), and the silt and clay fraction (< 63 μm) was determined. The results of these analyses are reported in Table 3-4.

The results of these analyses confirm that the silt + clay fraction can contain higher concentrations of TP than other size fractions. Concentrations of individual samples in the silt/clay fraction ranged from about 2-10 times the concentration in the medium to coarse sand fraction. The ratio of TP for silt + clay (mean = 1183 μg/g), fine-very fine sand (mean = 621 μg/g) and medium-coarse sand (mean = 338 μg/g) was 2 : 1 : 0.5. There was little difference between the TN content of medium-coarse and fine to very fine sand. While TN was somewhat elevated in the silt + clay fraction, the sample size was small (n = 5) with a single large value. This was most likely the result of a predominance of nitrogen bound in organic matter which may occur in all size classes. This is in contrast to phosphorus, which although it too is bound in organic matter, is bound to a significant extent by inorganic sediments.

3.4.2. Soluble Inorganic Nutrients in Elutriate

An elutriate test was used to determine the amounts of soluble nutrients which might be leached from the sediments during dredging. The amounts of soluble NO_3-N, NH_4-N and SRP in the elutriate represented inorganic forms present in the sediment interstitial water or loosely bound (adsorbed) to the sediments which were easily removed during agitation in lake water. Similar release may occur to a lesser or greater extent during dredging as sediments are disrupted and mixed into the water column. The elutriate test data are presented in Table 3-1 both as concentration of soluble constituent in the elutriate solution (μg/l) and weight of constituent normalized to dry weight of sediment originally shaken (μg/g sediment shaken).

Similar to the variability observed in total raw sediment constituents, sediments collected within and in the vicinity of harbors exhibited high variability in soluble constituents in elutriate water from individual core layers. High concentrations of soluble inorganic nutrients were found to be sporadic and associated with discreet layers in the sediments. For instance, in Tahoe Keys lagoons core C-1 a layer of high NH_4-N (249 μg/l) was associated with a sandy organic layer just below the surface (Core Section 1-2) while high SRP (134 μg/l) was associated with the bottom clay-sand layer. The remaining

Table 3-4. Levels of TN and TP ($\mu g/g$) in sand and silt/clay size fractions of sediments from areas inside or immediately outside of harbors. Medium to coarse sand included particles < 2 mm and > 250 μm; very fine sand included particles < 250 μm and > 63 μm; silt and clay included particles < 63 μm; sand included all particles <2 mm and > 63 μm.

Core Site	Section	Medium - Coarse Sand		Fine - Very Fine Sand		Silt + Clay	
		TN	TP	TN	TP	TN	TP
T. Keys Lagoons	1-3	60	207	120	367	*	1200
T. Keys Lagoons	1-4	180	111	270	336	*	967
T. Keys Lagoons	2b-2	620	489	680	453	*	898
T. Keys Lagoons	2b-3	90	84	300	496	90	979
Crystal Sh. E.	2-2	460	290	310	752	*	1633
Crystal Sh. E.	2-4	1340	550	390	1255	810	1593
Fleur Du Lac	1-6	180	452	140	704	*	937
Fleur Du Lac	3b-2	70	517	*	604	*	1122

Core Site	Section	Sand		Silt + Clay	
		TN	TP	TN	TP
Crystal Sh. E.	3-1	*	206	*	1614
Tahoe Boat Co.	3a-1	2290	755	2360	960
Tahoe Boat Co.	3a-2	660	946	690	1014
Tahoe Boat Co.	3a-3	270	974	280	1275

sections in this core had NH_4-N less than 100 μg/l and SRP less than or near 25 μg/l. The other constituents also showed a large degree of variability within this core. Variation was also observed among different cores at a harbor and between harbors. The following presents a summary of observations from the data for each soluble elutriate supernatant constituent.

3.4.2.1. Elutriate NO_3-N

NO_3-N released from individual core sections to the elutriate solution ranged from 0.01 μg/g sediment shaken in certain sand samples from Tahoe Keys and sandy gravels at Fleur Du Lac to 2.89 μg/g from a organic mud layer at Crystal Shores East. The resulting range of concentrations in elutriate solutions was from 3 μg/l to 636 μg/l. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate NO_3-N release (μg/g shaken) were: median = 0.05; 10th percentile = 0.02; 90th percentile = 0.24; n=42. While median, 10th percentile, 90th percentile, n values for elutriate NO_3-N concentration (μg/l) were: median = 13; 10th percentile = 6; 90th percentile = 76; n=42. Within individual cores, distinct layers released large amounts of NO_3-N and resulted in high elutriate NO_3-N concentrations. These high NO_3-N concentrations did not appear to be associated with any one set of visually identified physical characteristics. However, often these sediments were from the upper layers of the cores, which may indicate the NO_3-N was originally produced by nitrification in sediments where adequate oxygen was available. Gravel layers produced high NO_3-N concentrations in Fleur Du Lac Core Section 1-1 [410 μg/l] and Section 1-2 [352 μg/l], while at Crystal Shores East, an organic mud layer (Core Section 1-2) produced the high elutriate NO_3-N [636 μg/l]. NO_3-N released to elutriate (μg NO_3-N/ g sediment shaken) showed no association with raw sediment TN (r^2=0.07).

3.4.2.2. Elutriate NH_4-N

NH_4-N released from individual core sections to the elutriate ranged from 0.0 μg/g sediment shaken in some sands from Tahoe Keys Lagoons and some sands or muds from Fleur Du Lac to 23.69 μg/g in a layer of mud from Tahoe Boat Co. The resulting range of concentrations in the elutriate solutions was 2 μg/l (level of detection) to 3177 μg/l. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate NH_4-N release (μg/g shaken) were: median = 0.20; 10th percentile = 0.00; 90th percentile = 8.95; n=42. While median, 10th percentile, 90th percentile, and n values for elutriate NH_4-N concentration (μg/l) were: median = 72; 10th percentile = 1; 90th percentile = 1855; n=42. High NH_4-N layers often were visually identified as being muds, however some clay or sand layers also had high NH_4-N. NH_4-N released to elutriate (μg NH_4-N/ g sediment shaken) showed some association with raw sediment LOI (r^2=0.31), but little association to raw sediment TN (r^2=0.10). Thus there was a slight tendency for NH_4-N release to be associated with the level of organic matter in the raw sediments.

3.4.2.3. Elutriate SRP

SRP released to the elutriate solution ranged from 0.00 μg/g sediment shaken in certain gravel and cobble layers of Fleur Du Lac sediments to 0.50 μg/g in a sandy clay sample from Tahoe Keys. The resulting range of concentrations in elutriate solutions was 1 μg/l (level of detection) to 134 μg/l. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate SRP release (μg/g shaken) were: median = 0.02; 10th percentile = 0.01; 90th percentile = 0.20; n=39. While median, 10th percentile, 90th percentile, n values for elutriate SRP concentration (μg/l) were: median = 8; 10th percentile = 2; 90th percentile = 45; n = 39. Within individual cores, distinct layers released large amounts of SRP and resulted in high elutriate SRP concentrations. However, these high SRP concentrations did not appear to be associated with any one set of visually identified characteristics. The release of SRP from sediments to the elutriate (μg SRP/ g sediment shaken) showed little association with raw sediment TP (r^2 = 0.21) or raw sediment BAP (r^2 = 0.16). Thus the level of TP or BAP present in a raw sediment sample was not a good predictor of the amount SRP release in the elutriate tests. SRP release also showed little association with raw sediment LOI (r^2 = 0.19).

The potential release of NO_3-N, NH_4-N, and SRP from sediments is particularly important, since these inorganic forms are readily available for algal utilization. They may be utilized rapidly by algae to support growth. This is in contrast to organic forms of N and P which may either be unavailable to the algae or require mineralization to inorganic forms before algal utilization. The release of soluble NO_3-N, NH_4-N, and SRP in the elutriate test was not related to the levels of Total N and Total P in the raw sediments.

3.4.3. Total Soluble + Particulate Nutrients in Elutriate Supernatant

The amounts of TKN, BAP, TRP, and TP in the elutriate supernatant solution, include soluble + particulate fractions. While assessment of the soluble inorganic forms provided an estimate of nutrients immediately available to algae for growth, assessment of TKN and TP provides an estimate of complexed, particulate associated inorganic and organic forms of nutrients which through subsequent chemical or biological activity may become biologically available. In addition, TKN includes soluble organic nitrogen, and TP includes soluble organic phosphorus, which were not included in the discussion of the previous section. TRP measures the total soluble + particulate associated reactive (molybdate reactive P) phosphorus. BAP estimates the total soluble and particulate phosphorus present thought to be algal available. The data are presented in Table 3-1 both as concentration of soluble constituent in the elutriate solution (μg/l) and weight of constituent normalized to weight of sediment originally shaken in the elutriate test (μg/g sediment shaken). As will be discussed in Section 4, the elutriate test we used tended to overestimate the TKN, TN, and TP relative to maximum levels observed within the water column during dredging. However, maximum measured levels within the dredge areas were usually within an order of magnitude of the elutriate test values. Therefore the elutriate test results should be considered to provide a conservative estimate of potential release during dredging for these "Total" parameters.

Similar to the variability observed in the soluble elutriate constituents, sediments collected within and in the vicinity of harbors exhibited much variability in "Total" particulate + soluble constituents released to the elutriate supernatant solution. The following presents a summary of observations from the data for each "Total" elutriate supernatant constituent.

3.4.3.1. Elutriate Supernatant TKN

TKN released to the elutriate supernatant solution ranged from 0.29 μg/g sediment shaken in cobble and gravel outside Fleur Du Lac harbor to 185.53 μg/g in organic mud from the Tahoe Boat Co. harbor. The resulting TKN concentrations in elutriate ranged from 110 μg/l to 19310 μg/l. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate TKN release (μg/g shaken) were: median = 5.59; 10th percentile = 1.14; 90th percentile = 65.86; n=42. While median, 10th percentile, 90th percentile, n values for elutriate supernatant TKN concentration (μg/l) were: median = 1936; 10th percentile = 472; 90th percentile = 17584; n=42. Within individual cores, distinct layers released large amounts of TKN and resulted in high elutriate TKN concentrations. These high TKN concentrations were often associated with sediments visually identified to be predominantly organic muds, e.g. Crystal Shores East Core Section 1-2 [7766 μg/l] and Section 1-3 [23488 μg/l], but high levels were also produced by sandy sediments, e.g. Tahoe Keys lagoons Core Section 1-3 [4413 μg/l] and clay appearing sediments, e.g. Tahoe Keys Section 1-4 [12965 μg/l]. TKN released to the elutriate test supernatant (μg TKN/ g sediment shaken) showed some association with levels of raw sediment TN ($r^2 = 0.44$) and raw sediment LOI ($r^2 = 0.54$). This indicated a tendency of high elutriate TKN to be associated with high TN or organic levels in the raw sediments. Elutriate supernatant TKN concentration showed an association with suspended sediment concentration ($r^2 = 0.54$) indicating TKN can often consist of a significant particulate component. However, TKN in some supernatant solutions was composed of a large soluble component (e.g. soluble NH_4-N was a large percentage of TKN in elutriate supernatant solutions for some Tahoe Boat Co. samples).

3.4.3.2. Elutriate Supernatant Organic Nitrogen

The organic nitrogen component in the elutriate supernatant was estimated by subtracting the NH_4-N from the TKN concentration for each sample. Organic nitrogen concentration was strongly associated with TKN concentration ($r^2 = 0.99$) and comprised the majority of TKN for most sites. The median organic N as a percentage of TKN was 98% (10th percentile = 45%; 90th percentile = 99.9%; n = 41). Some exceptions were Tahoe Boat Co. Core Sections 3a-2 and 3a-3 in which inorganic NH_4-N comprised more than 60% of the TKN, and Crystal Shores East Core Sections 2-2, 2-3, and 3-3 in which inorganic NH_4-N comprised 35%, 68%, and 100% of TKN. The extent to which organic nitrogen is available for use by algae needs more study not only for Lake Tahoe, but for freshwater and oceanic systems in general. While not necessarily directly available for uptake, the organic nitrogen may undergo gradual mineralization by bacteria. The amount of mineralization to inorganic forms probably depends on the length of time the organic matter remains available to organisms in the water column and upper sediment layers, and on the degree of mineralization it has undergone prior to resuspension. Organic nitrogen may be considered a potential long-term source of nitrogen, however, the current level of scientific knowledge on this issue is weak. Regardless, the potential bioavailablity of this fraction within the water column increases significantly when organic N is re-exposed to the surface waters as a result of dredging.

3.4.3.3. Elutriate Supernatant Total Nitrogen

Total nitrogen in the supernatant solutions was determined by adding a core section elutriate NO_3-N concentration to the core section TKN concentration. TN released to the elutriate supernatant solution ranged from 0.32 μg/g sediment shaken in cobble and gravel outside Fleur Du Lac harbor to 185.53 μg/g in organic mud from the Tahoe Boat Co. harbor. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate TN release (μg/g shaken) were: median = 5.63; 10th percentile = 1.17; 90th percentile = 65.92; n=42. While median, 10th percentile, 90th percentile, n values for elutriate supernatant TN concentration (μg/l) were: median = 1954; 10th percentile = 503; 90th percentile = 17600; n=42. TN released to the elutriate supernatant solution (μg TN/g sed. shaken) was partially associated with TN in the original sediments (μg/g sed.) ($r^2 = 0.45$). From 1-19% (median level 4%) of the TN present in the sediments was released to the supernatant solution (10th percentile 2%; 90th percentile 12%; n=23). Usually a large proportion of the elutriate TN concentration was organic nitrogen (median organic N as % TN = 96%; 10th percentile = 45%; 90th percentile = 99%; n=41). Elutriate TN concentration was associated with elutriate suspended sediment concentration ($r^2 = 0.54$) demonstrating TN often has a significant particulate component. Cautiously applying these results to release from disrupted sediments during dredging, a significant fraction of the TN released in the water column may often be organic nitrogen. However, inorganic nitrogen may compose a significant proportion of the TN released from some harbor sediments.

3.4.3.4. Elutriate Supernatant Total Reactive Phosphorus

TRP represents the total reactive orthophosphate found both sorbed to the sediments and in solution (where reactive phosphorus describes the fraction of orthophosphate from solution and suspended particulate and colloid fractions, which reacts with molybdate to form a phosphomolybdate complex). TRP released to the elutriate test supernatant solution ranged from 0.01 μg/g sediment shaken in cobble and gravel outside Fleur Du Lac harbor to 22.17 μg/g in organic mud from the Tahoe Boat Co. harbor. The resulting concentrations in elutriate ranged from 5 μg/l to 5930 μg/l. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate TRP release (μg TRP/g shaken) were: median = 0.19; 10th percentile = 0.05; 90th percentile = 8.98; n=39. While median, 10th percentile, 90th percentile, n values for elutriate TRP concentration (μg/l) were: median = 68; 10th percentile = 13; 90th percentile = 372; n=39. High TRP was produced by some layers visually identified to be muds (e.g. Tahoe Boat Co. harbor Core Sections 3a-1 [688 μg/l], and 3a-2 [1500 μg/l]); and some sediments with a clay fraction (e.g. Tahoe Keys Section 1-4 [5930 μg/l]). TRP released to the elutriate test supernatant (μg TRP/ g sediment shaken) showed some association with levels of raw sediment TP ($r^2 = 0.51$) and raw sediment BAP ($r^2 = 0.67$). Elutriate supernatant TRP concentration showed an association to concentrations of SRP ($r^2 = 0.55$), BAP ($r^2 = 0.78$), and TP ($r^2 = 0.86$). The majority of TRP was particulate-associated as was evidenced by a strong association with elutriate supernatant suspended sediment concentration ($r^2 = 0.85$) - the median SRP as a percentage of TRP of 8.4% (90th percentile = 23%; n = 36). Elutriate TRP concentration was usually greater than BAP but less than TP concentration. Median elutriate supernatant BAP concentration as a percentage of TRP concentration was 31.4% (10th percentile = 8.9%; 90th percentile = 119%; n=38).

As indicated by the comparison between BAP and TRP, a variable proportion of the TRP fraction may be available to support algae growth. To the extent the sediment particles with associated TRP remain suspended in the lake water and available to algae, some of the adsorbed TRP may be utilized. Algae suspended in water containing particulate associated inorganic P have been shown to be able to extract sufficient P to maintain growth, particularly through the actions of phosphatase enzymes, produced by the algae, which release ortho-P (Wetzel, 1975).

3.4.3.5. Elutriate Supernatant Total Phosphorus

TP was estimated by an acid persulfate digestion of the elutriate supernatant. This method determines the total amounts of particulate and soluble organic P + adsorbed + complexed P in the sediments. Much of the TP present in the elutriate test supernatant solution was in forms unavailable to algae. The organic phosphorus component is thought to be largely unavailable for biological utilization (Boström et al., 1982) and only a portion of the P adsorbed to clay particles may be available to the algae for growth.

Individual core section TP released to the elutriate solution ranged from 0.18 μg/g sediment shaken in cobble and gravel outside Fleur Du Lac harbor to 61.91 μg/g in clayey sands at Tahoe Keys. The resulting TP concentrations in the elutriate supernatant ranged from 67 μg/l-16561 μg/l. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate TP release (μg/g shaken) were: median = 2.58; 10th percentile = 0.92; 90th percentile = 35.46; n=42. While median, 10th percentile, 90th percentile, n values for elutriate TP concentration (μg/l) were: median = 838; 10th percentile = 306; 90th percentile = 7580; n=42. High concentrations of TP were often found in elutriate supernatant solutions produced by sediments visually characterized as muds or clays. These sediment types are composed of a large proportion of fine-grained silts and clays. Size fractionation studies (Section 3.4.1.5.) indicated silt and clay particles can have higher concentrations of TP per unit weight than larger particle sizes. These fine-grained particles can remain in suspension for long periods of time. In fact, elutriate supernatant TP was found to be very strongly associated with the concentration of suspended sediment in the supernatant ($r^2 = 0.93$). TP released to the elutriate supernatant (μg TP/g sed.) was somewhat associated with raw sediment TP ($r^2 = 0.26$) and LOI ($r^2 = 0.34$). Interestingly, concentrations of TP in the elutriate supernatant were associated with elutriate TN concentration ($r^2 = 0.64$). Since both TN and TP are somewhat correlated with suspended sediment, increases in the level of suspended particulates tend to lead to increases in the levels of both TN and TP.

3.4.3.6. Elutriate Supernatant Biologically Available Phosphorus

While SRP provides an indication of the soluble orthophosphate in solution which is readily available to the algae and TRP and TP measurements give an indication of levels of total inorganic, and inorganic + organic P present in the sediments respectively, there is a clear need for a test which specifically assesses the bioavailable fraction of P in the sediments. We used NaOH extraction of aluminum-bound P and iron-bound P which has been shown to be a good indicator of biologically available phosphorus (BAP) (Dorich et al., 1985; Sharpley et al., 1991).

Individual core section BAP released to the elutriate supernatant solution ranged from 0.0 μg/g sediment shaken in cobble and gravel outside Fleur Du Lac harbor to 2.80 μg/g in an organic mud layer at Crystal Shores East. Elutriate supernatant BAP concentrations ranged from 0 μg/l in the gravel-cobble sediments outside Fleur Du Lac to 684 μg/l in clayey sands at Tahoe Keys. When all predredging sediment data was compared, median, 10th percentile, and 90th percentile values for elutriate BAP release (μg/g shaken) were: median = 0.09; 10th percentile = 0.03; 90th percentile = 1.45; n=40. While median, 10th percentile, 90th percentile, n values for elutriate BAP concentration (μg/l) were: median = 36; 10th percentile = 8; 90th percentile = 380; n=40. High concentrations of BAP were often found in elutriate test solutions produced by sediments visually characterized as muds or clays as indicated above. Some sandy sediments also had moderately high levels of BAP — e.g. Tahoe Keys Core Section 1-3 [261 μg/l]. BAP concentration in the elutriate supernatant solution was highly associated with the concentrations of TP ($r^2 = 0.93$), TRP ($r^2 = 0.78$), and SRP ($r^2 = 0.79$). BAP was usually higher than SRP but lower than the TRP. Figure 3-1 shows the percentage of elutriate TRP and TP determined to be BAP. Figure 3-2 shows the percent contribution of SRP to BAP.

From Figure 3-1 it is apparent that the BAP concentration in elutriate supernatant solutions was a small fraction of TP concentration. BAP ranged from 0-8% of the TP concentration in the elutriate supernatant (median = 3.6%; 10th percentile 1%; 90th percentile = 6.2%; n = 40). Cautious extrapolation of these values to dredging areas where sediments are resuspended in the lake water would indicate BAP to be generally between 1-6% of TP concentration. These low values for elutriate supernatant BAP as a percent of TP are similar to the low percentages (2-14%) found by Ellis and Stanford (1988) for stream bank and fluvial sediments entering Flathead Lake, Montana. BAP released to the elutriate supernatant was somewhat associated with raw sediment BAP (r^2 = 0.43) and slightly associated with raw sediment TP ($r^2 = 0.28$).

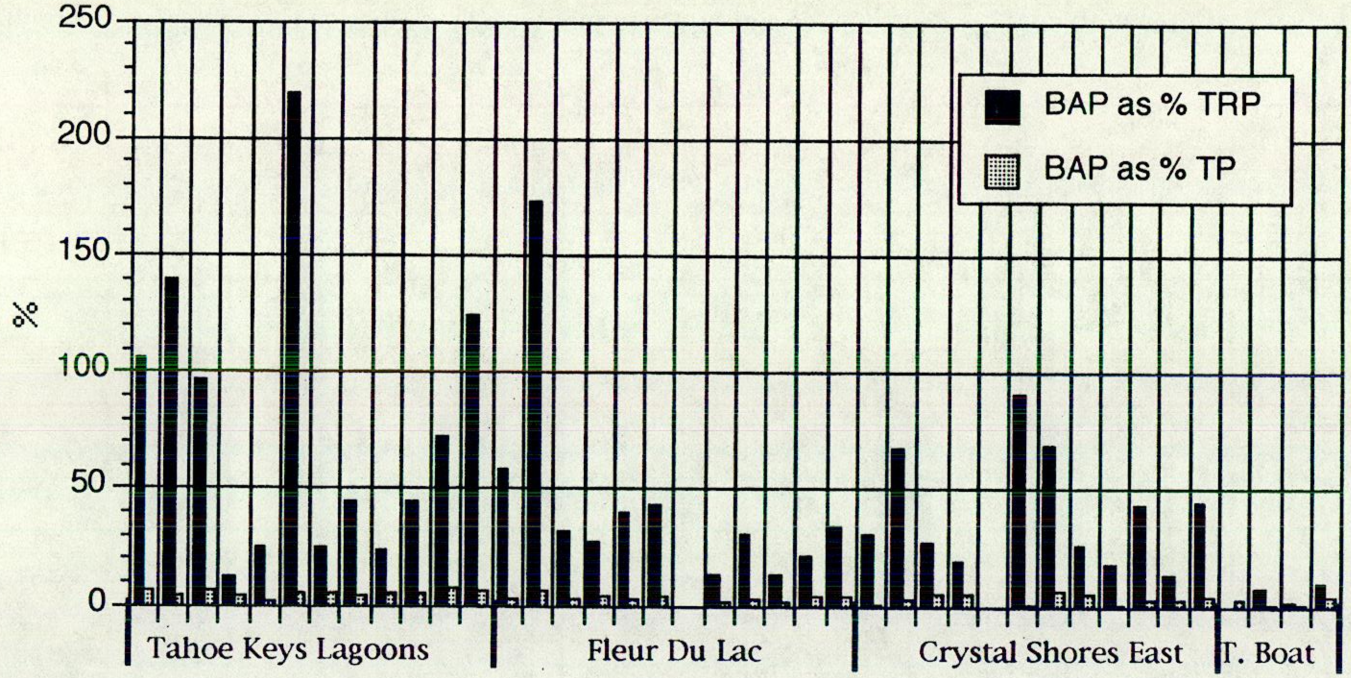


Figure 3-1. Comparison of BAP vs. TRP and TP in sediment elutriate supernatant solutions from core sections from the project sites. BAP is reported as percent of TRP or TP concentration.

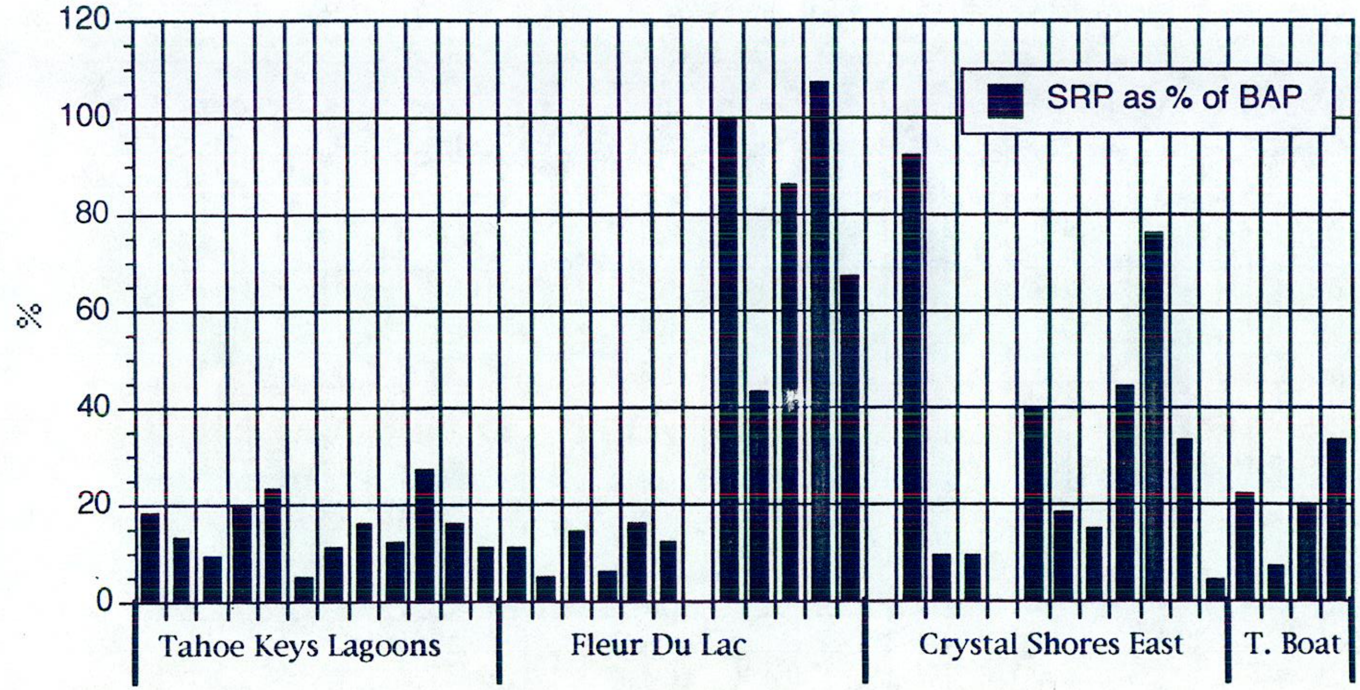


Figure 3-2. Comparison of SRP vs. BAP in sediment elutriate supernatant solutions from core sections from project sites. SRP is shown as percent of BAP concentration.

3.4.4. Additional Comparisons of Nutrient Levels in Sediments

3.4.4.1. Ingress/ Egress Channel Nutrients vs. Marina Sediment Nutrients

Ingress/egress channels are the access routes by which boats enter and leave harbors and marinas. The sediment types in these areas may represent transition areas between harbor and lake sediments. Channels may be partially protected from direct wave activity, allowing some accumulation of finer materials and nutrients on the bottom. They also experience heavy boat traffic which may impact the sediments through either disruption and resuspension by boat propellers or leakage of fuels and oils.

The Tahoe Keys East Channel provides a good example of an extended ingress/egress channel. This channel connects the Tahoe Keys Marina lagoon to the lake. It is confined by metal bulkheads along both sides between the marina lagoon and lake backshore. During drought conditions, it is bounded on both sides by dry lake bed out to the receding lake margin. Chemical analysis of channel sediments and grain-size analysis was required of the marina operator by the regulatory agencies and carried out by a commercial laboratory prior to the 1992 dredging. The results of these analyses are presented in Appendix A-14. Table 3-5 presents selected data for particle size, TKN, and oil and grease content.

The results of this testing indicated the section of the channel nearest to the lagoon to have a high fraction of silt + clay size sediments (35%) decreasing to only 7% at the outer channel station. The highest concentrations of TKN were associated with the silt + clay fraction for all sites. Compared to the sand fraction taken from the same sample, silt/clay contained between 2-10 times more TKN. Within the marina lagoon, TKN was less than the channel TKN for the sand fraction, and nearly the same as the channel TKN for silt/clay. TKN at the outer end channel was also less than at the other stations. Interestingly oil and grease were also highest in the inner channel (site #1) sediments and decreased at stations further out in the channel. Oil and grease levels were less in the lagoon than in this inner section of channel. The protected confines of the channel may promote settling of finer particles with attached nutrients. Further, it appears oil and grease are somewhat more concentrated in the channel (512 mg/kg in sand and 928 mg/kg in silt + clay), possibly as a result of the concentrated boat traffic through this area and the fine organic nature of the sediments. By the outer end channel station, oil and grease declined dramatically to <10 mg/kg (sand) and 24 mg/kg (silt + clay).

Table 3-5. Results of predredging analysis of grain size distribution and levels of TKN (mg/kg), and oil and grease (mg/kg) in Tahoe Keys East Channel and lagoon sediments, 1992. Data courtesy of Lahontan, analysis by Chemax Laboratories Inc., Sparks, NV.

Site	% Sand	%Silt+ Clay	TKN Sand	TKN Silt+Clay	Oil & Grease Sand	Oil & Grease Silt+Clay
Lagoon	86	6	296	1260	287	355
#1- Inner Channel	64	35	673	1380	512	928
#3 - Mid-lakebed Channel	84	13	168	1630	143	384
#5 - Outer End Channel	93	7	137	724	<10	24

3.4.4.2. Nearshore Sediment Nutrients vs. Marina Sediment Nutrients

Limited sampling of nearshore surface sediments was done at beaches along the south shore (Valhalla, Regan), west shore (Homewood), and north shore (Kings Beach). Although these sediments are not typically subject to dredging, they are subject to some natural disruption by wave activity and under some conditions might be impacted by boat propeller turbulence. We were interested in the nutrient levels within these sediments and how they relate to concentrations inside and outside of marinas. Disruptions of these sediments via wave activity or boat propeller turbulence are likely to be limited to the shallower surface sediments. Therefore we confined our sampling to shallower depths (approximately 7.5 cm maximum). Table 3-6 presents the results of these analysis and compares them with data for similarly shallow sediments within and immediately outside marinas.

Relative to the maximum levels in raw "Natural" nearshore sediments, samples from within marinas ("Inside") had substantially higher TN, BAP, and LOI in 2 of 5 samples. Relative to maximum levels in "Natural" sediment elutriate supernatant, "Inside" marina elutriate NO_3-N was substantially higher in 4 of 5 samples; "Inside" marina NH_4-N was higher in 2 of 5 samples; "Inside" marina SRP was higher in 2 of 4 samples and "Inside" marina BAP was higher in 1 of 4 samples. Raw sediment maximum TP and elutriate supernatant maximum TKN and TP values were similar for "Inside" marina and "Natural" sediments. Though these data are very limited, they suggest that surface sediments from some harbors can have higher levels of TN and organic matter in raw sediments, and release higher levels of NO_3-N, NH_4-N, SRP, and BAP in elutriate tests compared with surface sediments from natural shoreline areas. Boat propeller disturbance of sediments in these particular harbors may release more bioavailable forms of nutrients than similar disturbance in the natural nearshore areas sampled.

Natural nearshore lake surface sediments generally released low levels of bioavailable nitrogen and phosphorus (NO_3-N, NH_4-N, SRP, BAP) in the elutriate tests. These low levels of release may have been a consequence of previous losses associated with frequent wave mixing of the sediments and previous biological depletion of associated nutrients. Consequently, localized boat propeller disturbance over these natural nearshore sediments may not significantly increase nutrient loading. However, newly deposited sediments, which have not been subjected to such previous depletion in the lake (e.g. terrestrial-derived sediments recently transported into the lake), may potentially be more enriched in bioavailable forms of nitrogen and phosphorus. Boat propeller disturbance of sediments within areas receiving new sediments (e.g. near stream mouths), as well as within marinas, may release some biologically available nutrients.

Table 3-6. Results of comparison of the levels of nutrients in surface sediments collected from inside and outside marinas and harbors and from natural nearshore areas located away from harbors. "NATURAL" indicates lake sediments from natural nearshore areas located away from marinas, "INSIDE" indicates sediments collected inside the harbor or marina, and "OUTSIDE" indicates sediments collected just outside the harbor or marina and "Core S. Length" indicates Core Section length (cm) [extending from surface of sediments] included in analysis. Raw sediment was analyzed for TN, TP, BAP (μg/g), and LOI (mg/g); the elutriate supernatant was analyzed for NO_3-N, NH_4-N, TKN, SRP, and TP (μg/l).

		Raw Sediment				Elutriate Supernatant					
Site - Core	Core S. Length	TN	TP	BAP	LOI	NO_3	NH_4	TKN	SRP	BAP	TP
NATURAL											
Homewood	7.5	230	663	51	6	6	79	323	4	0	169
Kings Beach	3.8	100	294	0	3	8	25	365	3	65*	70
Regan Beach	5.0	160	48	0	5	12	75	5501	4	0	1209
Valhalla Beach	7.5	150	94	4	6	8	15	1097	8	0	448
OUTSIDE											
Fleur Du Lac Core 3a	6.0	110	687	54	10	8	5	901	9	21	794
Fleur Du Lac Core 3b	8.0	110	843	65	8	57	0	539	15	14	386
Tahoe Boat Co. Core 1	7.5	230	-	67	17	7	140	873	8	36	1040
INSIDE											
Tahoe Keys Marina C. 1	4.5	300	257	38	4	39	69	2362	13	73	1096
Tahoe Keys Marina C. 2b	1.5	850	347	73	34	38	299	4711	3	55	1069
Fleur Du Lac Core 1	8.0	230	677	149	9	410	6	1368	2	19	611
Crystal Sh. East Core 2	5.0	210	423	36	7	55	171	1547	-	0	362
Tahoe Boat Co. Core 2	7.5	180	-	39	31	7	1	285	33	-	367

* This BAP value may be anomalous, since it is such a high % of TP.

The impact of wave activity on release of nutrients from nearshore sediments needs further study. The data suggest that the potential nutrient release from nearshore surface sediments in many areas may be low. However, wave activity impacts large areas of shoreline. The cumulative impact of nutrient release from large areas of sediments may or may not be significant. It is important to recognize that although wind generated wave activity is a natural, non-controllable process which may potentially cause some nutrient release, the delivery of "new" sediments (with available nutrients) into the shorezone is controllable to a certain extent (through Best Management Practices to minimize erosion on land and environmentally efficient dredging).

3.5 Levels of Other Contaminants in Marina Sediments

As part of predredging project approval, regulatory agencies have required analysis of other sediment contaminants in addition to nutrients. These analyses have included: oil and grease (O&G), the potentially toxic heavy metals cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn), and tin (Sn) as an indicator of tributyl tin (TBT). These materials may have detrimental impacts upon biota in aquatic systems and human health if their levels are too high. However, as discussed for nutrients, a high concentration in the sediment may not necessarily mean a high bioavailability. Metals and organic contaminants can be effectively sequestered by bonding and complexing with the sediments and as a result, not be available to biota. Negatively charged surfaces of clay particles can bind large numbers of metal cations such as the above. Under reducing, alkaline conditions which typically occur in lake sediments, the cations are held tightly by the sediments. Humic organic compounds within the sediments also have a strong affinity for metal cations and certain toxic organic compounds including oil and grease.

These materials may be relatively inert if they remain embedded in lake sediments. However, disruption during dredging may release particles with adsorbed contaminants into the water column. Further, disposal methods may impact the release of materials from the sediments. For instance, upland disposal of highly metal-contaminated sediments can be a poor choice. As the sediments dry out they become oxidized. Sulfur present within the sediments may be oxidized to sulfate, forming sulfuric acid. If the sediments become very acidic (< pH 2), the metal cations will be released to ground water or surface runoff. Thus a change from alkaline-reducing conditions to oxidizing-acidic conditions can mobilize heavy metal ions.

3.5.1. Heavy Metals

Heavy metal sediment data were provided by Lahontan and TRPA and are presented in Appendices A-14 through A-18. The data was examined to determine what levels of heavy metals exist in Tahoe marina sediments. Table 3-7 presents a summary of observed concentration levels or ranges of selected priority pollutant metals in various harbor and channel sediments.

Levels of Cd, Cr, and Pb were all below the level of detection for the analyses. Zinc and tin levels were detectable in some marinas, however, concentrations were low — tenths of milligram per kilogram sediment levels. The Cr, Pb, and Zn levels are very low compared to levels observed in sediments in other lakes. ERA (1986) summarized from the literature metal concentrations in deep sediments from various North American, European and Scandinavian lakes and found Cr to range from 7 to 190 mg/kg; Pb to range from 5.6 to 100 mg/kg; and Zn to range from 5 to 260 mg/kg. Sediment metal levels of Cr (< 25 mg/kg), Pb (< 40 mg/kg), and Zn (< 90 mg/kg) were considered unpolluting in the Great Lakes (Intl. Joint Comm., 1982).

Levels of total tin were used as an indicator of the potential maximum amount of tributyl tin "TBT" (a potentially toxic antifouling agent included with some marine paints prior to the 1980's) in the sediments. Total tin analysis includes inorganic tin as well as all organic forms of tin, including TBT. Therefore TBT may range from a small proportion of the total tin to 100% of the total tin in the worst case. Specific determination of TBT requires specialized analytical techniques and is expensive. The majority of samples had total tin levels below the contracting laboratory's analytical limit of detection (0.1 mg/kg in the historical data). Therefore, the majority of TBT levels were necessarily less than 0.1 mg/kg. A slightly elevated total tin level (0.12 mg/kg) was found in sediments from Sunnyside marina, possibly reflecting a presence of elevated TBT.

Levels of TBT and DBT have been measured directly in Tahoe Keys sediments since 1987 by the California Department of Fish and Game (Calif. Dept. Fish and Game Report, in preparation). Elevated levels of TBT were found in some Tahoe Keys sediments in the late 1980's, however, these levels have been declining. For instance, within the marina lagoon near the Tahoe Keys East Channel, the range for five replicate samples was from 0.110-0.310 mg/kg in 1989; in 1993 at the same site the range was from 0.015-0.049 mg/kg. In comparison, TBT levels have been measured in many marine harbors along the Pacific Coast. Some general ranges for TBT in these marine harbors were provided by Jim Thoits of Toxscan Inc., Watsonville, CA.: TBT in "clean" marine harbor sediments was generally from 0.001-0.010 mg/kg; in recreational harbors TBT generally ranged from 0.001-0.020 mg/kg; in more heavily used larger harbors, the range was from 0.05-0.100 mg/kg.

Table 3-7. Levels of cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn), and tin (Sn) in various harbor and channel sediments from Lake Tahoe; [n] indicates number of samples in each range. Values are expressed as mg/kg dry weight. Chemical analysis was done by Chemax Laboratories, Sparks, NV.; data courtesy of Lahontan.

Sediment Source	Sand	Silt + Clay
	Cd (mg/kg): [n]	Cd (mg/kg): [n]
Tahoe Keys Marina (1992)	<0.001: [2]	<0.001: [2]
Tahoe Keys E. Channel (1992)	<0.001: [5]	<0.001: [5]
Fleur Du Lac (1990)	<0.05: [4]	<0.05: [2]
Sunnyside (1992)	<0.1 : [3]	<0.1: [3]
	Cr (mg/kg); [n]	Cr (mg/kg): [n]
Tahoe Keys Marina (1992)	<0.1: [2]	<0.1: [2]
Tahoe Keys E. Channel (1992)	<0.1: [5]	<0.1: [5]
Fleur Du Lac (1990)	<0.2: [4]	<0.2: [2]
Sunnyside (1992)	<0.1: [3]	<0.1: [3]
	Pb (mg/kg); [n]	Pb (mg/kg): [n]
Tahoe Keys Marina (1992)	<0.01: [2]	<0.01: [2]
Tahoe Keys E. Channel (1992)	<0.01: [5]	<0.01: [5]
Fleur Du Lac (1990)	<0.2: [4]	<0.2: [2]
Sunnyside (1992)	<0.2: [3]	<0.2: [3]
	Zn (mg/kg): [n]	Zn (mg/kg): [n]
Tahoe Keys Marina (1992)	<0.1: [1] 0.1: [1]	<0.1: [1] 0.14: [1]
Tahoe Keys E. Channel (1992)	<0.1: [5]	<0.1: [3] 0.11-0.12: [2]
Fleur Du Lac (1990)	<0.2: [4]	<0.2: [2]
Sunnyside (1992)	<0.1: [3]	0.13-0.25 [3]
	Sn (mg/kg): [n]	Sn (mg/kg): [n]
Tahoe Keys Marina (1992)	<0.1: [2]	<0.1: [2]
Tahoe Keys E. Channel (1992)	<0.1: [5]	<0.1: [5]
Fleur Du Lac (1990)	<0.2: [4]	<0.2: [2]
Sunnyside (1992)	<0.1: [3]	<0.1: [2] 0.12: [1]

Table 3-8. Concentration ranges for oil and grease in selected sediments collected inside and outside of Tahoe marinas. Values are reported as mg/kg dry weight. (Gr) = range for gravel fraction; (Sd) = range for sand fraction; (Sl/Cl) = range for silt and clay fraction; (total) = weighted mean range for whole sample. Sampling and chemical analysis by Chemax Laboratories, Sparks, NV.; data courtesy of Lahontan.

Oil and Grease Concentration Ranges in Sediments (mg/kg)				
Site	Inside Harbor	Access Channel	Outside Harbor (Near)	Outside Harbor (Away)
Tahoe Keys	44-287 (Sd) 96-355 (Sl/Cl) 50-291 (total)	343-512 (Sd) 383-928 (Sl/Cl) 348-659 (total)	143-150 (Sd) 252-384 (Sl/Cl) 165-175 (total)	<10 (Sd) 24 (Sl/Cl) 11 (total)
Fleur Du Lac	59-130 (Gr) 110-465 (Sd) 380-1300(Sl/Cl)		6-104 (Gr) 19-32 (Sd) <10 (Sl/Cl)	36 (Gr) 24 (Sd)
Sunnyside	526-732 (Sd) 526-635 (Sl/Cl)		154 (Sd)	
Obexer's	<10 (Gr) 340 (Sd) 265 (Sl/Cl)		20 (Gr) 45 (Sd) 40 (Sl/Cl)	

3.5.2. Oil and Grease

Oil and grease sediment data were provided by Lahontan and TRPA and are presented in Appendices A-14 through A-18. The data was examined to determine what levels of oil and grease exist in Tahoe marina sediments. Table 3-8 presents the concentration ranges for oil and grease in Tahoe sediments collected within, outside of, and away from marinas.

Levels of oil and grease tended to be higher inside marinas and access channels compared to sites outside the marinas. Sites furthest away had lowest levels of oil and grease (< 50 mg/kg). Inputs of oil and grease from boating activities and fueling, urban runoff inputs, and other sources likely contribute to the elevated oil and grease concentrations in marina sediments. When these values are compared to standards developed for the Great Lakes, most of the samples would be considered in the "unpolluted" range . Values < 1000 mg/kg were considered unpolluted for Great Lakes sediments, values of 1000-2000 mg/kg were considered moderately polluted, and values > 2000 mg/kg were highly polluted (International Joint Comm., 1982). Some values for Lake Tahoe sediments would be considered in the moderately polluted range. Highest values of oil and grease were associated with some silt/clay fractions.

Included within the broad category of oils and grease are a variety of specific petroleum hydrocarbons and degradation products, many of which may be toxic in nature. However, these substances like the heavy metals may be strongly held by sediment-organic complexes and not be readily bioavailable.

Summary - Section 3

1) Considerable variability may exist in the nutrient content of sediments among harbors, among sites at a harbor, and vertically within different layers of harbor sediments.

2) Elutriate tests were used to simulate the nutrient release to the surrounding water which occurs when sediments are disrupted during dredging. Raw sediment total nitrogen (TN) or total phosphorus (TP) content was not a good predictor of the level of soluble or total N or P release in these elutriate tests.

3) A large proportion of the TN released to the supernatant solution in elutriate tests was often organic nitrogen (median level of organic N as % TN was 96%). In a cautious extrapolation of these results to the amount of nitrogen release during dredging, a significant portion of TN released to the water column during dredging will often be organic nitrogen. However, inorganic nitrogen, which is readily available to algae, composed a significant proportion of the TN released from some of the harbor sediments analyzed.

4) The amount of Biologically Available Phosphorus (BAP) released to the elutriate supernatant solution was determined by using an NaOH extraction procedure. BAP usually was from 1-6% (median 3.6%) of TP in the elutriate test supernatant. In a cautious extrapolation of these results to the amount of BAP release during dredging, we would expect approximately 1-6% of the TP resuspended in the water to be BAP.

4. Impacts of Dredge Equipment and Practices on Water Quality

4.1. Resuspension of Particulates and Nutrients During Dredging

To assess the extent of turbidity and nutrient release occurring during dredging, monitoring was done during projects at the Tahoe Keys East Channel, Tahoe Keys lagoons, Fleur Du Lac, and Crystal Shores East. Three different dredge types were used in these projects: a horizontal cutter suction dredge at Tahoe Keys; dragline and clamshell bucket dredging at Fleur Du Lac; and an excavator dredge at Crystal Shores East. The results of TRG monitoring of these projects were combined with regulatory agency required monitoring to provide information on patterns of turbidity and nutrients within and in the vicinity of the dredging projects. From this data, inferences were drawn on impacts to the lake.

4.1.1. VMI 612 Horizontal Cutter Hydraulic Dredging (Tahoe Keys)

A VMI 612 horizontal toothed cutter suction dredge was used to dredge both the Tahoe Keys East channel in 1992 and Tahoe Keys lagoons in 1993. This dredge operated in the open lake, within the channel, and throughout most of the lagoon without the use of silt curtains. We investigated the turbidity and nutrient resuspension created by the VMI 612 by visual and water quality monitoring. The results of TRG and regulatory agency required monitoring are presented in Appendices A-1, A-3, A-6 and Appendices A-8, A-9 respectively; maps of the monitoring sites are located in Appendices B-2 and B-4.

Visual observation of the VMI 612 during open water dredging in the clear waters of Lake Tahoe provided information on the general resuspension characteristics of this dredge. Underwater observations indicated that the dredge produced a noticeable sediment plume which seemed to be pushed primarily out along the bottom ahead of the cutterhead. Some material from this plume also mixed upward and around the sides of the dredge to create a visible surface plume. Monitoring samples collected verified the presence of a plume of water with higher levels of turbidity and nutrients along the bottom than near the surface. Figure 4-1 shows the trend of higher turbidity and TP near the bottom for monitoring samples collected around the dredge on 11/12/92.

Distinct surface plumes were observed visually during dredging around the VMI 612 ranging from a small, localized plume of approximately 25 ft. x 50 ft. to plumes approximately 300 ft. x 100 ft. in the open-lake. Figure 4-2 gives an example of the distribution of turbidity and TP in a larger plume near the surface as the dredge operated in a shallow (2.5 ft. deep), open lake section of the Tahoe Keys East Channel on 11/12/92.

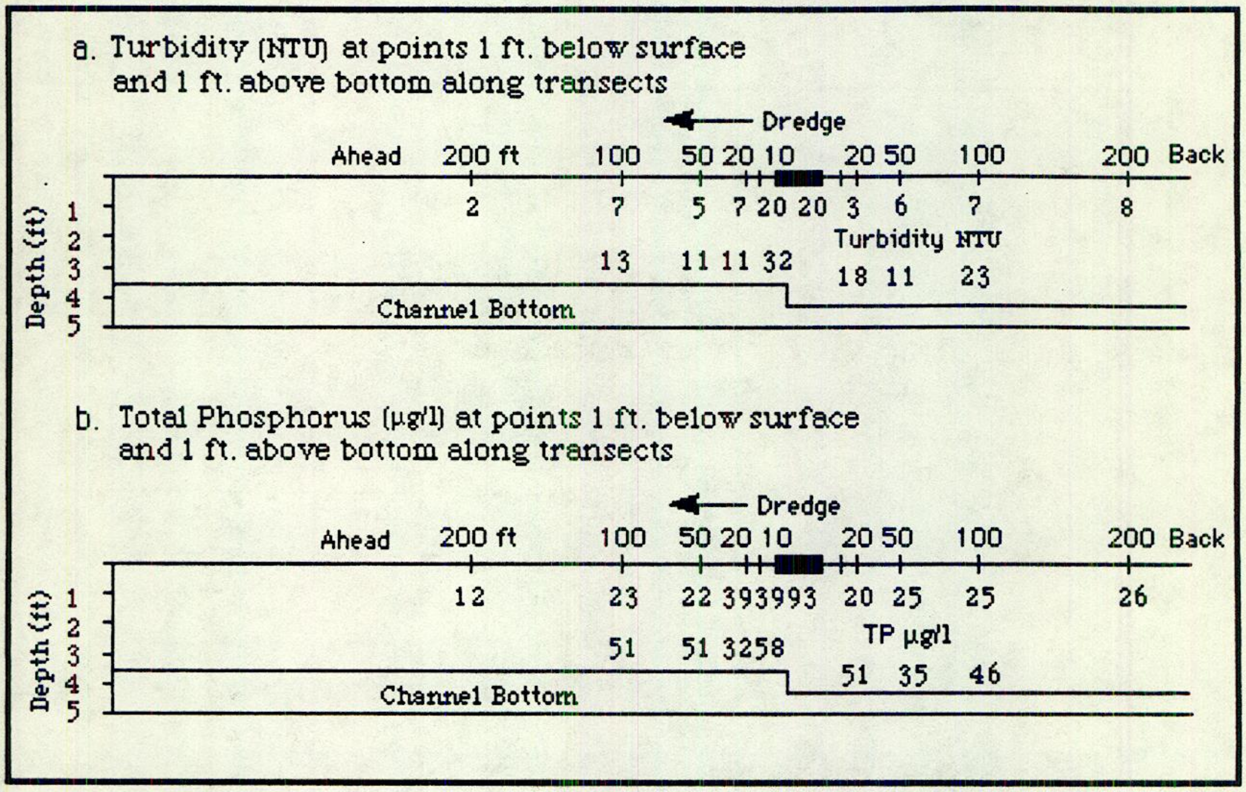


Figure 4-1. Turbidity and TP concentrations ahead of and behind the VMI 612 horizontal cutter hydraulic dredge. The dredge was operating in shallow open lake water, in the Tahoe Keys East Channel on 11/12/92

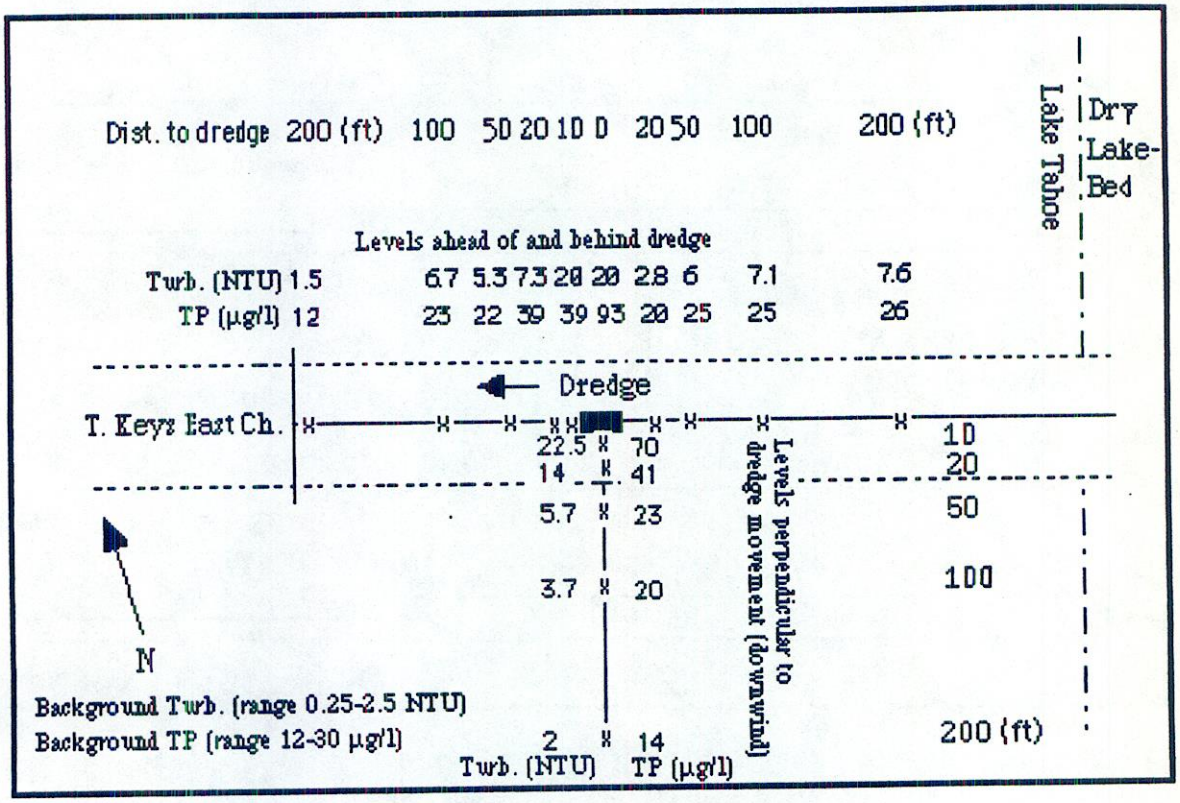


Figure 4-2. Near surface turbidity (NTU) and TP (μg/l) at sampling points "x" along transects ahead of, behind, and downwind of the VMI 612 hydraulic dredge. Samples were collected 11/12/92 in a shallow, open-lake section of the Tahoe Keys East Channel.

Although the level of turbidity was slightly above background 200 ft. away from the dredge on the surface, the most heavily impacted waters were relatively localized around the dredge. The highest near-surface turbidities (20-22.5 NTU) were confined to an area within 10 ft. of the front of the dredge to between 10-20 ft. downwind of the dredge. Highest surface concentrations of TP (39-93 μg/l) were located within 10 ft. of the dredge. This plume developed under calmer conditions in shallow water.

Localized impacts of dredging were also detected during dredging in the lagoons. Synoptic samples were collected at many points within the Tahoe Keys Lagoons on two dates 9/22 and 9/30 towards the end of the 1993 dredging (Appendix A-3). Turbidity and TP were found to be elevated at sites closest to the dredge operations. While at sites further away from the dredge, turbidity and TP remained low. NO_3-N, TKN, SRP, and TRP showed little variation among sites on the two sampling dates. There did not appear to be a general lagoon-wide increase in the concentrations of these nutrients resulting from the dredging. NH_4-N, however, showed a substantial increase at all sampling points between synoptics done on 9/22/93 and 9/30/93. NH_4-N concentration increases ranged from 5-18 μg/l on 9/30/93. These increases may have resulted from dredging in areas particularly enriched in NH_4-N. The fact that NH_4-N was much higher in the spoils discharge on 9/30 compared to 9/22 seems to support this.

Little information is available in the literature on the sediment resuspension characteristics of horizontal *toothed cutters*, such as the VMI 612. A similar type dredge which has a horizontal *auger cutter* rather than a toothed cutter, the Mud Cat dredge, has been studied in other aquatic systems (Cullinane et al., 1990). Similar to the VMI 612, the Mud Cat horizontal auger dredge has been shown to produce higher levels of sediment resuspension along the bottom near the cutter than in the upper water column. Suspended sediments near the bottom 5 ft. from the auger were usually slightly greater than 500 mg/l above background, while surface and mid-depth concentrations measured 5-12 ft. in front of the auger were typically less than about 150 mg/l above background (Cullinane et al., 1990). Direct measurement of suspended sediment was not done in monitoring around the VMI 612 suction dredge. However, a limited test of the relationship between suspended sediment and turbidity for different amounts of Tahoe Keys sediments and turbidity was done (see Appendix D). A predictable relationship between turbidity and suspended sediment was found. Based on this relationship, turbidity values of 20 NTU 10 ft. ahead of the VMI 612 dredge at the surface would equate to approximately 70-80 mg/l of suspended sediments. These levels are less than the reported levels of 150 mg/l 5-12 ft. away from the Mud Cat at the surface. It is interesting to note that the dredging contractor for Tahoe Keys (SWECO) indicated that in their experience with both the VMI 612 and a

Mud Cat horizontal auger suction dredge, the VMI 612 created less turbidity than the Mud Cat. They felt the sediments were more efficiently transported to the suction intake between the widely spaced teeth of the VMI 612's toothed cutter. Sediments may be less efficiently transported along the rotating blades of an auger-type cutter. In the literature, the Mud Cat is indicated to have low to moderate sediment resuspension characteristics (Randall, 1992).

4.1.1.1. Impacts of Varied VMI 612 Engine RPM and Cutterhead Pressure on Turbidity and Nutrient Resuspension

Several variables were under operator control on the VMI 612. These included cutter rotations per minute, dredge pull speed, engine RPM, and auger (cutterhead) pressure. The dredge operator can vary these controls to obtain maximum production while minimizing sediment resuspension in different types of bottom material. In operations at Tahoe, a moderate cutter speed was generally used. If the cutter was rotated too fast, excessive sediment was resuspended. Active pulling along the cable was generally utilized in easily-dredged sediments to drive the dredge forward. In difficult-to-dredge, turbidity-creating sediments, pulling along the cable was stopped and action of the cutter helped move the dredge forward. The remaining controls, engine RPM (which supplies overall power to the cutter), and auger pressure (the downward pressure forcing the cutter into the sediments) were subject to greater variability in operating control.

We investigated the amount of sediment resuspension produced by the VMI 612 under various combinations of auger pressure and engine RPM in a controlled test. During this test, the dredge made a single pass down a section of channel near the Tahoe Keys marina gas docks, with engine RPM and auger pressure varied in four combinations of settings (1300 RPM/400 PSI auger pressure; 1300 RPM/700 PSI; 1700 RPM/400 PSI; and 1700 RPM/700 PSI). For each combination of engine RPM and auger pressure, a full set of water samples were collected 10 ft. away from the cutterhead, ahead of the right and left edges of the cutter, as well as perpendicular to the cutter at a distance of 10 ft. Water samples were collected near the surface, mid-water column, and near the bottom at each location.

The test data are summarized in Appendix A-6. Figure 4-3 presents overall mean turbidity and TP values around the dredge for each of the combinations of settings. The results show that auger pressure was the primary variable leading to resuspension of sediment and that engine RPM appeared to have little impact on sediment resuspension. As the amount of pressure increased from 400 PSI to 700 PSI, the levels of turbidity and TP (as well as TKN not shown) increased. The setting of 1700 RPM and 700 PSI was considered by the dredge operator to be normal for the dredging conditions. At low auger pressures, the amount of sediment resuspension was low, however, production of the dredge was also indicated to be lowered. With less force exerted downward on the cutter, less material was removed by the dredge. Generally maximal production was sought by the dredge operator which produced turbidity less than the maximum permitted level of 20 NTU within 10 ft. of the dredge at the surface. At 1300 RPM and 700 PSI, the turbidity levels remained below 20 NTU at the surface and slightly exceeded 20 NTU in front of the dredge in the lower water column. The results of the dredge test showed that operator skill can have a large role in minimizing the levels of turbidity and nutrients resuspended during a project, while maximizing efficiency.

4.1.2. Dragline and Clamshell Dredging (Fleur Du Lac)

Dredging at Fleur Du Lac was done using clamshell and dragline buckets operated from a crane. The water in the areas dredged were isolated from the lake by use of heavy gage vinyl silt curtains. Dredge spoils were dewatered within the dredge areas prior to transport across the property on a portable conveyor belt system, then loaded onto trucks for transport out of the basin. We monitored both within the dredge areas and at various sites outside the silt curtains. The results of TRG and regulatory agency required monitoring are presented in Appendices A-4 and A-10 respectively; maps of the monitoring sites are located in Appendices B-5 and B-6.

Figure 4-4 (a,b) presents turbidity and nutrient values measured in the harbor area during and following dredging. The levels of all parameters showed some fluctuation and in general, fluctuations appeared to be related to the area the dredge was working. The values were initially high as the dredge operated within a section of harbor inside a sand bar (the sampling site was also in this area). Values dropped as the dredge operated outside the sand bar (isolated from the main harbor and sampling site), then rose again as the sand bar was removed. On 9/13/93 the silt curtain pulled loose from the south anchor point during strong SE wind and wave activity. As a result, some dredge-impacted water escaped to the lake. This curtain failure, together with ongoing pumping of dredge-impacted water to the sewer system were responsible for the steep decline in turbidity and nutrients following the completion of dredging. We were not notified during this failure and therefore unfortunately we do not have samples to indicate the magnitude of impact on the lake surrounding the dredge area. Moderate levels of turbidity were reported by the project consultant just outside the harbor mouth. However, the lake was noted to be clear a short distance away outside the breakwater. The silt curtain was replaced as rapidly as possible across the harbor mouth, however, some release of dredge-impacted water occurred. The

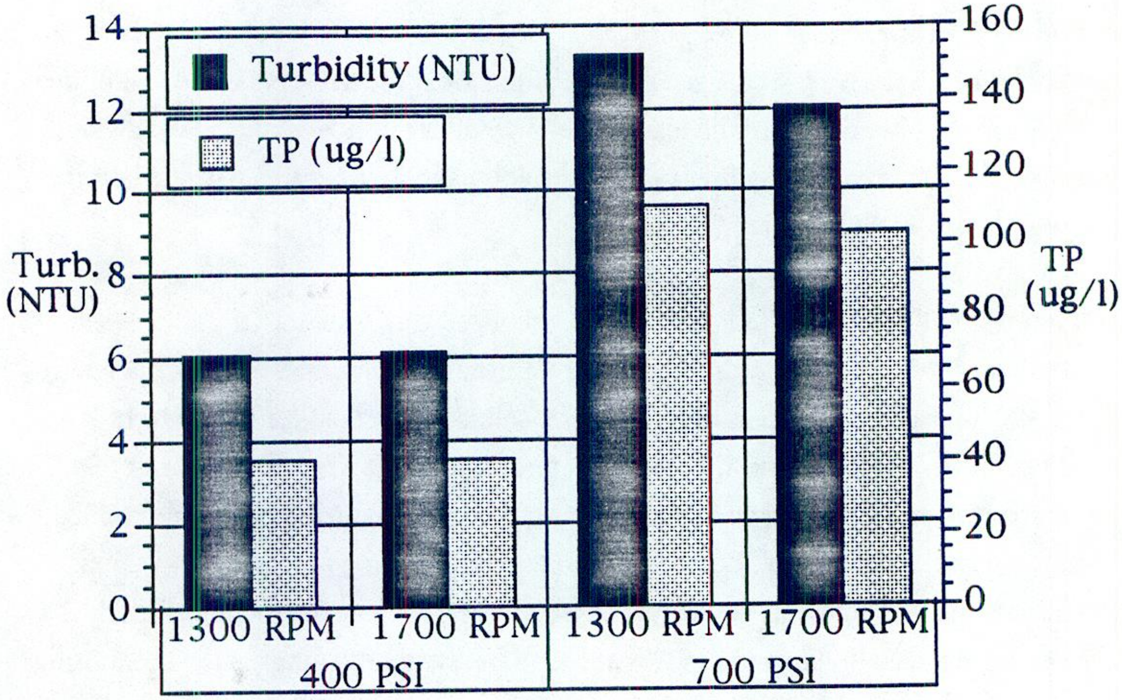


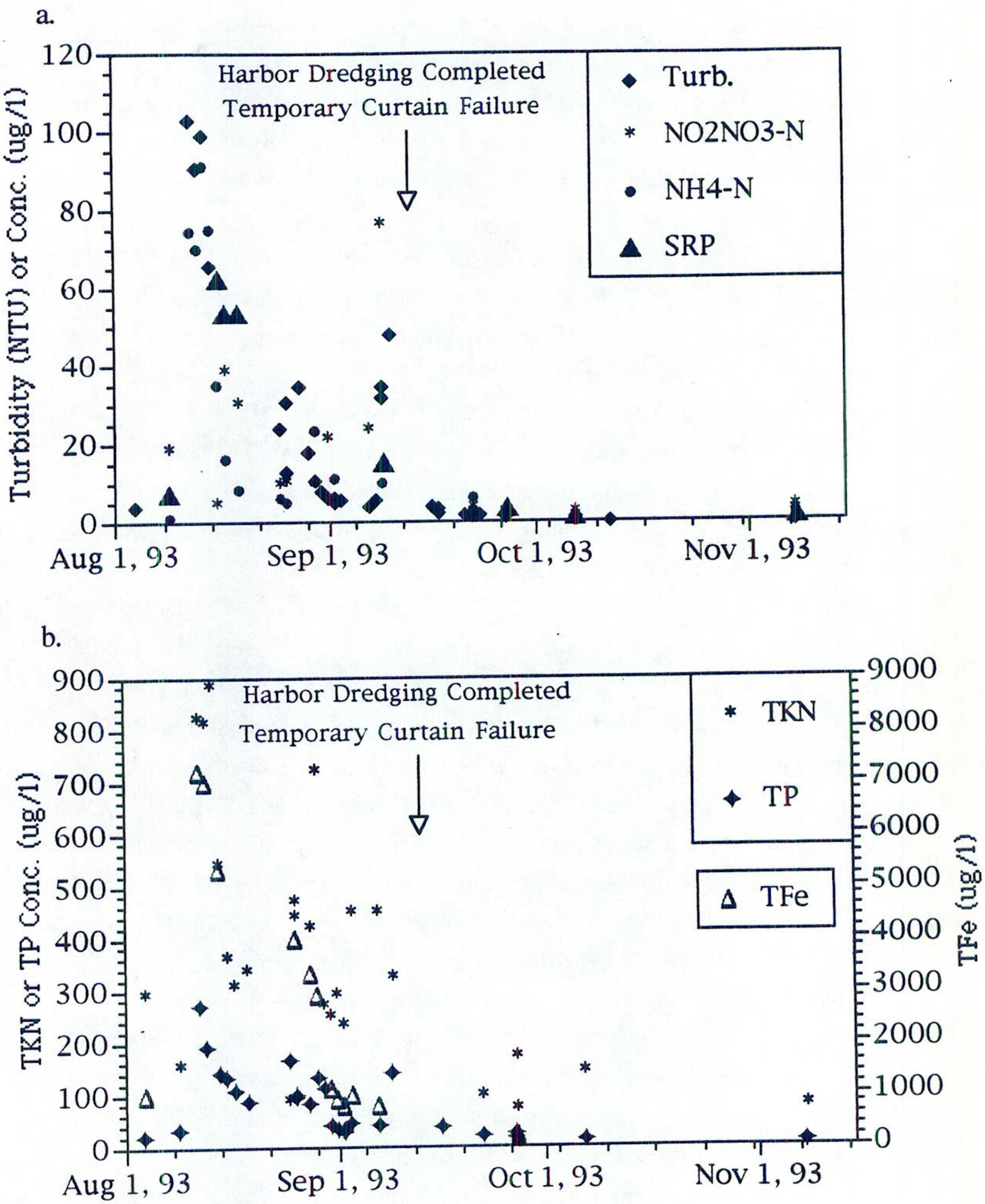
Figure 4-3. Mean turbidity and TP around the VMI 612 hydraulic dredge at different combinations of engine RPM and auger pressure (PSI) during testing in the Tahoe Keys Marina. Water samples were collected at locations 10 ft. ahead of the left and right sides of the cutterhead, and 10 ft. perpendicular to the cutterhead, at three depths: near the surface, mid-water column, and near the bottom. Means were calculated from all data collected for a combination engine RPM and auger pressure PSI. (Note: data for sample "D"-"4 ft." collected at 1700 RPM and 700 RPM was excluded from the calculations because the Van Dorn bottle appeared to contact the bottom and collect some bottom sediments).

failure of the silt screen during strong wind and wave activity occurred as a result of problems with anchorage to the breakwater. For future projects, it would be useful to consult with the manufacturer of the silt curtain to be sure of the strongest anchorage possible of the silt curtain for use in rough lake conditions. It is likely under the roughest lake conditions that even strong commercially constructed silt curtains may be subject to failure.

The highest turbidities observed during dredging at Fleur Du Lac were 103 NTU inside the harbor and 192 NTU within the silt curtain enclosed area near the south pier. These values are higher than the 88.5 NTU maximum turbidity observed within 10 ft. of the VMI 612 suction dredge during operations at Tahoe Keys. In general, clamshell buckets and dragline buckets have high sediment resuspension characteristics (Randall, 1992; Ian Orchard, Environment Canada, personal communication). The high levels of turbidity observed may be attributed to both the characteristically high sediment resuspension characteristics of the dredging technique, as well as to the increase in turbidity levels as materials accumulated within the silt screen enclosed area.

Except for the temporary failure of the silt curtain under strong wind and wave activity, the silt curtains proved very effective in retaining dredge-impacted waters within the dredge area at Fleur Du Lac. Low levels of turbidity and nutrients were found outside the dredge areas near the silt curtains and at sites further away. The highest levels of turbidity and nutrients 10 ft. outside the harbor silt curtain (above background) were turbidity (1.6 NTU), NO_3-N (6 μg/l), NH_4-N (5 μg/l), TKN (4 μg/l), SRP (3 μg/l), and TP (17 μg/l) for TRG monitoring. The highest levels of turbidity and nutrients 10 ft. outside the harbor silt curtain (above background) were turbidity (0.5 NTU), NO_3-N (0 μg/l note single high is likely a result of contamination), NH_4-N (0 μg/l), TKN (30 μg/l), TP (9 μg/l) and TFe (120 μg/l) for regulatory agency required monitoring.

The use of a strong silt screen to contain turbidity, as well as the ongoing removal of dredge area water to the sewer system helped minimize dredge area water escape to the lake for this project. A Containment Systems, Inc. silt screen was used to contain turbidity within the dredge area. This screen was made of heavy polyester reinforced vinyl in which flotation was welded into the upper portion of the curtain and a heavy chain was welded into the material along the bottom. The screen curved outward into the lake across the harbor mouth and was affixed to piles on the outward bend to provide further support. A



Figures 4-4 a, b. Patterns of turbidity and nutrient concentrations in the Fleur Du Lac harbor during and following the completion of dragline and clamshell dredging.

low-flow pumping system (20-30 gallons per minute) was utilized within the harbor to pump dredge impacted water into the sewer system during and following completion of dredging. Highly turbid dredge area water was thus replaced with clear lake water from outside the harbor. The effect of this pumping was to maintain the sediment and nutrient concentrations at moderate levels during dredging and clear the water more rapidly than natural settling following completion of dredging. By maintaining lower concentrations within the harbor, the potential impact of any leakage around the silt screen was also reduced.

4.1.3. Excavator Dredging (Crystal Shores East)

Dredging at Crystal Shores East was done using an excavator which was able to access most of the area by either working from shore or moving into the shallow lake water. The water in the area to be dredged was isolated from the lake by use of a plastic silt curtain. Following removal by the excavator, dredge spoils were deposited directly in a dump truck, then transported along a beach behind the harbor and deposited on the beach adjacent to the lake for dewatering. Filter fencing was installed between the spoils and the lake. Following dewatering, the spoils were transported to a nearby site within the basin for use as landfill. Again, we monitored both within the dredge areas and at various sites outside the silt curtain. Appendices A-5 and A-11 present the results for TRG and agency-required monitoring respectively; Appendix B-7 presents a map of sampling sites.

Very high levels of turbidity, NO_3-N, NH_4-N, TKN, and TP developed within the dredge area during dredging. High levels of these substances were also released from the sediments during predredging assessment of the sediments in elutriate tests (see Chapter 3). The use of the excavator bucket can be expected to have generally high resuspension characteristics, similar to the dragline or clamshell buckets. Maximum levels of turbidity and nutrients in the dredge area were turbidity (195 NTU), NO_3-N (154 μg/l), NH_4-N (66 μg/l), TKN (1677 μg/l), SRP (13 μg/l), TRP (89 μg/l), and TP (1294 μg/l).

Partial failure of the original silt curtain and leakage underneath the replacement curtain resulted in the escape of some turbidity and nutrients from the dredge area. The original silt curtain was unable to withstand the direct force of swells and winds from the south during dredging prior to 10/6/93. Again, we were not notified during this failure, so unfortunately, we do not have documentation of the nutrient concentrations outside the dredge area. It may be assumed that a portion of the nutrients within the harbor were released to the lake. Section 4.2 provides an estimate of the potential loading of nutrients to the lake associated with this curtain failure.

A commercial polyester reinforced vinyl silt curtain (borrowed from the Fleur Du Lac project) was added outside the remaining original screen to restore containment. This curtain provided better containment, however, some leakage still occurred around this screen. Maximum levels of turbidity and nutrients 10 ft. outside the commercial silt curtain at the surface corrected for background were turbidity (2.89 NTU), NO_3-N (0 μg/l), NH_4-N (0 μg/l), TKN (14 μg/l), SRP (1 μg/l), TRP (3 μg/l), and TP (10 μg/l). Slightly higher maximum levels of turbidity (3.09 NTU) and TKN (280 μg/l) were found outside the silt curtain at a distance of 1 ft. away. Turbid dredge area water was observed to be leaking from near the base of the silt curtain on 10/6, 10/8 and 10/13. On these dates a distinct plume of turbid water was observed extending away from the silt curtain along the bottom. On 10/8 this plume was estimated to be 30-40 ft. wide and extended the length of the breakwater (see Appendix Map B-7). The turbidity level of plume water collected near the bottom approximately 10 ft. away from the curtain was 6.15 NTU. The silt curtain rested on an uneven bottom consisting of boulders and cobble across the harbor mouth. Although sand bags had been used to fill in between the rock spaces, some turbidity and nutrient release still occurred underneath the curtain and between the sandbags. Since leakage can occur past silt curtains along the bottom, in future projects it would be useful to collect surface and near bottom water to better characterize leakage past the curtain (rather than only near-surface water).

4.2. Estimates of Nutrient Loading to Lake Tahoe from Dredging Activities

Nutrients released by dredging may be potentially available to the algae in the lake, to the extent these nutrients remain in the water column or settle to the upper, biologically-active zone of the sediments. We estimated the magnitude of nutrient additions associated with some dredging activities to the lake.

We applied monitoring data to obtain crude estimates of the levels of N and P in the water around the VMI 612 dredge during dredging. These estimates do not account for material resuspended by the dredge which resettled rapidly, or material which dispersed beyond the edge of the measured plume. Evaluation of the total levels of nutrients released around a hydraulic dredge cutter during open-lake dredging would require intensive monitoring and development of a model to describe such release and was beyond the scope of the current study. On 9/24/92, monitoring samples were collected along a transect ahead of and behind the dredge out to a distance of 400 ft. in a section of Tahoe Keys East channel estimated to be 77.5 ft. wide, and with a mean depth of approximately 4 ft. and confined on the edges by dry lakebed and bulkheads. To calculate loads, the channel was divided into "blocks" of water, each with a sampling point at its center. The concentration of TKN, NO_3-N, and TP at each sampling point (minus the pre-project background concentration for the channel) was multiplied by the volume in the "block" to obtain a weight of TN and TP. Using this method, a total of 2.4 kg TN and 0.17 kg TP was estimated to be in suspension around the dredge along the transect. Of this load, a portion may have been subsequently redeposited on the bottom within the channel and portions may have dispersed as soluble or suspended forms both into the main lake and into the Tahoe Keys lagoons. It should be recognized this load was not necessarily the result of only a single day of dredging. Several days of dredging had occurred in this section of channel prior to 9/24/92. Since this area of channel was partially confined, circulation and exchange of water in the dredge area daily was probably reduced. This may have caused some carry over of nutrients from the earlier days of dredging.

We also estimated the level of TP in suspension as the VMI 612 dredge operated within a section of the Tahoe Keys East Channel in the main lake on 11/12/92. Since this area of dredging was an open-lake area subject to circulation, nutrients in the water column around the dredge were assumed to be newly released during that day (and not accumulated from previous days of dredging). A similar approach of combining estimated volumes around the sampling points with concentration data, was used to obtain an estimate of amount of TP in suspension (TKN data was not collected on this date). Approximately, 0.13 kg of TP was estimated to be in suspension around the dredge following one-half day of dredging. Of this load a portion may have subsequently resettled to the lake sediments, and a portion dispersed into the surrounding lake waters as soluble and suspended forms.

During the hydraulic dredging at Tahoe Keys, solids were removed from the spoils water by settling in a series of impoundment basins. The water was then returned to a silt curtain enclosed area of the Tahoe Keys. The return of this water was a source of nutrients into the Tahoe Keys associated with dredging. We estimated of the loads of TN and TP returned to Tahoe Keys from the spoils retention ponds in 1993. Mean concentrations of TN (295 μg/l) and TP (62 μg/l) in pond 3 site 7 were used as estimates of quality of water discharged. The discharge from the ponds into Tahoe Keys was assumed to be equal to the inflow of water to the ponds (however, discharge was not necessarily concurrent with filling of the ponds). For an average pumping rate of 1000 gallons per minute during an average 7.38 hours of dredging each day, approximately 442,800 gallons entered and was discharged from the ponds. Therefore, approximately 0.49 kg TN and 0.10 kg TP were discharged to the silt curtain enclosed area in the Tahoe Keys each day. During 36 days of dredging, approximately 17.64 kg TN and 3.6 kg TP were discharged to the silt curtain enclosed area in the Tahoe Keys. A portion of this load may have settled to the bottom in the silt screen enclosed area, and a portion dispersed beyond the screen into other areas of the Tahoe Keys lagoons.

Mechanical dredging was done at both Fleur Du Lac (dragline and clamshell dredging) and Crystal Shores East (excavator dredging). Mechanical dredging has a high potential to resuspend turbidity and nutrients. This was demonstrated by increased levels of turbidity and nutrients which developed within silt curtain enclosed areas. An estimate of dragline dredging loading of N and P to the areas enclosed by silt curtains was made from monitoring samples collected from Fleur Du Lac. Within the main harbor, one-day totals were 1.08 kg TKN (NO_3-N data not available to calculate TN) and 0.51 kg TP released within the silt curtain enclosed area.

Monitoring during this study indicated the commercial vinyl silt curtain used at Fleur Du Lac to be effective in isolating the dredge area water from the main lake. Levels of nutrients outside the silt curtains were generally low which indicated little leakage was occurring. Thus daily nutrient loading to the lake past silt curtains was likely only a small fraction of the accumulated load of nutrients in the harbor. However, silt curtain failures can potentially result in the mixing of turbid, nutrient-rich dredge-area water into the surrounding lake waters. We estimated the levels of TN and TP which might be released to the lake during a silt curtain failure. We calculated essentially a "worst-case scenario" using monitoring data collected during the Crystal Shores East project. We assumed that concentrations in the harbor at the time of the curtain failure were at their maximum and that all the harbor water mixed into the lake. The harbor volume was estimated to be 521,041 gallons. Table 4-1 presents the maximum concentrations observed and the corresponding masses of nutrients present. Fairly significant quantities of TN (3.47 kg) and TP (2.52 kg) could potentially be released to the lake in such a worst-case curtain failure. Actual loading of nutrients to the lake during the failure at Crystal Shores East could not be determined, since harbor samples were not collected prior to and following the failure. Such loading would have been dependent on the concentrations in the harbor at the time of the curtain failure and the amount of mixing of harbor water into the lake.

While significant loading to the lake may occur during silt curtain failures such as occurred at Crystal Shores East and the partial failure at Fleur Du Lac, loading may also occur when the curtain is temporarily removed to move equipment into or out of an area or at the end of the project when the curtains are removed. The lower the concentrations within the dredge area at the time of removal, the lower the potential loading of suspended nutrients to the lake. For instance, the concentrations within the Crystal Shores East harbor at the time of curtain removal were approximately 60 μg/l TN and 28 μg/l TP, the potential loading of TN and TP to the lake upon curtain removal would be 0.155 kg and 0.073 kg

Table 4-1. Potential nutrient load to Lake Tahoe during a silt curtain failure at Crystal Shores East in "worst case" where concentrations of nutrients were at maximum levels in harbor at time of failure and all the harbor water mixed into the lake The harbor volume inside the silt curtain was estimated to be 521,041 gallons (dredging 1/2 completed).

	NO_3-N	NH_4-N	TKN	SRP	TP
Maximum Observed Concentration (μg/l) in Harbor (above background level)	151	64	1607	12	1277
Potential Nutrient Load (kg) to Lake Tahoe	0.298	0.126	3.169	0.024	2.519

TP respectively (assuming a final dredge area volume of approximately 684,350 gallons and that all the nutrients within the dredge area were mixed into the lake). These values are much lower than the 3.47 kg TKN and 2.52 kg TP potential loads when dredge area concentrations were at maximum levels.

Disposal of dredge area water to the sewer system or other suitable area outside the lake during or at the end of a project may help prevent suspended and soluble nutrients from impacting the lake. However, the fate of nutrients associated with settled material within dredged areas at the completion of dredging and removal of silt curtains needs further study. A portion of the particulate associated nutrients may be subsequently resuspended during turbulent lake conditions and resettle at other locations in the lake. Portions may be utilized by algal or microbial organisms or undergo degradation to bio-available forms, while other portions may potentially remain non-utilized and become buried again under shifting or newly deposited sediments. We were not able to assess the contributions of nutrients to the lake from sediments which settled within the enclosed area in this study.

The loading of TN and TP to the lake associated with silt curtain failures, spoils water return to the lake following settling, plumes produced around the hydraulic dredge ranges from less than single kg levels to tens of kg levels[1]. These amounts are small relative to large-scale processes such as stream flow, atmospheric deposition and internal loading from the deeper waters during turnover (see Goldman et al, 1989; Jassby et al., 1994). However, resuspension of 5 kg of TN and TP by dredging is roughly equivalent to the annual load in urban runoff from 5 acres of medium-developed residential area or 2-3 acres of tourist-commercial development.

4.3. Comparison of Sediment Nutrient Levels with Nutrient Levels Resuspended by Dredging

One of the goals of this study was to relate the concentrations of nutrients found in predredging harbor sediments to the concentrations resuspended in the water column during dredging. Previous investigators have found bulk analysis of sediments (determination of total interstitial and particulate nutrients in a sample) useful for determination of the composition of sediments to be dredged, but not necessarily for prediction of potential for release of contaminants. We used a modified version of the elutriate test to determine the amounts of soluble nutrients which might be leached from the

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1- It has been reported in the literature that dredging may resuspend from 0-5% of the total amount of sediments dredged. We estimated levels of nutrients which would be resuspended if 0.1%, 1%, or 5% of the total volume of sediments were resuspended in a project at Lake Tahoe. These estimates are presented in our follow-up report entitled: "Cost and Effectiveness Analysis for Implementation of Recommendations in: Impacts of Marina Dredging on Lake Tahoe Water Quality". Levels of TN or TP resuspended were similarly estimated to range from < kg levels to tens of kg levels.

sediments during dredging. We compared the levels of the major fractions of N and P found in the elutriate supernatant to the total levels of TN and TP in the original sediment material to see to what extent a relationship existed. We then related the concentrations measured in the elutriate test supernatant to the concentrations observed in the dredge areas during dredging.

Figures 4-5 (a-d) show the results of a comparison between TN present in dried core sediments with NO_3-N, NH_4, organic N, and TN released to the supernatant in the elutriate tests. Figures 4-5 (e-h) show the results of a comparison between TP present in dried core sediments with SRP, TRP, BAP, and TP released into the supernatant in the elutriate tests. Figure 4-5 (i) shows the results of a comparison between BAP present in the dried core sediments with BAP released into the supernatant in elutriate tests. The association between TN and TP in the sediments and various forms of N and P in the elutriate supernatant solutions was generally small. These results tend to confirm the idea that the analysis of raw sediments may not necessarily give a good indication of the potential for nutrients to be released when mixed with water during dredging.

The elutriate tests done in this study appeared to give a better indication of levels of nutrients which might be released into the water during dredging. Figures 4-6 (a-d) compare the concentrations of nutrients found in core elutriate test supernatant solutions with maximum concentrations observed in dredge areas during dredging. Concentrations of nutrients within the elutriate test supernatant solutions were often within an order of magnitude of the maximum observed concentration in the dredge area. Concentrations of TKN, TRP, and TP in the elutriate test supernatant were often higher than the maximum observed concentrations within the four dredging areas with the elutriate test overestimating the release of these nutrients to the water. Oxidized N (NO_2 + NO_3-N) and NH_4-N concentrations in the elutriate test supernatant were often within the same order of magnitude as maximum levels in the dredge area (except for NH_4-N in the Fleur Du Lac harbor) but were either lower or higher.

The standardized version of the elutriate test (Standard Elutriate Test) developed by the EPA and Army Corps of Engineers has been shown to overestimate levels of total soluble Kjeldahl nitrogen (DKN) and DP (Ludwig et al., 1988). These overestimates have been attributed to unduly long agitation times (30 minutes) which may not be representative of agitation and resuspension of sediments during dredging, and sediment-to-water ratios which may be too high (Bender et al., 1984). In order to obtain better predictive capabilities, the elutriate testing procedure has evolved from a basic test similar to the one we used. Some of the modifications of these revised tests entail using smaller proportions of sediments, reducing agitation times, and adding a settling test to assess the levels of

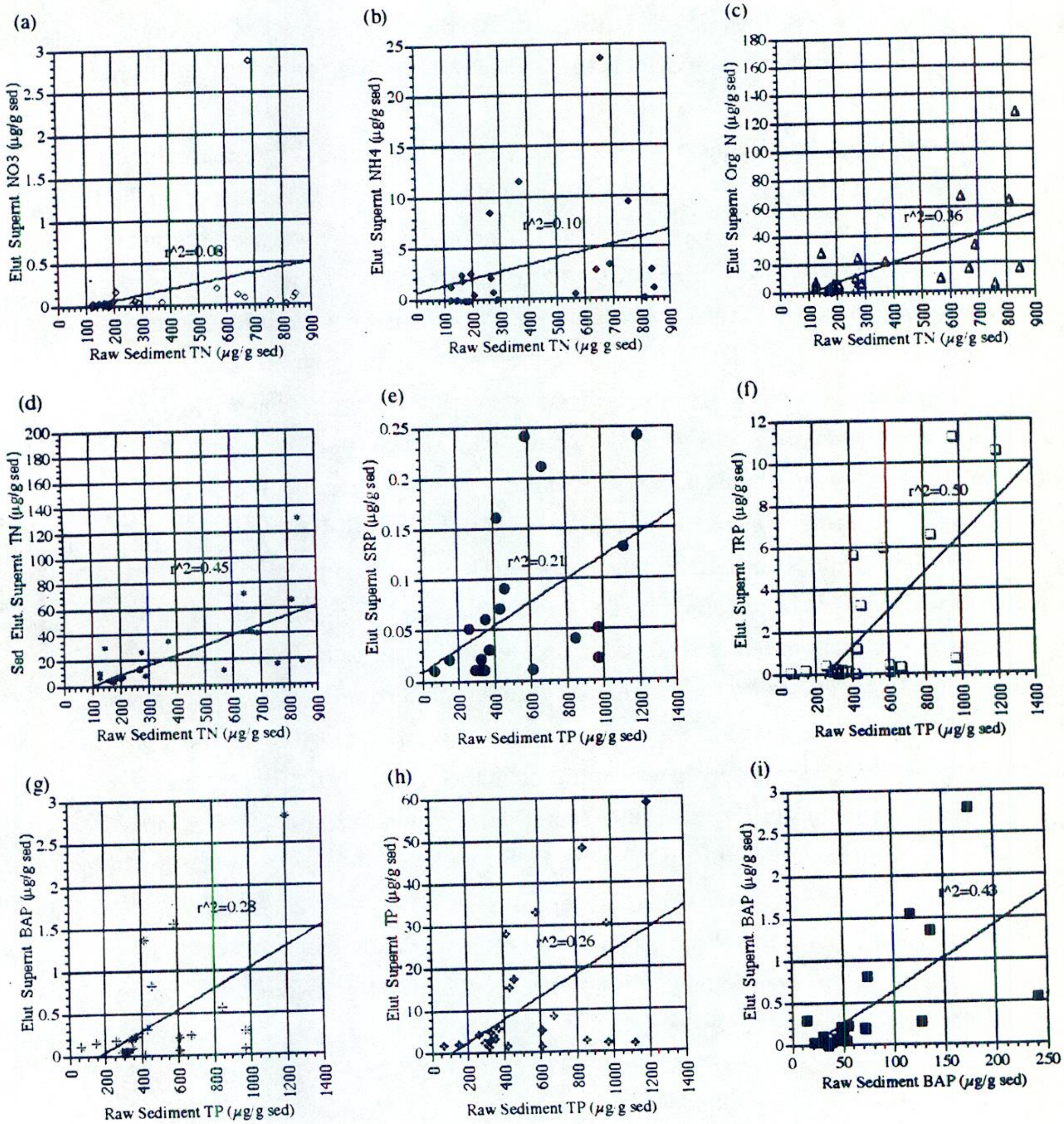

Figure 4-5. Associations between nutrients in dried core sediments and nutrients released into the supernatant solution in elutriate tests: (a) raw sediment TN vs. supernatant NO3; (b) raw sediment TN vs. supernatant NH4; (c) raw sediment TN vs. supernatant organic N; (d) raw sediment TN vs. supernatant TN; (e) raw sediment TP vs. supernatant SRP; (f) raw sediment TP vs. supernatant TRP; (g) raw sediment TP vs. supernatant BAP; (h) raw sediment TP vs. supernatant TP; (i) raw sediment BAP vs. supernatant BAP.

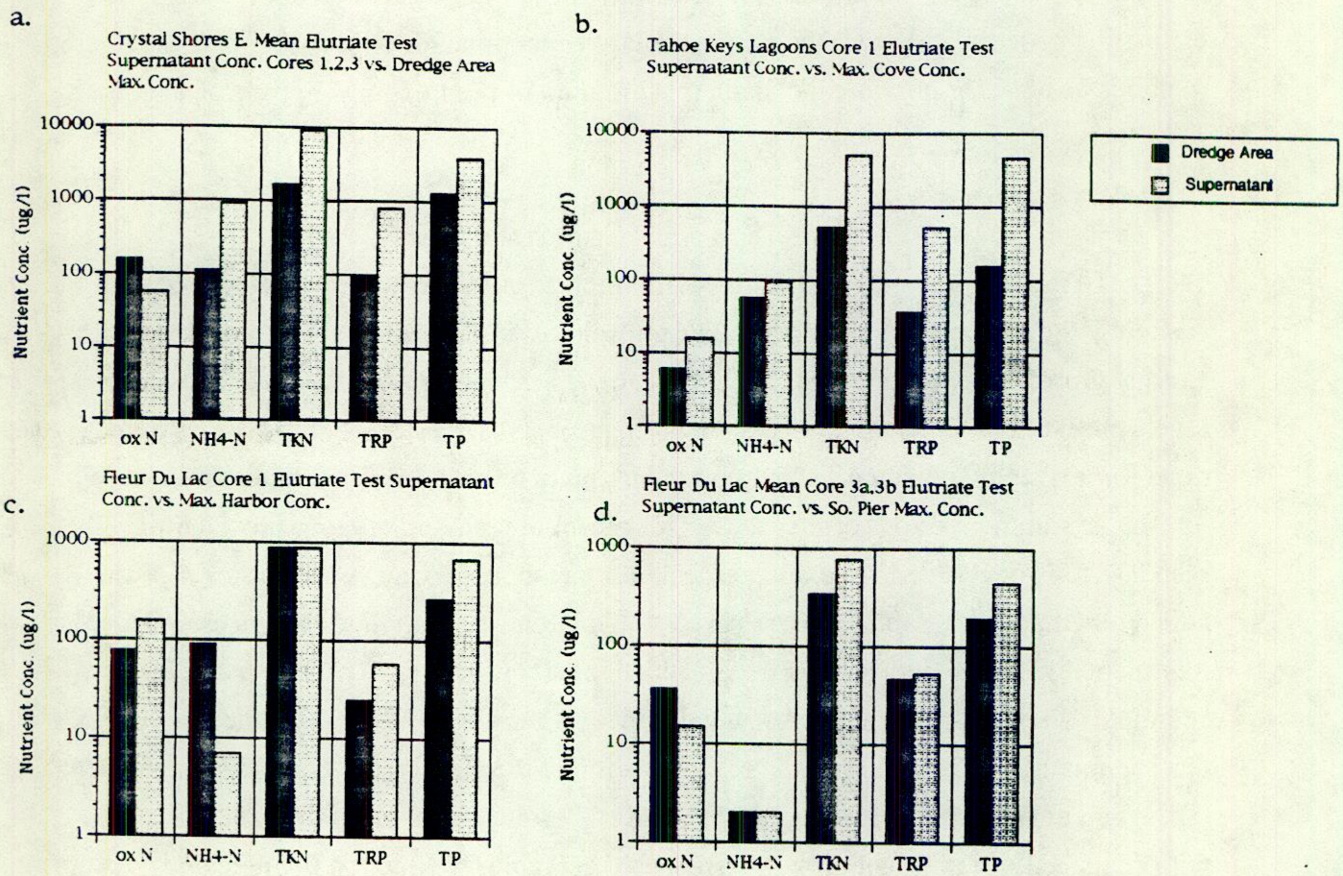

Figure 4-6. Plots of maximum concentrations of oxidized N, NH4-N, TKN, TRP, and TP observed in silt curtain enclosed dredging areas versus mean concentrations of these nutrients in elutriate test supernatant solution for cores collected within the following dredging areas: (a) Crystal Shores East; (b) a side cove in Tahoe Keys lagoons enclosed by silt curtain; (c) Fleur Du Lac harbor; (d) Fleur Du Lac south pier area.

particulates remaining in solution (Ludwig et al., 1988). Different testing procedures are used for prediction of levels at point of dredging and point of discharge (Palermo, 1986; DiGianno et al., 1993). While the very simple elutriate test we used has some utility in estimating concentrations within dredge areas, we recommend some testing of these revised methods be done for possible inclusion in a program of predredging analysis of Tahoe sediments.

4.4. Dredging Impacts On Short-Term Algal Growth and Clarity

To make an assessment of short-term impacts of nutrient release associated with dredging, the levels at which nitrogen and phosphorus in the sediments became stimulatory to algal growth were determined (see Section 6). These levels were then related to nutrient levels observed in the vicinity of the dredging projects. Bioassays of N and P response done for this study indicated Tahoe phytoplankton to be primarily co-limited by N and P, during the summer periods of the study. This meant that phytoplankton showed little response to N or P added alone, but a stimulatory response to the combination of N and P added together. Detectable increases in phytoplankton chlorophyll a were measured at treatment levels of 5 μg/l N and 2 μg/l P added together. A majority of the marina sediments were also shown to cause algal growth when added as a 1% solution of elutriate test supernatant in Lake Tahoe water. Calculation of the dissolved inorganic nitrogen (DIN) and biologically available phosphorus in 1% solutions of elutriate and comparison with statistically significant growth responses (see Table 6-3, Section 6) indicated significant growth responses were measured at DIN levels as low as 0.05 μg/l and 0.12 μg/l BAP. These sediment solutions not only contained DIN and BAP, but also some available N sorbed to particulates and organic N, as well as iron, which has been indicated to be potentially stimulatory to algal growth. Tahoe phytoplankton, thus, were indicated to be sensitive to additions of very small amounts of nutrients (on the order of tenths of μg/l of DIN and BAP) when added in concert with the dredged sediments.

The small amounts of DIN and BAP released with sediments around the dredge in the open lake, outside of the silt curtains, or within dredge areas can potentially lead to increased phytoplankton growth. Detectable increases in algal biomass in response to dredging were most likely in areas where the dredge-impacted waters were prevented from dispersing. Within sheltered harbors, areas enclosed by silt curtains, or confined sections of channel, the resuspended material and nutrients were held in place for long periods of time. Phytoplankton were similarly held in place within these areas and exposed to the elevated levels of nutrients. Increased chlorophyll a in response to elevated nutrients produced by dredging was, in fact, seen both within the harbor at Fleur Du Lac (which increased from a predredging level of 0.07 μg/l to 10.15 μg/l) and also within a side cove during dredging in the Tahoe Keys lagoons. This side cove developed high turbidity, TP and NH_4-N concentrations during dredging which necessitated sealing off of the cove with a silt curtain. During the time the cove was sealed off, the phytoplankton chlorophyll a biomass increased from 1.66 on 9/3/93 to 4.62 on 9/16/93.

Due to dispersion of plumes and associated phytoplankton during lake wind mixing, the development of localized areas of increased algae growth in the open lake is unlikely. Monitoring for chlorophyll a (an indicator of algal biomass) was not done around the suction dredge during open-lake dredging but was done outside silt curtains at Fleur Du Lac and Crystal Shores East. A slight increase in chlorophyll a (0.20 μg/l) was observed during monitoring outside the silt curtain at the Fleur Du Lac harbor, at site 2, on 9/9/93. However, this increase appeared to be more the result of leakage of dredge area water with high chlorophyll a (10.15 μg/l) from within the dredge area, than response of phytoplankton outside the dredge area to increased nutrients. A detectable increase in chlorophyll a was not observed outside the Crystal Shores East project.

4.5. Long-Term Impacts of Dredging

The contributions of N and P from individual dredging projects are low relative to contributions from stream inputs, atmospheric inputs and internal loading of nutrients from the hypolimnion of the lake. However, these dredging inputs are comparable to other inputs produced by man's activities within the watershed which are regulated (see Section 4.2). The management strategy at Tahoe is to minimize all incremental sources of nutrients and thereby minimize the potential cumulative input of nutrients to the lake. The additive contributions of individual dredging projects over several years of allowed dredging constitute non-natural inputs which when combined with other man-derived sources of nutrients (e.g. land disturbance, runoff from impervious surfaces on individual parcels, fertilizer usage, etc.) have a cumulative, additive effect on the levels of nutrients available in the lake to support algal growth. Management of Lake Tahoe as an Outstanding National Resource Water requires that all practical measures be taken to minimize any allowed short-term degradation associated with projects such as dredging. Long-term degradation of the lake is not allowed. Strict control measures, thus, help to minimize short-term degradation and help reduce the potential for long-term degradation.

4.6. Dredging Projects with the Greatest Potential for Impact

Open lake dredging without the use of silt curtains around the dredge may have the greatest potential for impact. Such impacts are primarily short-term in the localized areas in which the dredge operates. Localized plumes of turbidity are produced around the dredge.

With each day of an open lake dredging, the load of nutrients resuspended directly in the lake also increases. The number of days spent dredging in open lake areas should be minimized to that absolutely necessary to reduce the net loading to the lake. Hydraulic dredges or other specialized low-sediment-resuspending dredges should be used for such open-lake dredging. Mechanical dredges have a high potential for sediment resuspension in the open lake and should be avoided unless silt curtains are used.

The potential impact of new dredging in open lake areas (not protected by silt curtains) may be particularly high. Original sediments can be composed of very consolidated sediments including clays. These consolidated sediments may be difficult to remove. Generally, when a dredge has difficulty removing the sediment, the turbidity released will increase. Horizontal cutter dredges should not be used to dredge such consolidated original sediments, i.e. clays. Cutterhead dredges may be required in such new dredging.

Projects in which silt curtains are used in extremely exposed portions of the lake also have high potential for impact on the lake. During strong wind and wave activity, even very strong silt curtains may be subject to failure. Such failure may result in a portion of or all of the dredge-impacted water entering the lake. Careful evaluation should be done with respect to the severity of conditions likely to be encountered at a site and the feasibility of using a silt curtain. For some dredging projects, it may be more prudent to spend more resources on low-sediment-resuspension dredging technology and methodology (i.e. reduce the amount of resuspension at the dredge) and consider not using a silt curtain. When a decision is made to use a silt curtain, use of reinforced-vinyl commercial silt curtains is recommended in exposed areas of the lake.

Dredging areas which receive stream water inflows also have increased potential for impact and require special considerations. In a previous project, unexpected high flows from a stream entering the harbor during dredging forced dredge area water past the curtains. This problem may be remedied by diverting stream inputs around or through the curtain via piping.

<u>Summary - Section 4</u>

1) Monitoring was done around a horizontal cutter hydraulic dredge during operations in the Tahoe Keys East Channel. A plume of elevated turbidity and nutrient levels along the bottom ahead of the horizontal cutter and extending upwards to the surface was detected. Although the surface plumes were detectable quite a distance from the dredge (25-200 ft), the highest levels of turbidity and nutrients in the plume were localized within 10-20 ft. of the dredge.

2) The mechanical dredging methods monitored in this study (excavator, clamshell, dragline) had relatively high sediment resuspension characteristics. High levels of turbidity developed within the silt curtain-enclosed dredge area during excavator dredging at Crystal Shores East. While dragline and clamshell dredging produced high levels of turbidity within the silt curtain enclosed dredge areas at Fleur Du Lac.

3) The loading of N and P to the lake from release of dredge area water upon removal or failure of silt curtains, spoils water return to the lake from hydraulic dredging spoils impoundment basins, and plumes produced around the hydraulic dredge was estimated and found to range from less than single kg levels to tens of kg levels. These loads are comparable to other inputs produced by man's activities within the basin which are regulated. For instance, resuspension of 5 kg of TN and TP by dredging is roughly equivalent to the annual TN and TP load in urban runoff from 5 acres of medium-developed residential area or 2-3 acres of tourist-commercial development. The inputs associated with dredging are partially controllable. Management of Lake Tahoe as an Outstanding National Resource Water requires that all practical measures be taken to minimize any allowed short-term degradation associated with projects such as dredging.

5. Dredge Spoils

5.1. Background

Mechanical and hydraulic dredging produce dredge spoils, which must be handled somewhat differently prior to ultimate disposal. Mechanical dredging produces sediments which are removed at near *in situ* densities. Following removal, the spoils are usually piled in a designated basin or enclosed area and the excess water (a combination of interstitial water, suspended sediments and nutrients, and lake water) allowed to drain from the sediments. The sediments are typically dewatered briefly (during a period ranging from several hours to several days), then are loaded onto trucks for removal from the site. In hydraulic dredging, a liquid slurry of dredged sediments, interstitial water, and lake water is produced by the dredge. This slurry may either be piped directly to a disposal site along the bottom in another area of an aquatic system (a practice called bypass dredging — which is not allowed in Lake Tahoe due to the potential for resuspension of sediments and nutrients at the disposal site) or the slurry may be subjected to some form of solids separation in which the solid and liquid fractions of the slurry are separated. The solids are then further dewatered and disposed of, while the water from the slurry may be returned to the lake either directly, or indirectly through percolation into the ground water.

There are potential impacts to the lake associated with the spoils handling from both types of dredging. The water separated from the dredge slurry in hydraulic dredging may contain large quantities of nutrients in solution and in association with fine particulates. The return of this water to the lake can potentially add to the pool of nutrients utilized by algae for growth. The water which drains from piled spoils during dewatering may contain elevated levels of nutrients and other contaminants which may enter the lake either via surface runoff, or percolation into the ground water. Additional impacts can occur as these sediments dry out at a disposal site. Changes may occur which can potentially lead to further mobilization of some contaminants. For instance, dredge spoils tend to oxidize as they dry out. Oxidation of sulfides to sulfate and microbial decomposition of organic matter which also produces sulfate, may result in the formation of weak sulfuric acid and acidic soil conditions. Under oxidizing, acidic soil conditions, metal cations can be leached from the sediments and pose a possible contamination problem to the environment.

5.2. Use of Impoundment Basins at Tahoe Keys for Solids Separation and Nutrient Removal

5.2.1. Description of Impoundment Basins and the Sand Classification System

Two methods of solids separation and nutrient removal from hydraulic dredging slurry were used at Tahoe Keys during this study. In 1992, three impoundment basins, linked in series, were used to settle out particulates. These basins were excavated on land adjacent to the Tahoe Keys marina and surrounded by earthen berms to increase their effective depth. They consisted of a long basin (approximately 1 acre x 5 ft. deep) which received flow from the dredge, connected via a plastic-lined weir to smaller basin (approximately 1/5 acre x 5 ft. deep), connected by weir to a third long basin (approximately 1/3 acre x 5 ft. deep). A rock and gravel filter surrounding the drain was located at the end of the third pond. Water was discharged from the third pond via a pipe into a silt curtain enclosed section of the Tahoe Keys lagoons. As the water passed through these impoundment basins, particles and associated nutrients gradually settled to the bottom and quality of water was improved. Appendix Map B-3 shows the general configuration of the ponds in 1992, and the TRG monitoring sites.

In 1993, Pond 1 was decreased in size to about 3/4 acre and a sand classification system was added between the dredge and impoundment basins (see Appendix Map B-4). The purpose of this system was to remove coarse solids from the dredge slurry and selectively remove sand which might be used for beach replenishment at Tahoe Keys. This system first removed larger rocks and vegetation on a large shaker equipped with 12 mesh (1250 micron) screens. Sand classifiers equipped with 200 mesh screens then removed particles greater than 70 μm (120 mesh screens were also used for a period to separate sands greater than 117 μm). Sand was removed from the slurry using hydrocyclones, washed and removed to a stock pile. The remaining slurry of silts, organics, and water was pumped from the classifier into settling Pond 1. As water was being pumped into Pond 1, a mixture of alum and polymer was added to the slurry to promote settling of fine particulates.

5.2.2. Results of Monitoring in the Impoundment Basins in 1992

Turbidity and soluble and total nutrient levels were monitored at several locations within the pond system on selected dates during dredging operations in 1992. A summary of all data is presented in Appendix A-2. Figure 5-1 presents the data for SRP, NH_4-N, turbidity, TN, TP, and BAFe. Patterns for turbidity and nutrients were somewhat erratic for samples taken after the ponds were initially put into use (during the period 9/4/92 -

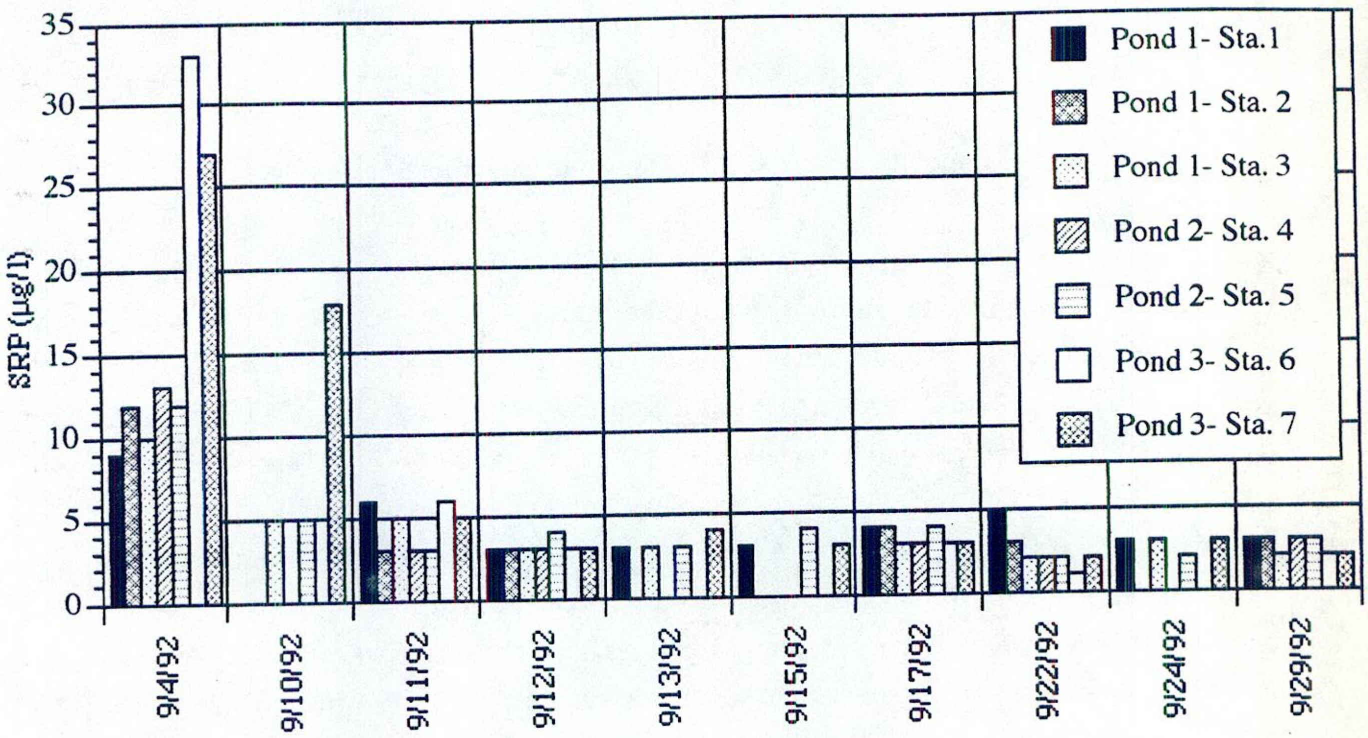

Figure 5-1 (a). Levels of SRP at TRG monitoring sites within the Tahoe Keys spoils impoundment basins during hydraulic dredging in 1992.

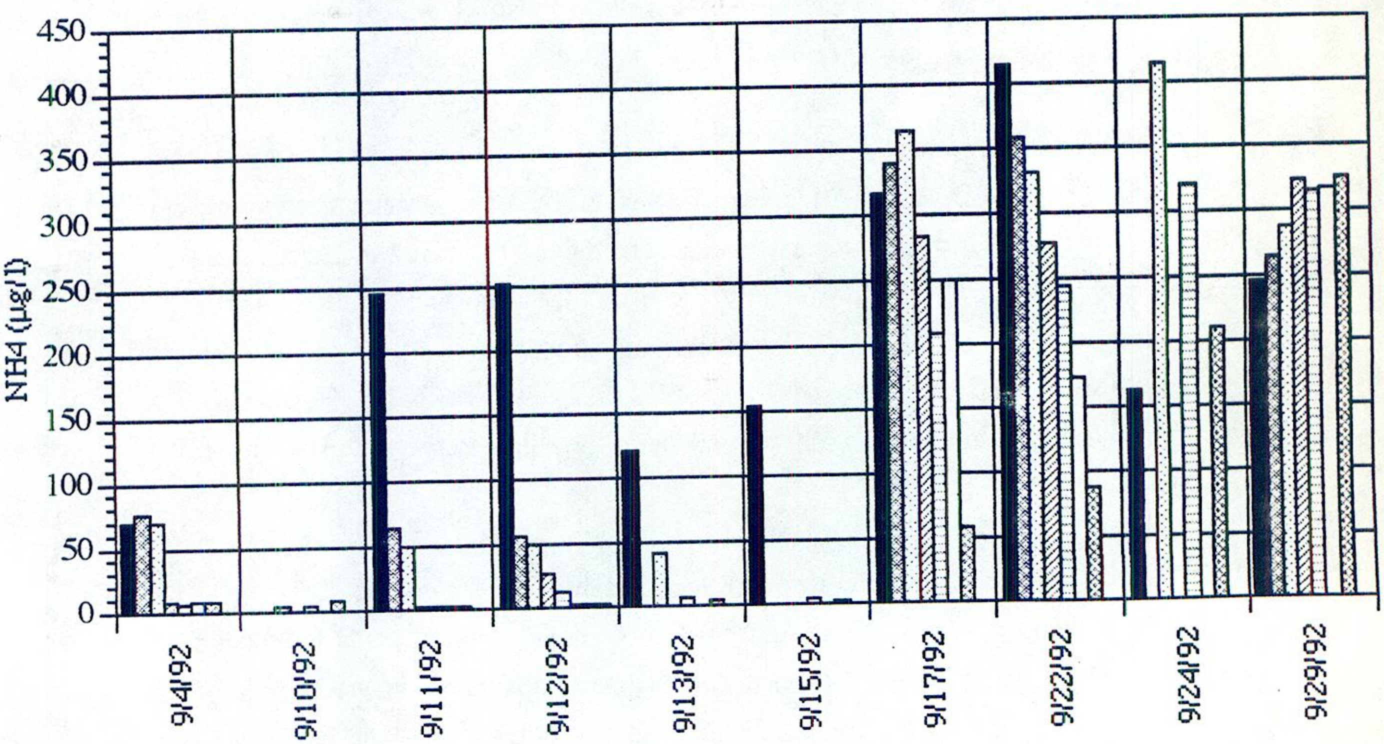

Figure 5-1 (b). Levels of NH4 at TRG monitoring sites within the Tahoe Keys spoils impoundment basins during hydraulic dredging in 1992.

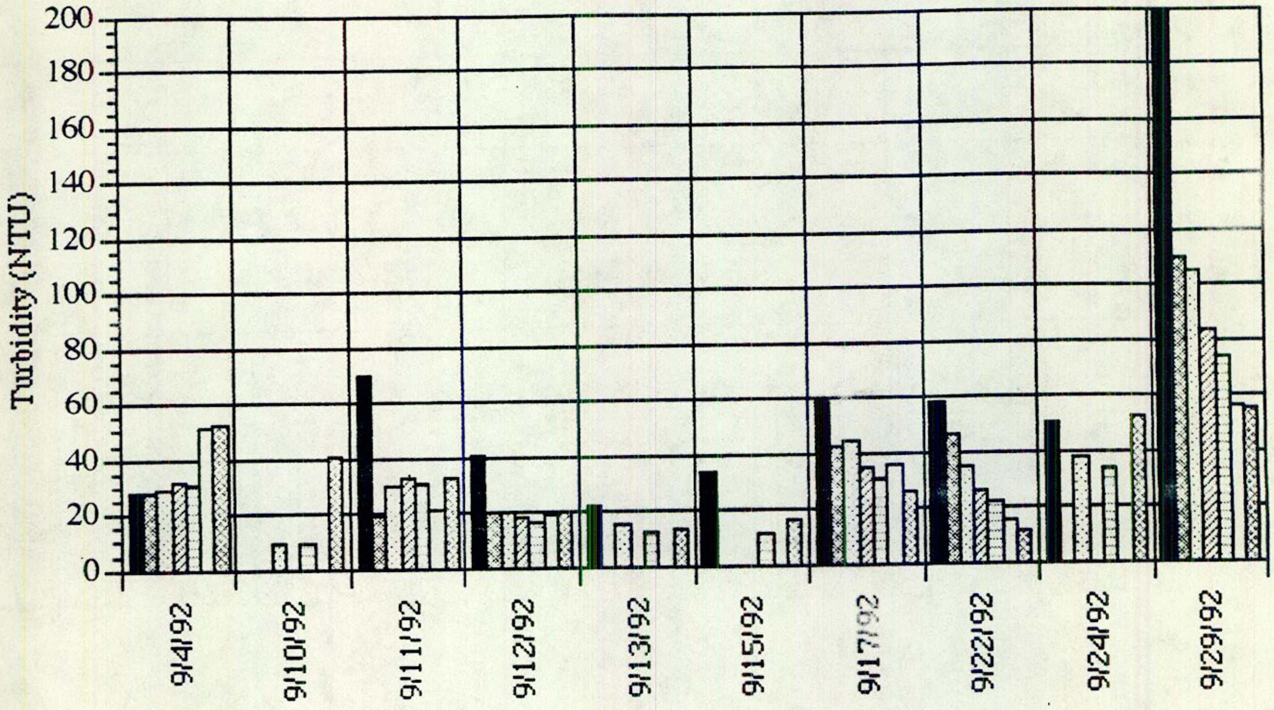

Figure 5-1 (c). Levels of turbidity at TRG monitoring sites within the Tahoe Keys spoils impoundment basins during hydraulic dredging in 1992.

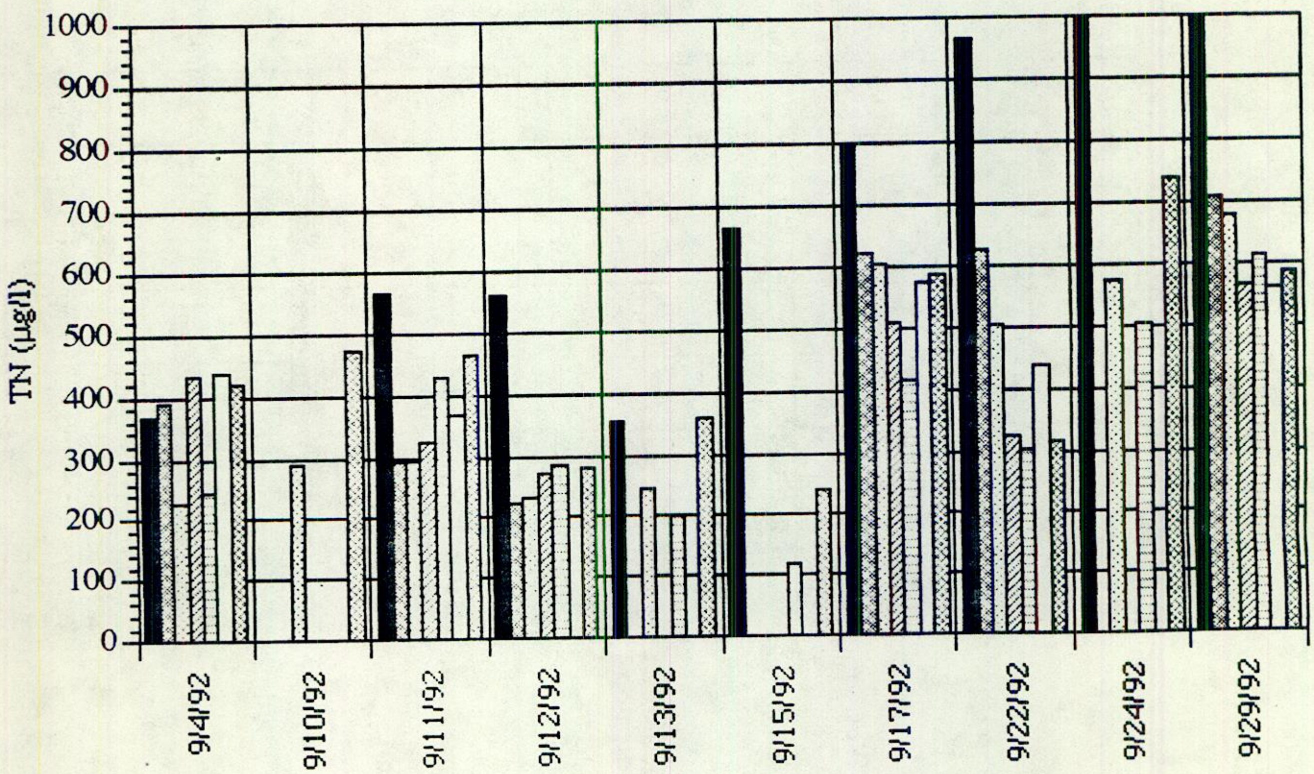

Figure 5-1 (d). Levels of TN at TRG monitoring sites within the Tahoe Keys spoils impoundment basins during hydraulic dredging in 1992.

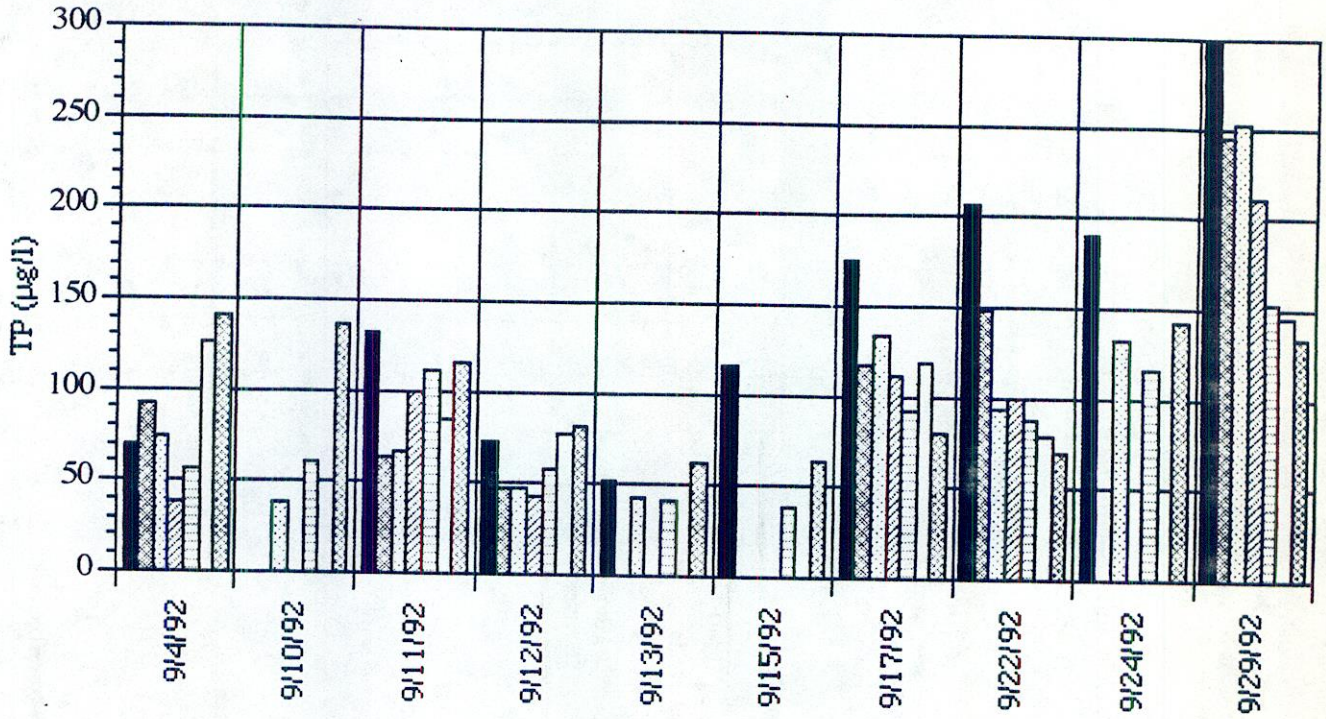

Figure 5-1 (e). Levels of TP at TRG monitoring sites within the Tahoe Keys spoils impoundment basins during hydraulic dredging in 1992.

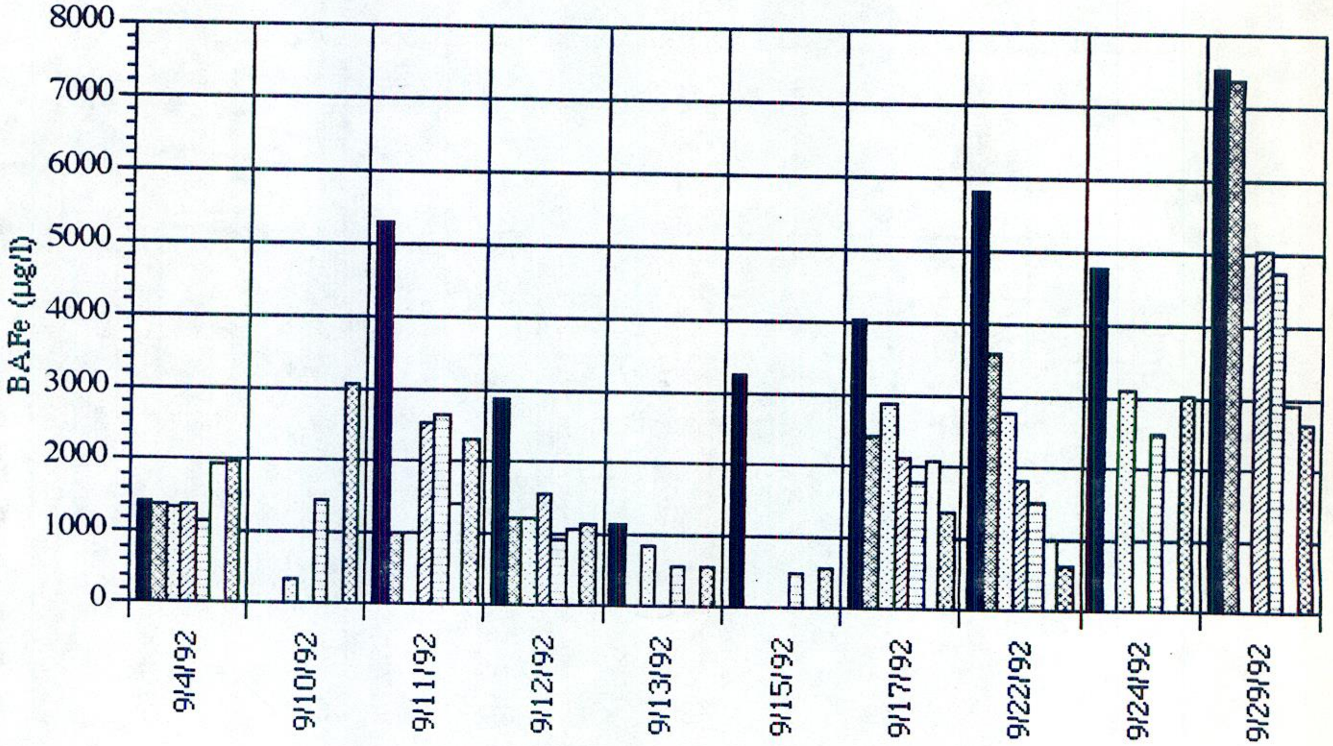

Figure 5-1 (f). Levels of BAFe at TRG monitoring sites within the Tahoe Keys spoils impoundment basins during hydraulic dredging in 1992.

9/11/92). Pond 3 initially had higher turbidity than Pond 2 and exceeded the discharge standard of 20 NTU. This was caused by erosion of sediments from the weir separating Ponds 2 and 3 as the ponds initially filled. After recirculating Pond 3 water back through the pond system, the impoundment basin system was able to meet the discharge standards by 9/12.

A more expected pattern, where turbidity decreased from Sites 1 to 7 as settling occurred in the ponds, was observed on 9/17, 9/22, and 9/29. Levels of TP and BAFe which are largely particulate associated also decreased from Sites 1 to 7 on these dates. TN initially decreased in Pond 1, then showed little decrease in Ponds 2 and 3 on these dates. Soluble NO_3-N and SRP entered the ponds in very low levels and remained at low constant levels throughout the ponds. Soluble NH_4-N decreased between Site 1 to 7 on 9/17 and 9/22, but increased slightly among these sites on 9/29, (NH_4-N often decreased between Sites 1 and 7 for all data). Occasionally, unexpected patterns for turbidity and particulate associated nutrients were observed in the ponds. For instance on 9/24, the levels of turbidity, TN, TP, and BAFe were higher in Pond 1 and 3 than in Pond 2. This may have been caused by wave-caused erosion of berm sediments in the larger Ponds 1 and 3 during strong winds on this date.

Throughout dredging operations, the impoundment basins afforded good removal of coarser solids. Large piles of sands and settled material accumulated near the base of the influent pipe. The most significant decrease in turbidity and particulate-associated nutrients (TN, TP, BAFe) occurred between Site 1 (near the influent pipe) and Site 2 (located about 1/3 the distance along the first pond). Turbidity, TP and BAFe tended to decrease more gradually between Sites 2 to 7 (Figure 5-1), while TN level often stabilized beyond Pond 1.

While the impoundment basins afforded good removal of coarser solids, the finer particulates were not always effectively removed. Turbidity at Site 7 in Pond #3 exceeded the discharge standard of 20 NTU on 9/17, 9/22, and 9/29. Significantly, TP and TN which are largely particulate associated also exceeded the discharge standards in TRG monitoring of Pond 3. TP exceeded the discharge standard of 100 μg/l on 9/24 and 9/29; while TN exceeded the discharge standard on 9/17, 9/24, and 9/29 (see Figure 5-1). Since TRG sampling was done on only a fraction of the total days in which some dredging was accomplished, the discharge standards for turbidity, TN and TP were likely exceeded in Pond 3 on many other days. In fact, data from the dredger's logs indicated the turbidity in Pond 3 was over the discharge standard of 20 NTU in over 90% of the samples taken (median turbidity 60 NTU; 90th percentile 126.8; 10th percentile 23.2; n=66).

Discharge from Pond #3 was piped into a section of the Tahoe Keys enclosed by a silt screen. Within this area, some additional settling of particulates occurred, which reduced the levels of turbidity and nutrients compared to Pond 3 levels. Data from the dredger's logs indicated the median turbidity within this area was 50 NTU (90th percentile 65 NTU; n=61). Discharge of nutrients to this area could also be quite high. The results of TRG monitoring also indicated that levels of nutrients discharged into the silt curtain enclosed area could exceed the discharge standards. For instance on 9/22 and 9/29 TN in "outflow" water from Pond 3 was 629 μg/l and 714 μg/l respectively exceeded the TN discharge standard. On 9/29/92, TP was 131 μg/l which exceeded the discharge standard for TP (see appendix A-2). The inflow of this water displaced some water from the enclosed area through the silt screen, into the Tahoe Keys lagoons. Levels of turbidity outside the silt curtain tended to increase when levels inside the curtain increased, which may indicate some water also moved around or under the curtain. Data from the dredger's logs indicated the median turbidity 1 ft. outside the silt curtain was 11 NTU (90th percentile 24 NTU; n=61) which is much higher than a typical background turbidity in the Tahoe Keys of about 2 NTU. The impoundment basins used at Tahoe Keys in 1992 were unable to provide the turbidity and nutrient removal necessary to achieve discharge standard limits after many consecutive days of dredging. Whenever the levels of turbidity or nutrients inside the silt curtain enclosed areas exceeded the discharge standards and moved into the lagoon water outside the silt curtain, the discharge standards were exceeded. The dredging contractor indicated the pond system "could not support dredging of 7-8 hours per day for more than 6 consecutive days and remain within permit regulations".

5.2.3. Comparison of Turbidity and Nutrient Levels in Impoundment Basins in 1993 with 1992 Levels

Alum + polymer flocculent treatment of effluent proved effective in controlling the levels of turbidity and particulate-associated nutrients in the impoundment basins in 1993. The results of TRG monitoring of the ponds are presented in Appendix A-3 and the results of agency-required monitoring are presented in Appendix A-9. The median levels of turbidity, TRP, TP, TKN, and TN at Site 7 in Pond 3 were lower in 1993, in which sand classification removed sands and coarser materials, and alum flocculent was added (see Figure 5-2). Soluble NH_4-N was also lower at Site 7 in Pond 3 in 1993, which may indicate it was also impacted by the alum additions, possibly through adsorption to settling particles and floc. Comparing the levels of each parameter presented as (median; 90th

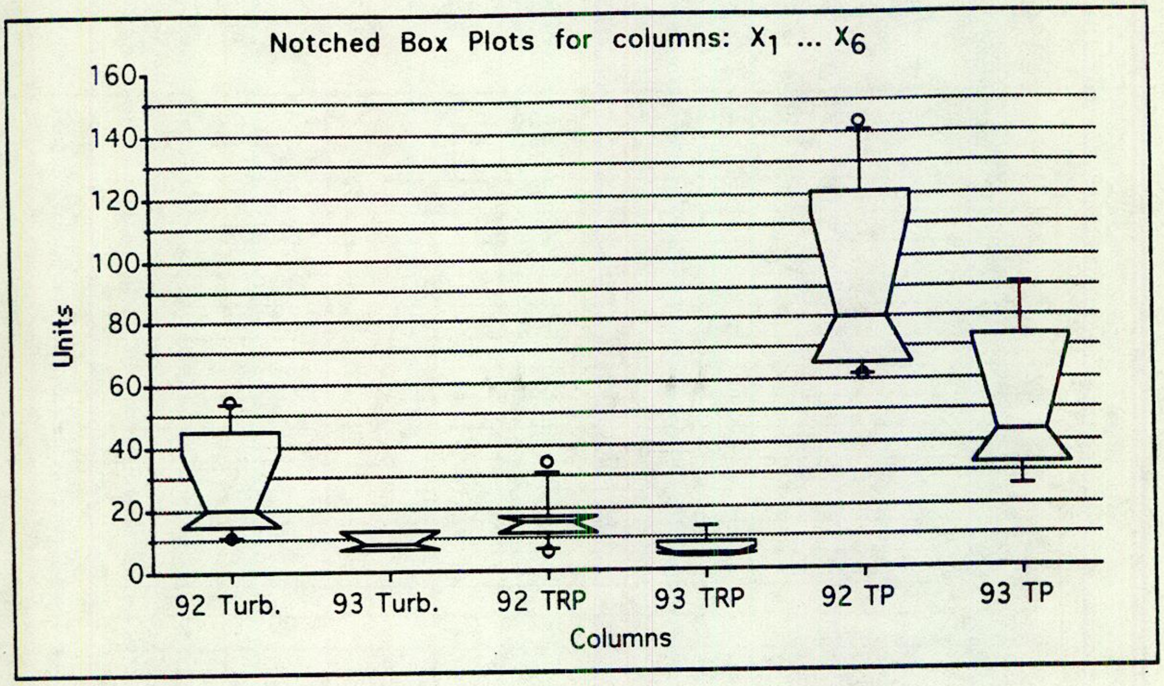

Figure 5-2 (a). Notched box plot comparison of 1992 versus 1993 levels of turbidity, TRP, and TP in Tahoe Keys impoundment basin (Pond) 3, Site 7. Units for turbidity are NTU and units for nutrients are μg/l. In 1992, spoils from the dredge were discharged directly into the impoundment basins. In 1993, sands and larger particulates were removed from the spoils first using a sand classification system, then alum was added to the remaining stream of dredge slurry as it was discharged to the impoundment basins. Box plots are interpreted as follows: the median value for each parameter is indicated by the middle line in each "box"; the notches in the "box" represent the 95% confidence intervals of the median; the top of the "box" represents the 75th percentile value; the bottom of the "box" represents the 25th percentile; the "tic" mark connected to the top of the box by a line represents the 90th percentile value; similarly the "tic" mark connected to the bottom of the box by a line represents the 10th percentile value; outlying points are indicated as circles. Data from 9/4/92, 9/10/92, 9/11/92 was excluded from these calculations since the ponds had not yet stabilized (Pond 3 had unusually high turbidity and nutrient levels resulting from erosion of sediments from the weir); data from 8/25/93 was also excluded as a malfunction occurred with the alum + flocculent injection system which resulted in unusually high turbidity and nutrients in Pond 3 and prevented discharge on this date.

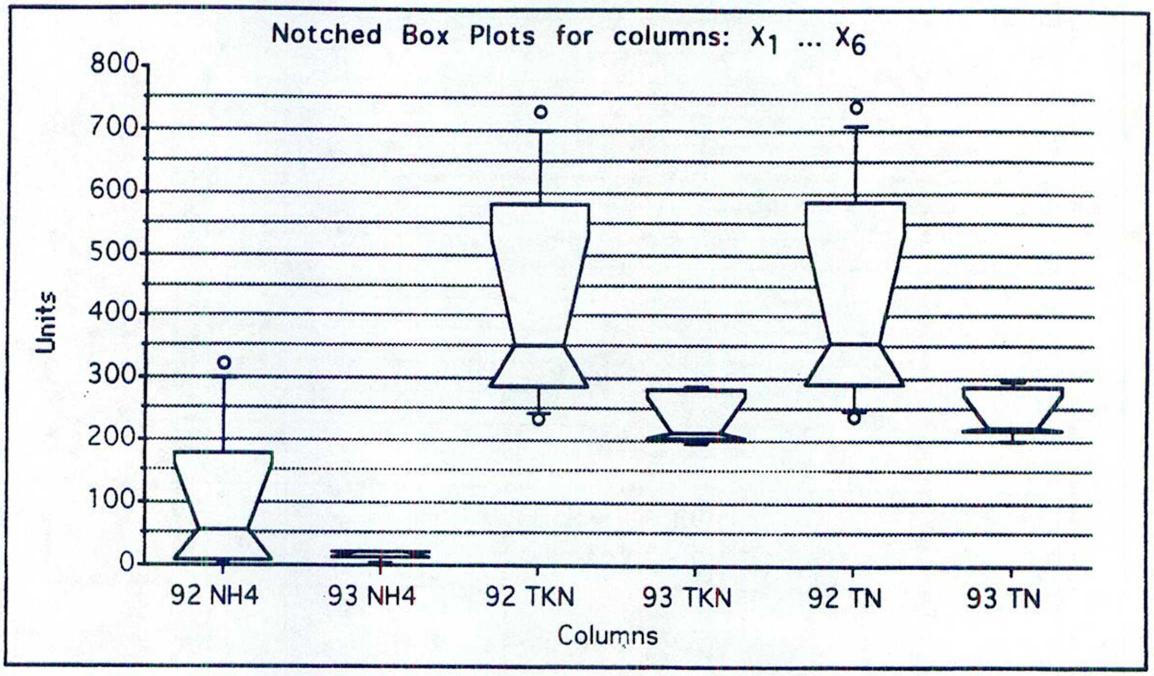

Figure 5-2 (b). Notched box plot comparison of 1992 versus 1993 levels of NH4, TKN, and TN in Tahoe Keys impoundment basin #3, Site 7. Units for nutrients are (μg/l).

percentile value; n) for TRG data[1]: 1992 turbidity (20; 54; 7); 1992 TKN (354; 701; 7); 1992 TN (357; 710; 7); 1992 TRP (16; 32; 7); 1992 TP (80; 141; 7); 1992 NH_4-N (58; 302; 7); 1993 turbidity (9; -; 4); 1993 TKN (213; 290; 5); 1993 TN (222; 296; 5); 1993 TRP (4; 14; 5); 1993 TP (44; 91; 5); 1993 NH_4-N (21; 24; 5). Data from the dredger's logs indicated the median pond 3 turbidity to be 14 NTU (n=33) in pond 3 in 1993 compared to 60 NTU (n=66) in 1992; and the median turbidity outside the silt curtain to be 4 NTU (n=32) compared to 11 NTU in 1992.

The majority of the reduction in turbidity and nutrients within the pond system may be attributed to the addition of alum + polymer flocculent. Although some finer particles may have been removed with sands in the sand classification system, the majority of finer particles likely were discharged into the impoundment basins. A mixture of alum and synthetic polymer was injected directly into this discharge. Alum (hydrated aluminum sulfate) when mixed into lake water (of higher pH) hydrolyzes and forms fluffy gelatinous precipitates of aluminum hydroxide which enmesh small particles and associated nutrients into larger particles or floc. The floc with associated sediments and nutrients then settled out of solution. Water soluble polymers, such as polyacrylamides, are organic flocculating agents often used in conjunction with alum, which also remove small particles from solution by flocculation. The combination of alum and polymer proved very effective in reducing turbidity within the impoundment basins.

5.2.4. Potential Impacts of Alum

Lahontan required monitoring of aluminum outside the silt screen at the discharge area and in the vicinity of the cutter, in association with the use of alum. Outside the silt screen, the (median; 90th percentile; n) values for aluminum were: 1 ft. outside the silt screen (0.11 mg/l; 0.41 mg/l; n=11); 50 ft. outside screen (0.10 mg/l; 0.18 mg/l; n=11). The predredging background level of aluminum inside the discharge area was reported to be < 0.1 mg/l. Thus, aluminum was often near the background level outside the silt screen. It was difficult to determine whether aluminum outside the silt screen was attributable to injected alum or aluminum released by dredging. Aluminum was often higher near the cutter during dredging (median 0.87 mg/l; 90th percentile 2.45 mg/l;n=8) than outside the silt screen. The dredging appeared to release aluminum from the

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1- Data from 9/4/92, 9/10/92, 9/11/92 was excluded from these calculations as the ponds had not yet stabilized (Pond 3 had unusually high turbidity and nutrient levels resulting from erosion of sediments from the weir); data from 8/25/93 was also excluded as a malfunction occurred with the alum + flocculent injection system which resulted in unusually high turbidity and nutrients in Pond 3 and prevented discharge on this date.

sediments. This aluminum may possibly have been contributed to the sediments from past applications of alum made in the lagoons. Levels of aluminum in the dredge slurry therefore may have been elevated both from aluminum released from the sediments and also possibly from abrasion of the aluminum spoils discharge pipe.

Alum is commonly used in water treatment as a flocculent to remove particulates and phosphorus. It also has been successfully applied in large volumes to lakes to deter phosphorus release from the sediments (Welch et al., 1988). Some concerns over the use of alum involve the potential toxicity of certain forms of aluminum and the effects alum may have on pH in water in which it is applied. However, aluminum species are not normally considered toxic at pH values between 5.5-9.0. The precipitates formed by administration of alum in aquatic systems are also nontoxic. Within the Tahoe Keys, the pH of lagoon water is generally between 8.0-9.0 with values occasionally exceeding 9.0 (Doug Helgeson, TKPOA Water Treatment Plant, personal communication). Thus, while only very small amounts of aluminum were found to be leaking past the silt curtains (detected as levels above background outside the curtains), these low levels were primarily in the nontoxic forms. The addition of large quantities of alum to unbuffered lake water can also lower pH and potentially impact biota. However, Tahoe Keys water can accept a relatively large dose of alum before pH is reduced to a level which might pose a problem (i.e. pH < 5.5). Doses of alum as high as 140 mg/l have been applied to Tahoe Keys water within the treatment plant system while still maintaining near neutral pH=7.0 (Doug Helgeson, TKPOA Water Treatment Plant). The microgram per liter additions of alum added to the ponds likely had little impact on the pH of discharge water and levels of toxic forms of aluminum present. The effects of various levels of alum on elutriate test water and lake water pH, turbidity, aluminum, and nutrient levels should be included in predredging testing for future projects where the use of alum is proposed. Until further study can be made of the impacts of alum on sediment-nutrient interactions in the lake and on lake biota, agency approval of the use of alum in impoundment basins should be made with caution. We strongly recommend that special provisions for monitoring be placed on projects using alum.

5.2.5. Criteria for Design of Impoundment Basins

Impoundment basins must be properly designed to achieve optimum settling of solids. USAEWES (1988) provide guidance for design of confined disposal areas for small hydraulic maintenance dredging projects. Cullinane et al. (1990) also provide information on proper design of impoundment basins and literature references for detailed procedures on sizing basins. Briefly, the size of an impoundment basin depends on the settling characteristics of the smallest particles requiring settling, the viscosity of the water, and the rate of discharge from the ponds. Impoundment basins are used to remove particles in the size range of gravels down to fine silt (10-20 μm when flocculents are used to promote settling). Thus, the smaller clay size particles may not be effectively removed within impoundment basins. Factors such as increased depth of basins, presence of spur dikes to alter flow patterns, and increasing the length of discharge weirs can enhance retention in the ponds.

5.3. Quality of Sands Generated from the Sand Classification System

Originally, sands produced from the sand classification system were proposed for use in beach replenishment on the Tahoe Keys Property Owners Association (TKPOA) beach. Detailed testing of these sand samples for nutrients and TBT was done by Lahontan to determine acceptability of these sands for beach replenishment. Based on the findings of Lahontan analyses, the sands were found to have associated nutrients which could add to the pool of available nutrients for algae growth in the lake and, therefore, potentially have a detrimental impact. The sands were not accepted for beach replenishment. The results of the TRG chemical analysis of sand classification system sands are presented in Appendix A-12. These results also indicated the sand produced from the classification system still had residual nutrients associated with them. The median levels of DIN, TN, BAP and TP released into the elutriate test water from sand classification system sands were: 0.06 μg DIN/g sediment shaken; 2.22 μg TN/g sediment shaken; 0.07 μg BAP/g sediment shaken; and 0.94 μg TP/g sediment shaken. The levels of nutrients measured in sand classification system sands were similar to levels found in a Tahoe Keys predredging core sample which was primarily sand (e.g. Tahoe Keys Core 3, see Table 3-1).

5.4. Other Solids Separation Systems

During previous dredging projects at Lake Tahoe, various other methods of solids removal have been used and have met with varying degrees of success. At Tahoe Keys, in 1991, hydrocyclones were used for removal of solids during dredging in the lagoons. This system separated out much of the solids and the remaining water and suspended particulates were pumped to a screened area of lagoon and then treated in the Tahoe Keys water treatment system. This method was effective but expensive ranging from $15-$20 per cubic yard (Charlie Ferguson, Western Industrial Environmental Services, personal communication). In the North Tahoe Public Utility District dredging of the Coon St. boat ramp in Kings Beach, settling tanks were used to remove solids prior to discharge of the slurry to the sewer system. However, the settling tanks were of insufficient size to effectively remove the sands. As a result, much of the solids were pumped into the sewer lines: an undesirable situation.

It should be noted that in addition to hydrocyclones, hydraulic classifiers and spiral classifiers are available to separate gravel and sand from slurries (Cullinane et al., 1990).

5.5. Spoils Dewatering

In mechanical dredging operations, the spoils are usually piled in a designated basin or enclosed area and the excess water allowed to drain from the sediments. This water is typically a combination of overlying lake water, sediment pore water, and elutriate-type water laden with sediments, which contains elevated levels of nutrients and other contaminants. This water may enter the lake either via percolation through the ground water or direct drainage and have an impact on the lake.

5.5.1. Spoils Dewatering at Crystal Shores East

Dewatering at Crystal Shores East was done on a section of sandy beach adjacent to the lake. A filtration fence was installed between the spoils and the lake to retain particulates in runoff. All of the water contained in these spoils percolated into the beach sands. However, along the shoreline downgradient of the dewatering area on 10/8/93, an area of white foam was observed. This seemed to be related to the nearby spoils pile. We collected samples of shallow (1 in. deep) lake water at the shoreline downgradient of the pile and at sites located along the shoreline away from the pile. Had spoils water entered the lake from percolation through the sands, it would have been concentrated in shallow areas adjacent to the shore where little dilution with lake water occurred. Five samples of shallow lake water were collected: Site A located downgradient of the east edge of the pile along a spit of sand adjacent to the bulkhead; Sites B and C located immediately downslope of the pile; Site E located 59 ft. from the western edge of the spoils pile; and Site F located 85 ft. from the western edge of the spoils pile. The water samples were analyzed for NO_3-N, NH_4-N, and SRP (Appendix A-5). Sites B and C located immediately downslope of the pile were significantly elevated in NO_3-N (1062 μg/l and 125 μg/l respectively), while the other three sites had low NO_3-N (ranging from 7-9 μg/l). NH_4-N and SRP were low at all sites. Within the silt curtain enclosed dredge area, a high NO_3-N concentration of 152 μg/l was also observed. This indicated high NO_3-N was present in the sediments being dredged and, therefore, likely present in water draining from the spoils pile. These data seemed to confirm that spoils water was percolating through the sand into the lake, and that some associated substances in the spoils water was a cause of the foam along shore. This high NO_3-N was diluted to near background levels in deeper (1-2 ft. deep) water approximately 7 ft. out from the shoreline at Site 11. Near background levels of turbidity, NH_4-N, TKN and TP were also found at Site 11.

Percolation of spoils water into the ground water can mitigate to some extent the potential impacts of nutrients and other contaminants contained in the spoils water. Particulates and particulate-associated nutrients will tend to be filtered out and retained in soils through which the water percolates. Additionally, ions such as PO_4^{-3} and NH_4^+ may sorb to clay particles in the soils and be retained at the site. Heavy metal cations may similarly sorb to organic and clay particles and be retained. However, soluble ions such as NO_3^- may move relatively unimpeded through the water table sediments. The movement of ground water downslope may eventually carry these soluble nutrients into the lake as underwater seepage or surface runoff from springs. The beach sand at Crystal Shores East appeared to be effective in filtering out particulates and particulate-associated nutrients associated with the spoils water (near background levels of turbidity were measured at Site 11 nearshore). Much of the NH_4-N and SRP may also have been retained in the sands, as these levels were low in shallow shoreline water adjacent to the spoils pile. However, NO_3-N appeared to move relatively rapidly with spoils water through the sands into the lake.

To minimize the potential impacts associated with dewatering and input of soluble nutrients into the lake, dewatering on porous beach sediments adjacent to the open lake is not recommended. One alternative is to line the dewatering area with an impervious material and provide for complete capture and disposal of the drainage water away from the lake. Another alternative when site conditions permit, would be to dewater spoils on land within an area enclosed by silt curtains or upgradient of the silt curtain enclosed area. Within such areas, the pore water draining from the sediments will remain within the confines of the dredge area. Percolation of water into sediments upslope of the dredge area may remove some particulates and nutrients. Particulates in spoils water draining into the silt curtain enclosed area may settle and be subject to later removal by the dredge. Suspended particulates and soluble materials may subsequently be removed from the area if impacted water is removed by pumping to the sewer or other suitable area outside the lake. Where the movement of spoils water through the ground water is slow, seepage may enter the lake after the silt curtains are removed. However, when the original dewatering is done upslope of a harbor, the ground water seepage should enter the protected waters of the harbor, where some additional removal may be afforded by algae and (if present) aquatic macrophytes. If this vegetation senesces and becomes incorporated into the harbor sediments, some of the potential impact of spoils nutrients on the main lake will be mitigated.

5.5.2. Spoils Dewatering at Fleur Du Lac

At Fleur Du Lac, initial dewatering was done on sections of land within the confines of the silt screen enclosed dredge areas. Water draining from the spoils returned to the dredge area water and added to the nutrient concentrations. Since pumping of the dredge area water to the sewer system was done, much of the nutrients released during dewatering were ultimately removed from the lake. The spoils were then loaded onto a conveyor belt and transported to a swale where the spoils were temporarily stored prior to transport out of the basin. Some additional dewatering likely occurred within this swale and the water percolated into the ground beneath the swale.

5.5.3. Other Dewatering Systems

Cullinane et al. (1990) describe dewatering systems used for contaminated dredge material. These consist of containment areas underlain by an underdrainage system for collection of percolating spoils water. Collector pipes are placed within an bottom layer at the disposal site. Free water percolating through the dredged material migrates into the underdrainage layer and is collected by the collector pipes. The water then may be removed by gravity or pumping for disposal. Such dewatering systems can prevent contamination of ground water. Ideally, a dewatering area will allow complete capture and removal of the spoils water prior to reaching the lake.

5.6. Spoils Disposal

During this study, the ultimate fate of dredge spoils from each project was different. Sediments from the Crystal Shores East project were used within the Lake Tahoe basin as landfill at a nearby site in Crystal Bay. Dredged materials from Fleur Du Lac were transported out of the Lake Tahoe basin on lined trucks to Truckee. The largely gravel and cobble sediments from this project were used in construction activities. Sands from the dredging at Tahoe Keys were transferred to a local cement plant for use.

Following partial dewatering, spoils are often disposed of outside the basin. This reduces potential impacts associated with leaching of nutrients and contaminants from the sediments. It is generally recognized that difficulties can arise following land disposal of extremely contaminated sediments. Oxidation and production of sulfate in the sediments, can lead to acidic conditions which may mobilize metal cations. However, past analyses of Lake Tahoe marina sediments required by the regulatory agencies, have indicated levels of several heavy metals to be low. Moderate levels of oil and grease have been found in some Lake Tahoe marina sediments. Since many of the degradation products of oils and fuels are potentially toxic, disposal of very polluted sediments within the basin could impact fauna detrimentally. Predredging analysis of heavy metals, and Total Petroleum Hydrocarbons (TPH) in the sediments should be done and should aid in decisions on the ultimate fate of spoils material. Where levels of heavy metals or TPH are high, consideration should be given to disposal outside the basin.

The dredge spoils have also been shown to have potentially high levels of nitrogen and phosphorus associated with them. In the absence of other contaminants, such as metals and TPH, the presence of these nutrients may not warrant mandatory disposal outside of the basin. Much of the nitrogen and phosphorus present in the sediments is often strongly bound to the sediments or bound in particulate organic matter. These forms of nutrients may take long periods of time to degrade, and inorganic degradation products could potentially be utilized by terrestrial vegetation. The finer sediments associated with the dredge material, however, may be easily mobilized during surface runoff of rain or snowmelt. When dredge spoils are disposed of within the basin, it is recommended that the disposal is well away from the lake and surface water bodies such as streams and lakes. Further, it is recommended the sediments be stabilized via revegetation once deposited within the basin. Further study is needed to determine the fate of nutrients in this disposal material and to determine the mitigating effects of revegetation.

<u>Summary - Section 5</u>

1) The series of three spoils impoundment basins used at Tahoe Keys in 1992 were unable to provide the turbidity and nutrient removal necessary to consistently achieve discharge standard limits at inflow rates of approximately 1000 gallons per minute during 7-8 hrs. of operation per day. However, the addition of alum + polymer flocculent to spoils water discharged into the impoundment basins in 1993 proved effective in reducing the levels of turbidity and nutrients (NH_4-N, TRP, TP, TKN, TN) such that discharge standards were more consistently attained.

2) Spoils dewatering on land within an area enclosed by silt curtains or upgradient of the silt curtain enclosed area is preferable to dewatering along the shoreline adjacent to the lake. Ideally, a dewatering area will provide for complete capture and removal of the spoils water prior to reaching the lake.

3) Predredging analysis of the levels of heavy metals, Total Petroleum Hydrocarbons (TPH), and other potentially toxic substances in marina sediments, as well as their potential to be mobilized, should be done in order to make decisions on the ultimate fate of dredged spoils. Where levels of toxic substances are high, consideration should be given to disposal outside the Lake Tahoe basin.

6. Algal Bioassays

Algal bioassay experiments were done to determine the potential impact of nutrients released during dredging on Lake Tahoe algae growth. In these bioassays, small quantities of marina or nearshore sediment, or elutriate supernatant solution were added to Lake Tahoe water containing natural phytoplankton assemblages in 500 ml culture flasks. The cultures were incubated in a laboratory incubator for 6 days at ambient temperature and with a natural light cycle. The change in biomass or growth response of the algae was then followed by monitoring changes in chlorophyll concentration. The growth response of cultures to which nutrient, sediment, or elutriate supernatant additions were made were contrasted with the response of "control" cultures to which no addition had been made.

In Section 6-1, we discuss the results of bioassays in which algal response to additions of N or P was measured. These bioassays provided information on the nutrients "limiting" phytoplankton growth during the study. The concept of "limiting nutrient" is based upon Justus von Liebig's "Law of the Minimum" which states that the yield or growth of an organism will be determined by the abundance of the food material (or nutrient) that relative to the needs of the organism is least abundant in the environment. For instance, phosphorus is said to be "limiting" when sufficient nitrogen and all other required nutrients except phosphorus are present to cause growth. Upon supply of phosphorus to "P-limited" algae, growth would increase, but only to a point until another nutrient, or perhaps P again became limiting. Under natural conditions, nutrient limitation is not quite so simple. The abundance of many potentially limiting algal nutrients relative to need may change spatially and temporally, leading to fluctuations in nutrient limitation. Lake algal populations may also consist of many different species of algae and the nutritional requirements may vary among some of these species. Further, it is possible for two or more factors to be colimiting. For instance, such a situation may arise when two nutrients, such as N and P are equally scarce relative to the organism's need. All of these conditions have been observed in Lake Tahoe.

6.1 Response of Lake Tahoe Phytoplankton to Nitrogen and Phosphorus

Bioassays were done in November 1993, and July and October of 1994, to test the impacts of nitrogen (N) and phosphorus (P) added alone and in combination on algal growth. The results of these bioassays are presented in Appendices A-21, A-22, A-24, A-25, A-26. Table 6-1 summarizes the results from these bioassays for additions of 20 μg/l N, 10 μg/l P and the combination of 20 μg/l N + 10 μg/l P treatments.

Table 6-1. Results of bioassays which tested the response of Lake Tahoe phytoplankton to treatments with 20 μg/l N, 10 μg/l P and 20 μg/l N+10 μg/l P. Phytoplankton growth response was measured as (+) increase or (-) decrease in culture extracted chlorophyll relative to control cultures to which no addition was made. The probability (p) values that treatment responses were not statistically different from the control are shown; "NS" indicates treatment differences from the control were not statistically significant (p>0.05).

Test Date	20 μg/l N		10 μg/l P		20 μg/l N+10 μg/l P	
	(+) Incr. or (-) Decr. in Chlor. (μg/l)	Stat. Signif. Level	(+) Incr. or (-) Decr. in Chlor. (μg/l)	Stat. Signif. Level	(+) Incr. or (-) Decr. in Chlor. (μg/l)	Stat. Signif. Level
Nov. 30, 1993	+0.67	p≤.001	-0.25	p≤.05	+0.94	p≤.001
July 6, 1994	+0.01	NS	-0.04	NS	+0.20	p≤.001
July 20, 1994	+0.04	NS	+0.04	NS	+0.10	NS
July 28, 1994	+0.04	NS	+0.01	NS	+0.22	p≤.001
Oct. 31, 1994	+0.07	NS	+0.05	NS	+0.30	p≤.001

During the bioassays of July and October, 1994, additions of N or P alone did not significantly stimulate algal growth. However, the combination of N+P added together did stimulate growth. These results indicated that phytoplankton were primarily colimited by N and P during the summer and early fall period. In late fall 1993, the phytoplankton were significantly stimulated by N, and showed a greater response to the combination of N+P added together.

The results of these bioassays showed that phytoplankton were colimited by N and P in the summer, when dredging is most likely to occur. This indicated that the release of nutrients from dredging which consisted of a combination of both algal-available N (NO_3-N and NH_4-N) and P (BAP) were likely to increase algal growth. The forms of algal available N and P immediately bioavailable included inorganic NH_4-N and NO_3-N, SRP and BAP. However, where the dredging released predominantly only one or the other, or very low levels of both, little algal growth was likely to occur. These results are similar to bioassays performed during the summer period in previous years, which have shown the N+P treatment often to cause the greatest phytoplankton growth response compared to N or P alone (see Goldman et. al., 1993). However, they differ from recent years in that phosphorus alone did not stimulate algal growth in the summer. 1994 was another year of drought in California, with well below normal input of stream water and precipitation into the lake. The lake did not mix completely to the bottom and this resulted in reduced internal loading of nutrients into the upper water column where algae grow. The absence of normal inputs of N and P, and algal utilization of the N and P available in the upper water column may have severely depleted levels of both, and resulted in colimitation.

The bioassay done on 31 October 1994 also investigated the response of Lake Tahoe phytoplankton to several different concentrations of added N and P. The results of this bioassay are presented in Table 6-2, and also in Appendix A-26. The results of this bioassay indicated that phytoplankton growth could be stimulated upon addition of very small quantities of N and P added together. Quantities as low as 4 μg/l N and 2 μg/l P were tested in this study and found to stimulate algal growth. Lower levels than this may also cause detectable growth responses, based on the apparent trend of a gradual decrease in growth response in association with decreased N and P levels. Where dredging operations resulted in small, microgram per liter increases of DIN and BAP concentrations in the water an increased algal growth response was possible.

Table 6-2. Results of 31 October, 1994 bioassay which tested the response of Lake Tahoe phytoplankton to treatments with varied levels of N, P, and N+P. Phytoplankton growth response was measured as (+) increase or (-) decrease in culture extracted chlorophyll relative to control cultures to which no addition was made. The probability (p) values that treatment responses were not statistically different from the control are shown; "NS" indicates treatment differences from the control were not statistically significant ($p>0.05$).

Treatment as ($\mu g/l$) of N or P	(+) Increase or (-) Decrease in Chlorophyll a ($\mu g/l$)	Statistical Significance Level
N (4)	+0.02	NS
N (10)	+0.05	NS
N (20)	+0.07	NS
P (2)	+0.07	NS
P (5)	+0.05	NS
P (10)	+0.05	NS
N (4) + P (2)	+0.19	$p\leq.001$
N (10) + P (5)	+0.24	$p\leq.001$
N (20) + P (10)	+0.30	$p\leq.001$

6.2 Response of Lake Tahoe Phytoplankton to Nutrients Released from Marina Sediments

To determine what impacts the particulate and soluble nutrients released during dredging might have on algal growth, small (1% by volume) additions of elutriate test supernatant water from selected sediment samples, were added to Lake Tahoe water containing phytoplankton, and growth response monitored. The results of these bioassays are presented in Appendices A-19 through A-25, and summarized in Table 6-3.

A majority of the predredging harbor and marina sediment elutriate solutions stimulated Lake Tahoe phytoplankton growth. When the amount of DIN and BAP added in the elutriate test solutions was calculated, statistically significant growth responses were measured at DIN levels as low as 0.05 μg/l + 0.12 μg/l BAP. It is important to recognize that the dredging may release not only readily bioavailable forms of N and P to the surrounding water, but also organic N which may undergo some degradation to inorganic N, BAFe, and possibly iron and other trace metals and growth factors required by the algae for growth. The combined effect of all of these nutrients added together likely resulted in the observed algal growth responses. Tahoe phytoplankton appear to be sensitive to additions of very small amounts of nutrients, (on the order of tenths of μg/l of DIN and BAP) when added in concert with the dredged sediments. Lake Tahoe stream water has been shown to have a similar effect in algal bioassays, where the amount of increase in algal growth was often more than could be explained based only on the levels of N and P. The effect was attributed to the presence of trace metals, chelators and other substances present in the stream water that enhanced the growth response (Goldman and Armstrong, 1969).

Elutriate test supernatant from shallow nearshore sediments (which were collected away from harbors and marinas) were found to be non-stimulatory. These natural surface sediment treatments contributed low-to-moderate levels of DIN (0.23-0.87 μg/l), and treatments from Homewood, Valhalla, and Regan Beach sediments contributed no measurable BAP, while the Kings Beach treatment contributed a low level of BAP (0.65 μg/l). Natural sediments are likely affected by microbial and algal communities which grow at or near the sediment surface. Previous utilization by these communities may reduce levels of nutrients, trace metals and vitamins present in these surface sediments. As a result, low levels of algal available N and P were released to the supernatant water during elutriate tests, along with potentially low levels of trace metals and other important growth factors. This may explain the general non-stimulatory effects of these treatments.

Table 6-3 (a). Results of bioassays which tested the response of Lake Tahoe phytoplankton to treatments with 1% by volume additions of elutriate test supernatant water from predredging harbor and marina sediments, and natural nearshore sediments. Phytoplankton growth response was measured as (+) increase or (-) decrease in culture extracted chlorophyll relative to control cultures to which no addition was made. The probability (p) values that treatment responses were not statistically different from the control are shown; "NS" indicates treatment differences from the control were not statistically significant (p>0.05). Levels of DIN and BAP present in 1% additions of elutriate supernatant are shown along with the date of the bioassay.

Project / Core Section	Chlorophyll (+) Increase (-) Decrease (μg/l)	Statistical Signif. Level	1% Elutriate DIN (μg/l)	1% Elutriate BAP (μg/l)	Test Date
Marina Sediments Prior to Dredging					
Tahoe Keys Lagoons					
C1-3	+0.39	p≤0.001	0.90	2.61	Sept. 7 1993
C2B-1	+0.43	p≤0.001	3.37	0.55	"
C2B-2	+0.17	p≤0.05	0.27	2.15	"
C2B-4	+0.28	p≤0.01	0.16	3.39	"
Fleur Du Lac					
C1-1	+0.34	p≤0.001	4.16	0.19	Sept. 7 1993
C1-4	+0.26	p≤0.01	0.37	0.32	"
C2-1	-0.04	NS	0.16	0.00	"
C3B-2	+0.31	p≤0.001	0.05	0.12	"
Crystal Shores East					
C1-4	+1.03	p≤0.001	3.55	6.10	Nov. 30 1993
C2-3	+0.84	p≤0.001	20.83	0.11	"
C2-4	+1.48	p≤0.001	8.01	4.20	"
C3-1	+0.64	p≤0.001	4.17	0.09	"
Tahoe Boat Co.					
C1-1	-0.03	NS	1.47	0.36	July 6 1994
C1-2	+0.02	NS	4.44	NA	"
C3a-1	+0.27	p≤0.001	23.52	0.57	"
C3a-2	+0.13	p≤0.001	31.89	0.36	"
C3a-3	+0.07	p≤0.05	17.68	0.15	"
Natural Lake Nearshore Surface Sediments					
Kings Beach	+0.07	NS	0.33	0.65	July 28 1994
Homewood Beach	+0.01	NS	0.85	0.00	"
Valhalla Beach	-0.06	NS	0.23	0.00	"
Regan Beach	+0.16	NS	0.87	0.00	"

Table 6-3 (b). Results of bioassays which tested the response of Lake Tahoe phytoplankton to treatments with 1% by volume additions of elutriate test supernatant water from postdredging harbor and marina sediments. Phytoplankton growth response was measured as (+) increase or (-) decrease in culture extracted chlorophyll relative to control cultures to which no addition was made. The probability (p) values that treatment responses were not statistically different from the control are shown; "NS" indicates treatment differences from the control were not statistically significant (p>0.05). Levels of DIN and BAP present in 1% additions of elutriate supernatant are shown along with the date of the bioassay.

Project Core Section	Chlorophyll (+) Increase (-) Decrease (μg/l)	Statistical Signif. Level	1% Elutriate DIN (μg/l)	1% Elutriate BAP (μg/l)	Test Date
Marina Sediments 10 Months After Dredging					
Tahoe Keys Lagoons					
pd C 1-1	-0.04	NS	0.08	0.25	July 6 1994
pd C 1-2	-0.04	NS	0.03	0.27	"
pd C 1-3	-0.02	NS	0.32	0.34	"
Fleur Du Lac					
pd C 1a-1	+0.09	p≤0.01	2.58	1.08	July 6 1994
pd C 1a-2	+0.16	p≤0.001	5.23	3.97	"
pd C 1b-2	+0.35	p≤0.001	8.75	4.18	"
Crystal Shores East					
pd C 1b-1	-0.06	NS	0.42	2.18	July 28 1994
pd C 2	+0.02	NS	1.14	1.01	"

The absence of growth response caused by the Fleur Du Lac sample C2-1, and Tahoe Boat Co. samples C1-1, C1-2 - which were collected outside the harbors - could also be attributed to previous biological utilization and mechanical reworking of the sediments. Similar to the nearshore samples, these were all relatively shallow samples, collected from areas exposed in the open lake. Fleur Du Lac sample C2-1 sediments were primarily cobble and gravel, from the entrance area outside the main harbor and the elutriate supernatant treatment from these sediments contributed low DIN (0.16 μg/l) and no appreciable BAP. Tahoe Boat Co. sample C1-1 sediments consisted of sand, gravel and cobble and the elutriate supernatant contributed moderate DIN (1.47 μg/l) and low BAP (0.36 μg/l). Tahoe Boat Co. C1-2 sediments consisted of clay, and the elutriate supernatant treatment contributed moderate DIN (4.44 μg/l), there was not enough sample to analyze BAP. It is possible these sediments from outside the harbor were depleted in trace metals and other growth factors which enhance the growth response to N and P. The presence of a low level of either N or P under colimiting conditions, and low levels of other important growth factors, may explain the nonstimulatory response to these sediment treatments.

Bioassays were also done which tested the stimulatory potential of elutriate supernatant solutions from sediments collected from the dredge areas approximately 10 months after dredging. Elutriate supernatant solutions from postdredging sediments collected from Tahoe Keys Lagoons, and Crystal Shores East did not significantly stimulate algal growth. These sediments were collected from relatively shallow depths at both areas (approximately the top 20 cm from Tahoe Keys site 1 and the top 5 cm from Crystal Shores East sites 1 and 2 were collected). The sediments had likely undergone some biological depletion of nutrients and possibly other algal growth factors during the 10 months following dredging. In addition, there was evidence that significant depletion of interstitial water nutrients from the Tahoe Keys sediments exposed by dredging had occurred, during or immediately following dredging (see section 7). These releases may have resulted in lower post dredging sediment nutrient concentrations and the resulting nonstimulatory effects on algal growth of the elutriate supernatant solutions. (The DIN in the Tahoe Keys post dredging sediment elutriate supernatant ranged from 3-32 μg/l, and BAP ranged from 25-34 μg/l; while DIN and BAP elutriate test supernatant from a similar layer of sediments prior to dredging [Core Section C1-3] was 90 μg/l and 261 μg/l respectively).

Interestingly, postdredging sediment elutriate supernatant from Fleur Du Lac stimulated algal growth. Significant quantities of DIN (ranging from 2.58 μg/l-8.75 μg/l) and BAP (ranging from 1.08 μg/l-4.18 μg/l) were contributed with the treatments, and may account for the stimulatory responses. Rather than representing sediments newly exposed by dredging, the post dredging sediments sampled at Fleur Du Lac site 1 may have represented sediments which had shifted from other locations in the harbor. These sediments were composed of unconsolidated mud, and overlaid a very consolidated layer (at the depth where dredging ended). The nutrient levels in these sediments were similar to nutrient levels in a sample taken prior to dredging from the inner harbor. Predredging analysis of inner harbor sediments in 1990, indicated the sands and silts to have high TKN levels (1600 μg/g in sand, 1910 μg/g in silt+clay) (Appendix A-15) . TN levels in the postdredging muds at site 1 were also high, ranging from 970-1380 μg/g for the sediments subjected to bioassays.

6.3. Comparison of Bioassay Response Between Project Sites

Since the bioassays testing algal response to elutriate supernatant solution were done on different dates for the Crystal Shores East samples (November 1993) and the Tahoe Keys and Fleur Du Lac samples (September 1993), the magnitude of responses were not directly comparable. Changing conditions of nutrient limitation, algal species present and nutritional status, water temperature and lighting, among other factors, can lead to differing magnitudes of algal response to a particular treatment on different dates. To make comparisons of magnitude of stimulatory response caused by sediments, a bioassay was done which tested the response of Tahoe phytoplankton to sediments from all 3 dredging areas. In this bioassay, 0.1 g/l of (<2mm particle size) dried sediment was added to Lake Tahoe water containing natural phytoplankton and the growth response monitored. The results of this bioassay are presented in Table 6-4, and in Appendix A-27.

The sediments from Crystal Shores East appeared to be generally more stimulatory than sediments from either Fleur Du Lac or Tahoe Keys. The mean levels of TN, TP, and BAP for each these cores are presented in Chapter 3, Table 3-1. Dried sediments from Crystal Shores East core C1 had a higher mean TN (501 μg/g) compared to Tahoe Keys core C1 (136 μg/l) and Fleur Du Lac core C1 (175 μg/l). The mean level of BAP in the dried sediments for the cores were fairly similar: Crystal Shores East (88 μg/l); Tahoe Keys (90 μg/l); Fleur Du Lac (109 μg/l). It is possible the higher level of TN in the Crystal Shores East samples, may have caused the greater algal growth response to these sediments.

Table 6-4. Results of 31 October 1994 bioassay which tested the response of Lake Tahoe phytoplankton to treatments with 0.1 g/l additions of (<2mm) dried predredging harbor sediments from Tahoe Keys Lagoons, Fleur Du Lac, and Crystal Shores East. Phytoplankton growth response was measured as (+) increase or (-) decrease in culture extracted chlorophyll relative to control cultures to which no addition was made. The probability (p) values that treatment responses were not statistically different from the control are shown; "NS" indicates treatment differences from the control were not statistically significant ($p>0.05$).

Project Core Section	(+) Increase (-) Decrease Chlorophyll a (μg/l)	Statistical Significance
Tahoe Keys		
C1-1	+0.13	NS
C1-2	+0.16	NS
C1-3	+0.11	NS
C1-4	+0.20	p≤.05
Fleur Du Lac		
C1-1	+0.36	p≤.01
C1-2	+0.13	NS
C1-3 + C1-4	+0.22	p≤.05
C1-5 + C1-6	+0.11	NS
Crystal Sh. East		
C1-1	+0.47	p≤.01
C1-2	+0.41	p≤.01
C1-3	+0.37	p≤.01
C1-4	+0.32	p≤.01

6.4 Implications of the Bioassays

The results of the bioassays indicated Lake Tahoe phytoplankton were primarily colimited by N and P during the summer when dredging is most likely to occur. Phytoplankton showed little response to experimental enrichments of reagent N or P alone, however, a stimulatory response to the combination of N and P together was observed. This is commonly seen in Lake Tahoe during the summer when both biologically available N and P are in low supply. Marina and harbor sediments have been shown to release both algal available N and P to lake water during elutriate tests and the algae have been shown to be sensitive to additions of very small amounts of nutrients (on the order of tenths of μg/l of DIN and BAP) when added in concert with the dredged sediments. The small amounts of DIN and BAP released in concert with other nutrients during dredging, can potentially lead to short-term, localized areas of increased phytoplankton growth in the lake. Such increased phytoplankton growth was observed primarily in protected areas in which the dredge-impacted waters were prevented from dispersing (e.g. in silt curtain enclosed areas at Fleur Du Lac and Tahoe Keys). Outside of silt curtains or in the open lake, phytoplankton and nutrients may disperse so rapidly, that localized increased growth was not readily detectable. However, given the low concentration of algal growth nutrients in the lake, all limiting nutrients will eventually be used to fuel algal growth. The fact that dredging may possibly release other cofactors in addition to N and P which may enhance algal growth, underscores the importance of keeping sediment disturbance and sediment resuspension to a minimum. With proper use of silt curtains, the impacts of nutrients released on algae growth outside the dredging area can be reduced. Within dredging areas, the release of nutrients during dredging has been shown to result in increased algae growth (see Section 4).

<u>Summary - Section 6</u>

1) Phytoplankton were colimited by N and P in the summer, when dredging is most likely to occur.

2) A majority of the marina sediments were shown to stimulate algal growth when added to Lake Tahoe water as a 1% solution of elutriate test supernatant (lake water containing suspended sediments + soluble nutrients released from the sediments). Lake Tahoe phytoplankton appeared to be sensitive to additions of very small amounts of nutrients (on the order of tenths of μg/l of DIN and BAP) when added in concert with the dredged sediments. In addition to DIN and BAP, these sediments may also contribute other nutrients (e.g. possibly trace metals and other substances) which enhance algal growth.

3) The small amounts of DIN and BAP released in concert with other nutrients during dredging, can potentially lead to short-term, localized areas of increased phytoplankton

growth in the lake. Such increased phytoplankton growth was observed primarily in protected areas in which the dredge-impacted waters were prevented from dispersing (e.g. in silt curtain enclosed areas at Fleur Du Lac and Tahoe Keys). Outside of silt curtains or in the open lake, phytoplankton and nutrients may disperse so rapidly, that localized increased growth was not readily detectable. However, given the low concentration of algal growth nutrients in the lake, all limiting nutrients will eventually be used to fuel algal growth.

7. Nutrient Release from Newly Exposed Sediments Following Dredging

During dredging, layers of sediment immediately underneath those removed are suddenly located adjacent to the overlying lake water. This change from relatively stable conditions found in deeper sediments (which may include low oxygen and low redox), to conditions near the surface (which may include increased oxygen, increased redox, and increased microbial and algal activity), may cause changes in the chemical and nutrient balance between the sediments and the surrounding water. Some of these changes may favor the release of nutrients from the sediments into the surrounding water. Of particular concern in Lake Tahoe is the extent to which the sediments exposed by dredging release nutrients to the overlying lake water and the time frame over which such release might occur.

7.1 Background

It is important to recognize that a large concentration of nutrient or contaminant in the sediment relative to surface water does not necessarily equate to a large release of the material from the sediment. For instance, the phosphorus content of sediments can be several orders of magnitude greater than the overlying lake water. Release of material from the sediments to the overlying lake water is dependent on two processes: mobilization of nutrients or contaminants from the sediments to the dissolved pool in the interstitial water and transport of substances in the interstitial water to the overlying lake water. A relatively complex set of physical, chemical, and biological factors governs the transfer of nutrients between sediments and interstitial water including: original composition (forms) of nutrient or contaminant in the sediments, redox, pH, sorption properties, temperature and the activities of bacteria, algae, fungi, and invertebrates. Transport of nutrients in the interstitial water to the overlying lake water can occur by several processes including: diffusion, turbulent mixing by wave activity, biological or physical disruption of the sediments, and interstitial water flow (ground water seepage). Transport of interstitial nutrients to the overlying water is largely affected by the presence or absence of an oxidized "cap" layer at the surface of the sediments. When a large amount of oxygen is present in the surface waters, a layer of oxidized sediments often exists at the sediment-water interface, while deeper sediments are often chemically reduced due to microbial and chemical utilization of oxygen. This oxidized surface layer may act as a barrier or "cap" which prevents diffusional transport of ions (which are largely soluble under reducing conditions) through adsorption to sediments or iron oxides under oxidizing conditions.

7.2. Results of Interstitial Water Quality Monitoring in Pre- and Postdredging Sediments at Tahoe Keys

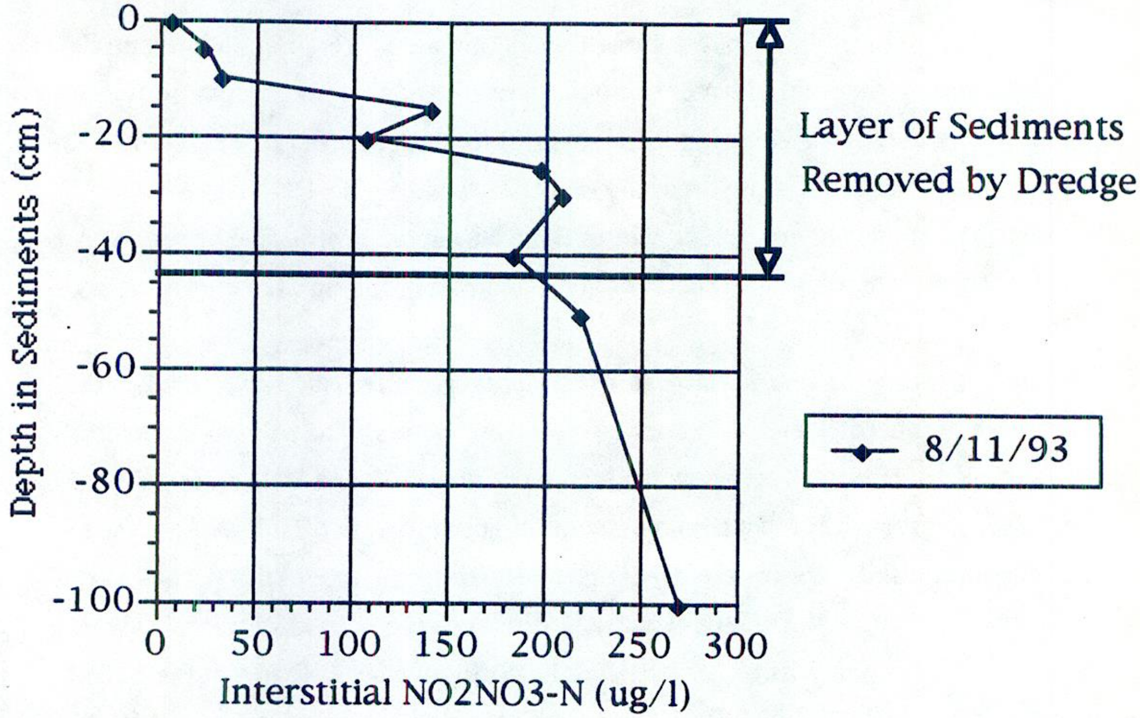
In this part of the study, we investigated the net impact of dredging on interstitial nutrient concentrations. Interstitial water samples were collected along a depth profile in the sediments within the Tahoe Keys lagoons just prior to dredging (8/11/93) and on several dates over the year following dredging (9/16/93, 1/12/94, 5/11/94, 8/4/94). Through observing changes in nutrient concentrations within the profile, we hoped to draw conclusions on the movement of nutrients within the sediments and into the overlying lake water.

Pre- and postdredging interstitial water samples were collected from a regular series of depths in the sediments at Tahoe Keys, using minipiezometers. The minipiezometers (plastic tubing perforated and screened on the intake end) were placed at discrete depths, and interstitial water was withdrawn through the tubing directly into 60 ml syringes (see Section 2). The interstitial water was subsequently filtered through 0.45 μm pore-size filters and analyzed for NO_3-N, NH_4-N, and SRP. Predredging interstitial samples were collected on 8/11/93 from depths of (5, 10, 15, 20, 25, 30, 40, 50, 100 cm) at the 6221.44 ft contour near Core Site #1. The VMI 612 horizontal toothed cutter removed 1.43 ft (44 cm) of sediments from this site on approximately 8/30/93. Follow-up samples of interstitial water were collected to a depth of 50 cm into the sediments. Appendix A-29 presents the results for all data, and Figures 7-1 (a-d) summarize the pre- and postdredging results for interstitial NO_3-N and NH_4-N in sediments at Core Site #1 in the Tahoe Keys.

We limited our data presentation to NO_3-N and NH_4-N only. SRP was very low in deeper samples (> 40 cm) from the predredging profile, and also low in a majority of the postdredging profile samples. However, we believe these low concentrations resulted from introduction of oxygen into the samples following filtration and do not represent *in situ* concentrations in the pore water. Exposure of apparently chemically reduced, deep predredging and postdredging samples to oxygen following filtration, caused formation of iron oxides ($Fe[OH]_3$) from chemically reduced iron (Fe^{+2}). Colloids of $Fe(OH)_3$ are positively charged and strongly sorb phosphate (PO_4^{-3}). These colloids and sorbed phosphate were not included in the analysis of the samples, therefore levels of interstitial SRP were underestimated.

Predredging profiles of NO_3-N and NH_4-N showed an increase in concentration with depth between 5 to 50 cm in the sediments. NO_3-N increased from 24 μg/l at 5 cm to 219 μg/l at 50 cm, while NH_4-N increased from 2 μg/l at 5 cm to 1752 μg/l at 50 cm. Slightly higher concentrations were measured at 100 cm than at 50 cm in the sediments.

a)



(b)

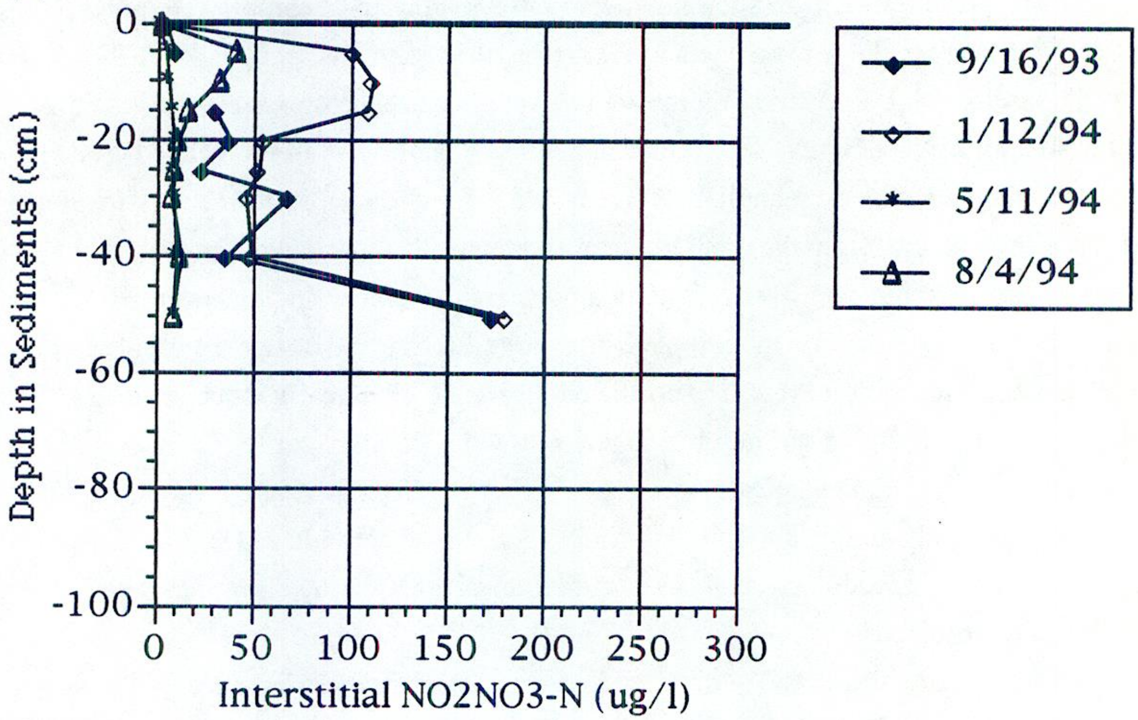
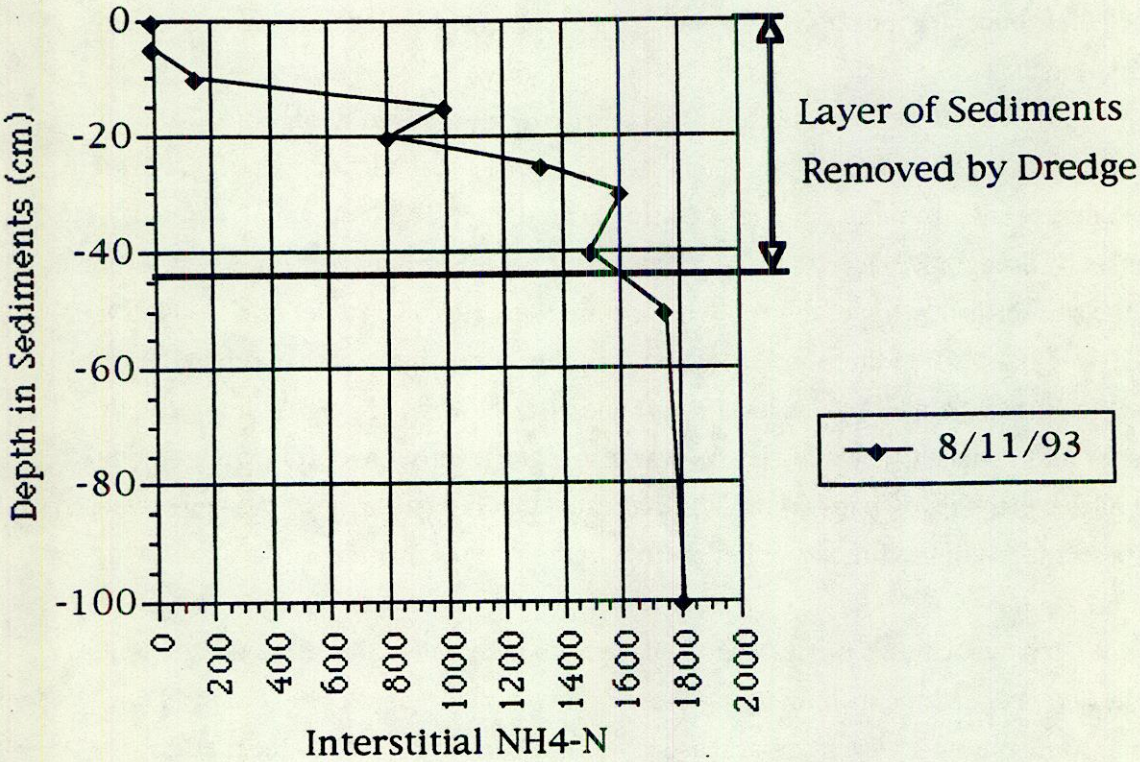


Figure 7-1. (a) Predredging profiles of sediment interstitial NO_2NO_3-N (μg/l) collected at Tahoe Keys core site #1 on 8/11/93; (b) postdredging profiles of sediment interstitial NO_2NO_3-N collected 9/16/93, 1/12/94, 5/11/94, 8/4/94.

(c)



(d)

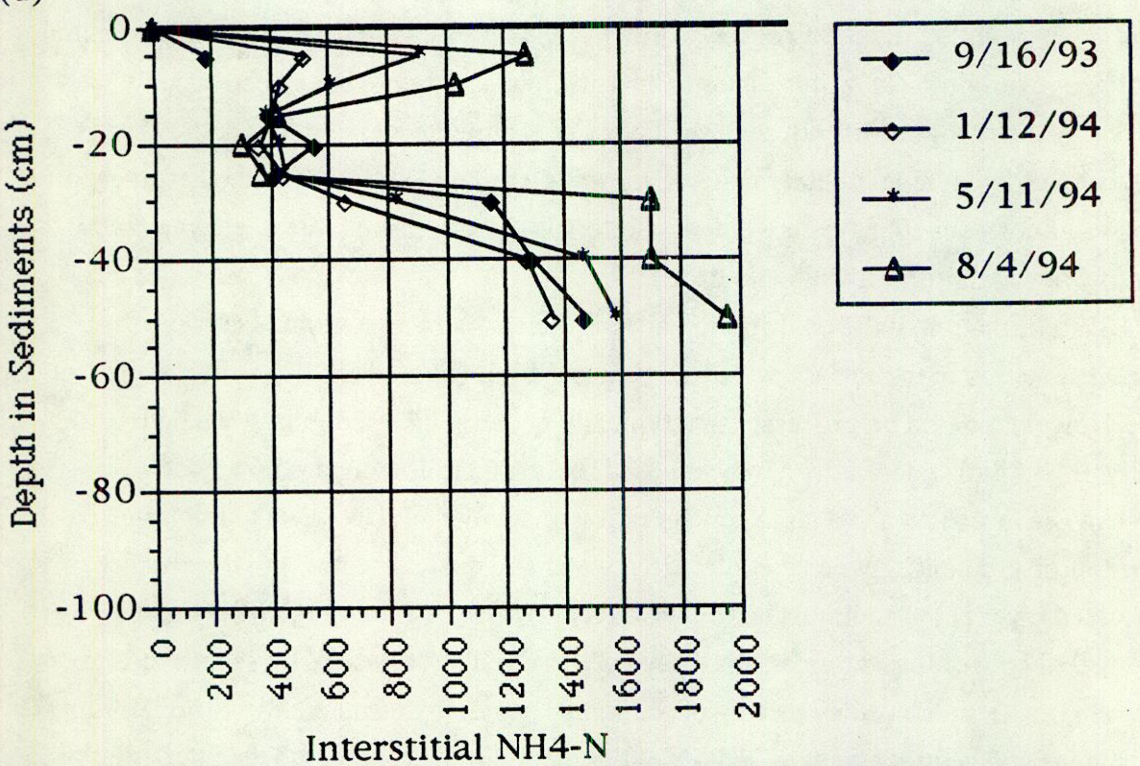


Figure 7-1. (c) Predredging profiles of sediment interstitial NH_4-N (μg/l) collected at Tahoe Keys core site #1 on 8/11/93; (d) postdredging profiles of sediment interstitial NH_4-N (μg/l) collected 9/16/93, 1/12/94, 5/11/94, 8/4/94.

Though no predredging samples were taken intermediate between 50 and 100 cm, we assumed that concentrations of NO_3-N and NH_4-N remained high and fairly constant in these sediments.

Follow-up interstitial water samples collected 2 weeks after dredging at Tahoe Keys showed that the levels of NO_3-N and NH_4-N in sediments down to a depth of 50 cm were lower than amounts from the same layers prior to dredging. The removal of 44 cm of sediments by dredging, placed these sediments which were originally 50 cm deep, within 6 cm of the surface following dredging. The postdredging (9/16/93) level of NO_3-N (9 μg/l) and NH_4-N (184 μg/l) of these sediments (at 5 cm) were much lower than predredging levels at (50 cm) where NO_3-N was 219 μg/l and NH_4-N was 1752 μg/l. Similarly, the amount of interstitial NO_3-N and NH_4-N was also significantly lower following dredging for samples collected down to 50 cm. This indicated that interstitial nutrients were released from these underlying sediments either during dredging or during the 16 days following dredging.

We believe that two processes may have been involved in the release of nutrients from the layers of sediments underlying those removed by dredging. First, during dredging some physical disruption of these layers may have occurred as the dredge removed the overlying sediment layers. The cutter teeth may have penetrated into these deeper layers resulting in mixing of the sediments and the release of high nutrient interstitial water to the overlying lake water. These nutrients may or may not have been largely removed by the dredge. Second, as upper layers of sediments were removed, the chemical equilibrium of layers immediately underneath was disrupted. Diffusion and other transport processes likely resulted in the movement of interstitial nutrients into the overlying lake water as a new equilibrium was established.

Determination of the contribution and sequence of processes that occurs in sediments exposed to the surface water following dredging would require more detailed study. However, based on processes that typically occur in lake sediments, we believe that initially, interstitial water in the newly exposed sediments following dredging was chemically reduced and had a large concentration of soluble NH_4-N. Due to the large concentration gradient between the interstitial water and the lake water, and the absence of an oxidized layer in the sediments (which was removed by the dredge), diffusion of NH_4-N and NO_3-N out of the sediments may have occurred. The release of these nutrients may have been further enhanced by mixing of sediments caused by turbulence in the overlying lagoon waters. The movement of NH_4-N out of the sediments decreased the interstitial NH_4-N concentration. However, as surface sediments became oxidized, (from diffusion and mixing of oxygen into the newly exposed sediment), an oxidized "cap" likely formed.

NH_4-N may have been resorbed to sediments in this oxidized layer. As the interstitial concentration of NH_4-N decreased in the surface sediments, the amount of NH_4-N transported out of the sediments by diffusion decreased.

We could not determine from the data the magnitude of the contributions from physical disruption of the sediments during dredging versus the contribution which occurred after dredging and therefore escaped to the overlying lagoon water. It is likely both processes caused release of nutrients from the sediments, and that a portion of the nutrients released were removed by the dredge. We did make an approximation of the combined magnitude of these releases: we estimated 0.097 g NH_4-N /m^2 or 0.39 kg NH_4-N / acre surface area dredged and 0.021 g NO_3-N/ m^2 or 0.087 kg NO_3-N/ acre surface area dredged to be released from the sediments during or in the 16 days following dredging[1].

Over the course of the year following dredging, interstitial NH_4-N increased steadily in the upper sediments (5 cm and 10 cm below the surface) to near levels found in these layers (originally approximately 50-55 cm deep) prior to dredging. Several factors may have led to this increase in interstitial NH_4-N. First, microbial decomposition of organic matter in the upper layer of sediments probably increased, as microbial communities became established. As a result, ammonification (production of NH_4-N from organic matter) increased and oxygen likely became depleted. As oxygen levels dropped, conditions likely became more strongly reducing and additional NH_4-N may have been desorbed from the sediments. The levels of NH_4-N that developed in the sediments at 5 cm (1281 μg/l) and 10 cm (944 μg/l) one year after dredging were higher than levels found at the same depths prior to dredging (the predredging NH_4-N concentration at 5 cm was 2 μg/l, and at 10 cm was 147 μg/l). This is important in two respects. First, it indicates that dredging may cause layers of previously deeper sediments with organic material to be located near the surface of the sediments, this may lead to enhanced microbial ammonification, and production of NH_4-N. Second, the presence of higher NH_4-N near the surface of the sediments in postdredging profiles relative to predredging profiles may indicate these postdredging sediments have a greater potential for subsequent release of

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1- An estimate of total release from the sediments was calculated as follows: the concentration for each sampling point was considered representative for a layer of sediment extending one half the distance to the sampling point above and below it, the net decrease in concentrations for each layer was calculated by subtracting each postdredging concentration from the corresponding layer concentration in predredging cores. An estimate of 20% water content for these postdredging sediments was used to calculate the loss from each layer in grams with the total loss from all layers down to 50 cm under 1 m^2 calculated.

NH_4-N. Such release may occur largely as a result of mixing of these shallow sediments during wave activity, and also through diffusion.

The results from this study provided evidence that nutrient release may occur from newly exposed sediments during or following dredging. The data also indicate dredging may increase the potential for nutrient release over a long period of time. High concentrations of NH_4-N developed in shallow sediments near the surface of Tahoe Keys lagoons sediments, over the course of the year following dredging. This increase may have been associated with ammonification of previously deeply-buried organic matter in the sediments which were now brought near the surface. The proximity of such high concentrations of NH_4-N to the surface indicated potential for release to the lake through disruption of the sediments or mixing during turbulence in the overlying water, and possibly through diffusion. Determination of the magnitude of such long term releases would require additional detailed study.

<u>Summary - Section 7</u>

1) Sampling of sediment interstitial water prior to and following hydraulic dredging at a site in the Tahoe Keys indicated that NO_3-N and NH_4-N were released from the newly exposed sediments either during dredging or in the 16 days following dredging, or both.

2) 0.39 kg NH4-N/ acre dredged and 0.087 kg NO3-N/ acre dredged were estimated to have been released from the newly exposed sediments.

3) Dredging may increase the potential for release of NH_4-N from the sediments over a long period. Interstitial NH_4-N concentrations increased in the upper layers of newly exposed sediments at Tahoe Keys during the year following dredging. This increase may have been the result of microbial degradation (ammonification) of available organic matter. The proximity of this NH_4-N to the surface sediments suggested release to the overlying lake water could potentially occur through physical disruption of the sediments and/or possibly through diffusion. Further study would be required to determine the magnitude of such release.

8. Selection of Dredging Technology

8.1 Factors Guiding Decisions on Dredging Equipment

The selection of proper equipment is important to achieve an efficient dredge operation and help minimize environmental effects. Among factors contributing to selection of proper dredging equipment and method are:

- Physical characteristics of the material to be dredged.

  Geotechnical analysis of the sediments should be done, this may include such properties as: grain-size analysis, cohesion, plasticity and permeability. Certain dredges will not operate efficiently in certain types of sediments. Generally, if a dredge has difficulty excavating the sediment, turbidity will be increased. Samples for analysis should be representative of the dredge area as a whole. Assessment of the degree of confounding factors such as presence of large debris, erratic rocks, or large pieces of wood would also be useful in selection of dredge methodology.

- Quantities of material to be dredged.

  The production capabilities in cubic yards per hour of the different dredge types varies.

- Dredging depth

  The different types of dredges have differing minimum and maximum depths of dredging.

- Distance to the disposal area

  Large distances between dredge and disposal area require some means of transport of the spoils. One of the advantages of hydraulic dredging is that the spoils may be transported over large distances through a pipeline system.

- Physical environment of and between the dredging and disposal areas

  In some instances transfer of spoils from dredge to disposal areas will be obstructed by buildings or natural land forms.

- Contamination level of the sediments and mobility of contaminants

  High levels of contamination, require specialized dredging techniques and disposal practices.

- Method of disposal

  The use of settling ponds requires that large areas of land be available. Dewatering on land also requires that a suitable area be available.

- Production required and cost constraints

  Dredges vary in their production capability and operating costs.

- Type of dredges available

- Ability to use silt curtains, sheetpile, or other containment structures to contain turbidity. Where such containment is feasible, the possible choices of dredging technology may be expanded to include dredges with higher sediment resuspension characteristics such as bucket dredges and excavators, since the resuspended material can be isolated from the lake.

At Lake Tahoe, a variety of marina configurations, sediment types, project sizes, and site characteristics require that various dredge types be considered during pre-project planning. Further, depending on sediment type, more than one type of dredge may be required for some projects. Below, we review some of the common technology available for use at Tahoe.

8.2 Review of Available Dredging Technology

8.2.1 Mechanical Dredges

Mechanical dredging methods remove bottom sediment through the direct application of mechanical force to dislodge and excavate the material at almost *in situ* densities. Included in this category are bucket dredges, excavators, and backhoes.

Bucket Dredges

These dredges utilize a bucket to excavate the material to be removed. The buckets used include the clamshell and dragline types which can be quickly changed to suit project needs. Buckets are operated from a crane which may either be barge mounted or land-based. They may be used to excavate most types of sediments except for very cohesive, consolidated sediments and solid rock. Bucket dredges are effective while working near docks, piers, and breakwater structures because they do not require much area to maneuver.

Bucket dredges tend to produce high levels of sediment resuspension during dredging. The majority of turbidity is released near the bottom as the bucket impacts, penetrates and is removed from the sediments. Additional turbidity is released as the bucket is drawn through the water column, as it breaks the water surface and is moved over the water, and during descent back through the water. The suspended sediment plume from a clamshell operation may extend 1500 feet along the bottom, and concentrations of suspended sediment within 50 feet of the dredge can range to 500 mg/l (Hayes et al., 1988). Dragline buckets which are very effective in sediment removal, also produce high concentrations of resuspended material (Ray Burgeron, Cable Arm Inc., personal communication).

Included in this category are suction, cutterhead, horizontal cutterhead, horizontal auger and small interconvertible dredges.

Suction Dredges

Suction dredges are pipeline dredges without a cutterhead. Suction dredges generate low levels of turbidity. However, they are limited to dredging soft, free-flowing and unconsolidated material. They are subject to clogging by debris.

Cutterhead Dredges

Cutterhead dredges are equipped with a rotating cutter apparatus that surrounds the intake end of the suction pipe. They can effectively excavate a variety of substrate including soft rock, densely packed deposits, clay, silt, sand, and gravel. They are designed to operate in calm water in waves less than 2-3 feet and require a minimum of 3-15 ft. of water in which to operate. The dredge moves by alternately setting anchor pins or spuds as the cutterhead cuts from side to side ahead of the dredge. The suspended solids plume generated by the cutterhead is usually contained in the lower portion of the water column. Concentrations of suspended sediments may range from 200-300 mg/l near the cutterhead to a few mg/l 1000-2000 feet from the dredge (Cullinane et al., 1990). The cutterhead dredge may be the most sensitive of any type of dredge to changes in operating techniques. The rate of sediment resuspension by a cutterhead dredge is dependent on thickness of cut, rate of swing, and cutter rotation rate (Hayes et al., 1988).

Horizontal Cutter Dredges

These dredges utilize a toothed rotating horizontal cutter shaft, to excavate the sediments ahead of the suction intake. The cutter may be partially surrounded by a shroud to contain turbidity. Horizontal cutter dredges produce less slurry for a given cut compared to cutterhead dredges, thus reducing the amount of water pumped. The dredge moves by pulling itself along anchored cables, the rotating motion of the cutter may also help to advance the dredge. Horizontal cutter dredges are particularly useful for removing fluid muds, highly organic soils and some cohesive soils. High turbidity may be produced when more cohesive sediments (i.e. original soils, compacted sands and clays) are encountered. The VMI 612 horizontal cutter suction dredge was monitored during this study during dredging operations at Tahoe Keys. A turbidity plume usually extended out in front of the dredge with highest turbidity along the bottom (see Section 4.1.1.). Turbidity 10 feet away from the cutter near the surface could often be maintained near the 20 NTU level required by the dredging permit. However, when the dredge encountered

Watertight clamshell buckets have been developed in which the top is enclosed and the joints are sealed. These buckets can reduce the amount of sediment resuspension as much as 30-70% over conventional clamshell buckets. However, these buckets may produce increased resuspension at the bottom due to the pressure wave which precedes the bucket. As a result, they can influence a greater area on the bottom, although concentrations at the point of dredging are lower (McLellen et al. 1989).

Excavators

These dredges utilize a shovel-type bucket mounted on a articulated arm. The cab and associated arm rotate 360 degrees and the excavator moves via crawler tracks. By operating from solid ground the excavator has more digging power and pull than barge mounted systems. Dredging can be done as much as 3-4 times as fast with an excavator compared to conventional dredging techniques (John Macsween, John Macsween Construction, personal communication).

We did not encounter any studies specifically addressing turbidity produced by excavator-type dredging in the literature. However, observations of the excavator dredging at Crystal Shores East indicates sediment resuspension from this type of dredging is high. Maximum turbidities within the dredge area at Crystal Shores East ranged up to 195 NTU. Factors governing sediment resuspension from the excavator bucket are likely similar to the those for other bucket type dredges, i.e. impact, penetration and removal of bucket from sediment, and withdrawal through the water column. Additionally, the bucket typically removes a volume of turbid lake water overlying the sediment which may be sloshed (often intentionally to dewater) out of the bucket as the excavator rotates to dump the material.

Backhoes

These utilize a shovel-type bucket mounted on the back of a toploader. These may be used in small scale sediment removal operations and likely have similar high resuspension characteristics to the excavator.

8.2.2 Hydraulic Dredges

Hydraulic dredges remove and transport sediment as a liquid slurry. They are usually barge-mounted and typically have centrifugal pumps which can move the dredge slurry considerable distances though large diameter pipes to a discharge area.The slurry is typically discharged to large settling basins or in some cases subjected to mechanical solids removal, then the clarified water is discharged back into the lake. Large areas of available land which can be used for settling basins are typically required for this type of dredging.

entrance. Most of these dredges were developed in Japan and the technology is not available in the U.S. The Pneuma system was originally developed by a consortium of corporations in the Italy and Canada and is available in the U.S. However, it does not operate effectively in shallow water dredging.

8.2.4 Newer Dredging Technology Which May Have Application at Lake Tahoe

Environment Canada of the Canadian government is involved with extensive research on the remediation of contaminated sediments within the Laurentian Great Lakes. As a result of industrial, agricultural and municipal discharges, the quality of Great Lakes water has significantly deteriorated and bottom sediments have acted as a depository for pollutants. The Canadian government has allocated significant resources to address protocols for assessing contaminants in sediment and for the development of technologies to remove and treat the contaminated sediment. The program focusing on technologies for the removal of sediment is called the Contaminated Sediment Removal Program (CSRP). The goal of the CSRP is to identify and demonstrate suitable techniques that have wide application for the efficient removal of contaminated sediments in the Great Lakes Basin. It was also expected that demonstrated technologies would have applicability to dredging of contaminated sediments in other areas, as well as in routine navigational and recreational dredging projects.

The CSRP has evaluated several technologies which have especially promising potential for low impact removal of contaminated sediment. These technologies were narrowed from a list of 130 original potential technologies. Among the technologies evaluated to date have been a modified version of the Mud Cat Dredge (Mud Cat MC 915 ENV), a modified clamshell bucket (Cable Arm 100E Clamshell Bucket), and a 150/30 Model Pneuma Pump. We present here information available on the Cable Arm Clamshell, the Mud Cat MC 915 ENV. Another type of low impact dredge called the Eddy Pump has also recently become available. Information is also presented on this dredge.

<u>Mud Cat MC 915 ENV</u>

A modified Mud Cat called a Mud Cat MC 915 ENV was specifically designed by Ellicott Machine Corporation, Baltimore, Maryland for the removal of industrial deposits and contaminated clayey silt from the Welland River in Canada. Unique modifications to this Mud Cat horizontal auger suction dredge included:

- a multi-flight, variable pitch, dual convergence horizontal auger head designed to minimize windrows;
- auger head and truss boom able to swivel and tilt to work with sloped river bottom;

fine sediments or more consolidated layers of sediments, turbidity increased to levels as high as 88 NTU. Turbidity was observed to increase under rough lake conditions. Erratic rocks, and other large debris also posed problems (i.e. plugging, obstructing or damaging the cutterhead) for this dredging system.

Mud Cat Dredge

This horizontal auger dredge utilizes a rotating horizontal cutterhead equipped with cutter knives and a spiral auger that cuts the material and moves it laterally toward the center of the auger where it is picked up by the suction. The Mud Cat can work in water as shallow as 1 ft. and to a maximum depth of 15 ft. Similar to the horizontal cutter dredge, this horizontal auger dredge is useful in removing softer sediments and is capable of producing a high concentration of sediment in the slurry. This results in less water being pumped. The Mud Cat produces low to moderate levels of turbidity. In a monitored study of the Mud Cat, near-bottom suspended solids concentrations 5 feet from the auger were usually slightly greater than 500 mg/l above background, while surface and mid-depth concentrations measured 5-12 feet in front of the auger were typically less than about 150 mg/l above background (Cullinane et al., 1990). By covering the auger with a retractable mud shield, the amount of turbidity generated by the Mud Cat can be reduced.

Small Interconvertible Dredges - Aquamog Dredge

The Aquamog is a small interconvertible dredge in which a variety of dredge functions may be interchanged. The dredge can be set up to perform bucket dredging, hydraulic dredging with auger or cutterheads, as well as aquatic plant control. The dredge is paddlewheel driven between sites. Anchoring is by pins driven into sediments rather than by cables. A shroud can be used over the auger to reduce turbidity. The Aquamog was shown to be effective in dredging a Northern California drinking water feeder canal without causing significant turbidity problems in one study (Internat. Dredg. Rev., 1991). However, no specific levels of turbidity or suspended sediment were given, for comparison with other technologies.

8.2.3 Specialized Dredges

Very specialized dredges have been developed for use in low turbidity removal of highly contaminated fine sediments. The technology includes hydraulic and pneumatic types of dredging systems see Randall (1992) for a review. Reported suspended sediment concentrations for special purpose dredges (Pneuma, Clean-up, Oozer and Refresher) are very low and range from near 1 to 48 mg/l in the near vicinity (10 feet) of the suction met the Environment Canada's operational and performance standards. It produces turbidity levels 2-3 times less than conventional buckets and, in one project, the turbidity levels were approximately 10 times less than for conventional mechanical dredging (Hempel, 1993). The Cable Arm Environmental Clamshell was indicated it to be an environmentally suitable alternative to a conventional clamshell operation. The lack of weight of the bucket creates a disadvantage in that the bucket cannot penetrate firm materials. It's use may be limited to softer, unconsolidated sediments. The Environmental Clamshell might be useful in Tahoe dredging situations where large volumes of silty material are to be removed and the dredge area may be isolated from the lake by silt curtains.

The Eddy Pump

The Eddy Pump® is a unique dredging system which transfers high concentrations of dredged solids materials at high velocity along pipelines while creating low turbidity at the dredge intake. HazTECH News (1996) indicates: "The Eddy Pump® moves material by creating and harnessing a dynamic fluid eddy effect. The pump's snout is inserted through the water directly into the solids. The spinning of a rotor in the valute creates an inverted water spout that moves down the hollow center of the intake with immense energy. As the swirling flow of water enters the solids, it creates a peripheral eddy, which causes the solids — such as sand, gravel, silt, sludge or mineral slurries — to be drawn up along the sides to the valute and carried to the discharge line." In a demonstration at the Cresta Reservoir in Northern California, the Eddy Pump was able to achieve solids content transfer over 70%, and achieve production rates as high as 300 m^3/ hr. when dredging sand (Eddy Pump Demonstration Video, Soli Flo Corporation). Very low turbidity was observed in the vicinity of the dredge (Creek and Sagraves, 1995). The combination of low resuspension around the dredge and high production rates is desirable for dredges used in Lake Tahoe. This is because the increased production rate may reduce the amount of time spent dredging, which in combination with low levels of resuspension around the dredge may reduce the overall resuspension produced by a project. The Eddy Pump cannot remove cobble effectively and may have difficulty in more consolidated materials. This dredge should be considered for future evaluation of its ability to remove sediments while causing low resuspension in Lake Tahoe.

- shroud encompassing the auger which was increased in size to account for sediment resuspension;
- hydraulic vibrators, which complement the action of the auger, allowing the excavation of material more readily, thus reducing turbidity; and
- removable front screens which restrict oversized material from entering and blocking the auger head and pumping system.

The dredge met all requirements for performance established by Environment Canada, two conditions of which were: turbidity was not to exceed ambient levels by 30% 25 m away, and suspended sediment was not to exceed ambient levels by 25 mg/l 25 m away. For Lake Tahoe projects in which horizontal auger dredging is chosen as the technology (i.e. in silty sediments), similar modifications to horizontal auger dredges to be used at Tahoe may prove useful for further minimizing the resuspension of sediments. We recommend that regulatory agencies work with the dredgers and equipment manufacturers to address these new developments.[1]

Cable Arm 100E Environmental Clamshell Bucket

The Cable Arm 100E (Environmental) Clamshell bucket was developed by Cable Arm Clamshell of Trenton, Michigan. The Environmental Clamshell is a unique closed clamshell design which features moveable top plates/vents which allow water to pass through as it submerges. This reduces the pressure wave beneath the dredge as it is lowered. The bucket makes a wide-footprint level cut into the sediments, rather than the ypical pot-hole configuration created by other bucket dredges. As the Clamshell is removed from the sediments there is less suction created than experienced during removal of a typical bucket from a pot-hole type cut. During ascent, the rubber side seals ensure that no additional water is mixed with the dredged material. When the clamshell reaches the water surface, the ambient water is allowed to exit via air-operated vents fitted with screens to trap any fines. Other unique features include 40% less weight than traditional buckets, and sensors which may be fitted to the bucket to indicate proper closure. The Cable Arm

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1- In our follow-up report titled: Cost and Effectiveness Analysis for Implementation of Recommendations in: Impacts of Marina Dredging on Lake Tahoe Water Quality, we assessed costs associated with modifications on the Mud Cat MC 915 ENV and feasibility of making similar modifications, in particular, shroud modifications on Mud Cat for use in Lake Tahoe. The overall costs of modifications to the Mud Cat were very expensive (over $86,000) and may be prohibitive for dredging operations at Lake Tahoe. Increasing the shroud size was also found to be potentially expensive (may cost $5000) and could detrimentally affect the efficiency of a dredge. It was also found there is no guarantee that an increase in shroud size will reduce resuspension. We therefore recommend that modification of shrouds on dredges not be pursued.

placed at the disposal point. Smoothing the bottom should not be done where turbidity is to be kept to a minimum (McLellen et al., 1989).

8.4.2 Hydraulic Dredge Operational Controls to Minimize Turbidity

In addition to rigging to control turbidity - which may include:

- mud-shields and use of hydraulic rams to move the mud shield;
- complete auger shielding and full width suction;
- variable cutter speed and reverse auger to kick out obstructing objects;
- additional side control cables for staying in the dredge cut;
- flap valves in the discharge line for preventing backflushing of the discharge line into the lake;
- mechanical seals in the submersible pump;
- hydraulic pressure gauges in the cab for horizontal cutter pressure, pump hydraulic pressure and boom pressure (Seagren, 1994);

operational controls may be applied to control turbidity. Engine RPM, auger pressure, cutter RPM and dredge pull speeds may be adjusted as different sediments are encountered to balance efficiency of sediment removal with generation of turbidity. The results of our monitoring around the VMI 612 suction dredge during conditions of varied engine RPM and auger pressure (see Section 4) showed that of these two variables, auger pressure was the primary factor controlling levels of turbidity near the cutter. Other operational practices to help minimize turbidity include avoiding open water dredging during rough lake conditions and avoiding dredging of materials which a dredge cannot dislodge easily.

8.5 Suggested Applications of Dredges to Different Dredging Situations at Tahoe

Lake Tahoe as an Outstanding National Resource Water, is afforded the highest level of protection under the EPA's antidegradation policy. Water quality is required to be protected and maintained. In some instances, the state may allow some limited activities that result in temporary and short-term changes in water quality. But such activities (which may include dredging) must not permanently degrade the water quality. The preamble to the Water Quality Standards Regulation (48 F.R. 51402) states where the state "allows such temporary degradation, all practical means of minimizing such degradation shall be implemented." Therefore, all practical dredging technologies and procedures which minimize impacts on the lake must be used. The information gained from this study was combined with information available on environmentally sensitive dredging technology and procedures to develop a procedure for decision making on choice of dredge and possible mitigation measures. The suggested procedure follows.

8.3 Turbidity Containment Systems

8.3.1 Silt Curtains

Silt curtains are used to control the dispersion of turbidity and contaminants in the vicinity of dredging projects, and to create a relatively calm environment where particle settling can occur. At Lake Tahoe, these devices have been used to enclose and seal off the dredging area from the rest of the lake waters. The curtains consist of flexible nylon-reinforced polyvinyl chloride (PVC) fabric or other similar material (a polyester-reinforced vinyl silt curtain constructed by Containment Systems, Inc. proved very effective in containing turbidity in this study at Fleur Du Lac). They are maintained in position by flotation segments at the top and a ballast chain along the bottom, which helps the curtain "hug" the natural sediment contours. Additionally, sand bags may be placed along the bottom to improve the curtain seal. In dredging projects elsewhere, these curtains typically extend only partially down through the water column, providing control of dispersion of near-surface turbidity. Silt curtains are generally deployed in a configuration that is U-shaped or circular. They are not recommended for use in areas frequently exposed to high winds and breaking waves.

8.3.2 Other Barriers

In areas where the configuration of the dredge area permits, dikes or sheet pile enclosures may be used to seal the area. Consideration for ingress/egress of dredging equipment and removal of the barrier must be given (Cullinane et al., 1990).

8.4 Operational Controls

Operational procedures may play a large role in minimizing the amount of turbidity produced by the different dredge types. Cullinane et al. (1990) provide a review of operational procedures for several dredge types. The following provides a brief summary of some of the operational controls which may be applied to bucket dredges and hydraulic dredges.

8.4.1 Bucket Dredge Operational Controls to Minimize Turbidity

Operational controls can be applied to hoist speed, placement of material and dragging the bucket over the bottom at the end of the project to smooth bottom contours (termed "smoothing"). Hoist speed should be kept below 2 feet per second and should be as smooth as possible to eliminate jerking the bucket. Material should be deliberately the Dredging Elutriate Test (DRET) as described by DiGianno et al., 1993 (used to estimate nutrient release at point of dredging).]

The unfiltered elutriate test supernatant water should be analyzed for TKN, TP, TFe, and TPH. Filtered supernatant which passes through a 0.45 μm filter should be analyzed for NO_2NO_3-N, NH_4-N, and SRP, soluble Fe and metals.

When the potential for release of nutrients, TPH, or metals are identified as being extremely high in the elutriate tests, selection of a low-resuspension dredge for proposed open-lake dredging becomes particularly important. Selection of very strong silt curtains in areas where silt curtain use is feasible and use of more rigorous monitoring may help minimize impacts of dredging in such sediments.

c) Evaluation of the site characteristics

A general site evaluation should be made to aid in selection of proper dredging technology. Such an evaluation should include the amount of land available for spoils dewatering or settling ponds, proposed dredging depth, distance to the disposal area, physical environment between dredging and disposal areas, amount of large debris on the bottom which may interfere with dredging and ability to confine the area with silt curtains.

d) Evaluation of factors specific to the project

Factors such as the amount of material to be dredged, production required and cost constraints will affect the choice of dredge.

e) Evaluation of dredging technology available

The availability of the dredge technology must also be considered. From the dredging technology available to a project, consideration should be given to sediment resuspension characteristics and ability to remove anticipated sediment layers efficiently. Open lake dredging without the use of silt curtains requires that dredges of very low sediment resuspension characteristics be chosen. As new, environmentally efficient dredging technology becomes available, this technology should be considered for evaluation and use at Lake Tahoe.

f) Evaluation of additional equipment available to minimize resuspension

Consideration should be given to use of additional equipment available for a dredge which may help minimize resuspension during dredging. Such equipment may include:

- additional shrouds to minimize resuspension around the cutter;

8.5.1. Choice of Appropriate Dredge

A variety of dredges must be considered, no one dredge can effectively operate in all situations encountered in Lake Tahoe. The process of selecting an appropriate dredge should include:

a) Evaluation of the physical characteristics of sediments

Well in advance of the project, the physical characteristics of sediments in the proposed dredging area should be evaluated. Sediment cores should be obtained from several representative locations throughout the proposed dredge area which are taken down to the depth of permissible sediment removal. The following analyses should be performed:

- General visual inspection to characterize the sediments and identify consolidated layers of clays, layers of large cobble, boulders and other large and irregular debris etc. which may cause difficulties for certain types of dredges.
- Grain-size analysis to determine the clay and silt fraction (< 63 μm), sand fraction (> 63 μm < 2 mm), gravel (> 2 mm < 64 mm), and cobble (> 64 mm < 256 mm).
- Water content of the sediments.

The results of such testing will help identify where certain dredges are inappropriate. For instance, where layers of extremely consolidated fine-grained sediments are encountered, a horizontal auger dredge may not be effective, rather mechanical dredging or cutterhead hydraulic dredging may be required. Mechanical dredges may also be more effective in removal of very course-grained cobble material.

b) Evaluation of the chemical characteristics of sediments

Sediments obtained from coring should be chemically analyzed. The following analyses should be done:

- For raw sediments (< 2 mm size fraction) analyses should include: TN, TP, Total Petroleum Hydrocarbons, Metals (Cd, Cr, Pb, Zn, Sn), and organic content (Loss on ignition).
- An elutriate test is recommended on a wet composite of dredge area sediments to evaluate the nutrients which might be released to the lake during dredging. Pending further evaluation by Lahontan, a standardized elutriate test should be used. [Two tests should be evaluated by Lahontan for ability to most accurately predict nutrient release during dredging projects at Tahoe: the Modified Elutriate Test as described in Cullinane et al., 1990 (which is used to estimate the nutrient release from spoils in confined disposal areas) and

9. Mitigation Measures to Reduce the Impacts of Dredging

9.1 General Mitigation Measures

In addition to selection of the most appropriate dredging technology to minimize impacts, additional measures may be taken to help minimize impact on Lake Tahoe. A first measure is to assure that the dredge operator is familiar with, and skilled in using, operational controls to minimize turbidity and nutrient release during dredging. Some of these operational controls were discussed in chapter 8. For bucket dredging, they included keeping the hoist speed through the water below 2 ft. per second, operating the equipment as smooth as possible to eliminate jerking the bucket, and avoiding the practice of smoothing the bottom. For hydraulic dredging, operational measures included: careful control of engine RPM, auger pressure, cutter RPM, and dredge pull speeds. It is also important that the dredging contractor be skilled in the proper use and anchorage of silt curtains in projects where they are to be used. Other operational controls to be included when open lake dredging must be done include not dredging during rough lake conditions, and avoiding dredging of materials which the dredge cannot dislodge easily. Use of optional equipment which may reduce resuspension of sediments during operations should also be considered. Such equipment may include a flap valve in the discharge line of hydraulic dredges, additional shrouds around the cutter and real-time turbidity monitoring equipment.

The dredging contractor and marina or harbor owner should also be provided material which outlines why there is a need for environmentally sensitive dredging at Lake Tahoe. Such information should outline in effect Best Management Practices for dredging in Lake Tahoe and describe typical monitoring protocol, discharge standards, and water quality objectives around dredging projects.

9.2 Seasonal Considerations

The summer season is the most acceptable period for dredging operations. Lake conditions are generally calmer and there is less chance for prolonged storms which may damage the silt curtains and contribute surface runoff. Brief, strong thunderstorms can occur during the summer, however, therefore silt curtains must be of sufficient strength to withstand the wave activity associated with these storms. Open lake hydraulic dredging should be stopped when strong winds and rough lake conditions develop. Potential conflicts with spring or fall spawning of game fish species may also be avoided by confining dredging to the summer. Evaluation for potential impacts on the fisheries will still need to be done as part of the permitting process regardless of season. By dredging at

- a flap valve for preventing backflushing of the discharge line into the lake;
- real-time turbidity monitoring equipment;
- gauges in the cab to allow monitoring of horizontal cutter pressure, pump hydraulic pressure and boom pressure;
- additional flotation for pipes to keep them from dragging on the bottom.

Summary - Section 8

1) Several factors must be considered in selection of an appropriate dredge, these include: physical and chemical characteristics of the sediments to be dredged, site characteristics, ability to use silt curtains to isolate dredge area, amount of material to be dredged, cost constraints, and dredges available.

2) Mechanical dredges (which include clamshell, dragline, excavator and backhoe types) can remove a variety of sediment types effectively, and produce spoils which are similar in water content and density to the original sediments. These dredges have high sediment resuspension characteristics and should only be used in silt curtain enclosed areas.

3) An environmentally efficient bucket called the Cable Arm Clamshell has been developed which produces sediment resuspension which is about one third that of conventional buckets. The Cable Arm clamshell may have applications in larger harbors at Lake Tahoe which contain finer unconsolidated sediments. It should be considered for future testing.

4) Hydraulic dredges (which include suction, cutterhead, horizontal auger or horizontal cutter types) remove and transport sediments through pipelines as a liquid slurry. Solids are removed from the slurry either through settling in spoils impoundment basins (which require large areas of available land) or through mechanical solids separators. These dredges have low to moderate sediment resuspension characteristics.

5) The Eddy Pump should be considered for testing of its ability to remove sediments while causing low resuspension in Lake Tahoe. This dredge has capability to remove high concentrations of solids (> 70%) while apparently creating very low turbidity.

6) Operational controls are important for minimizing sediment resuspension. For bucket dredges, these include hoist speed, deliberate placement of material and avoiding smoothing of the bottom. For hydraulic cutter dredges, these may include careful control of cutter pressure, engine RPM, cutter RPM, and dredge pull speed.

the beginning or end of summer and avoiding peak tourist times, conflicts associated with boating needs in the harbor may be avoided.

9.3 Use of Silt Curtains

One method for physically controlling the dispersion of turbid water in the vicinity of dredging operations in quiescent environments involves placing a silt curtain around the operation. Silt curtains are impermeable floating barriers that extend vertically from the water surface to a specified depth (to the bottom when used in Lake Tahoe dredging operations). Through use of a silt curtain, the area over which a plume of turbid water extends can be minimized and levels of turbidity and nutrients outside the curtain may potentially be maintained near the water quality objectives for Lake Tahoe. By controlling dispersion, some sediments which otherwise would move beyond the dredging area into the lake will settle out within the enclosed dredging area. A portion of these settled sediments and associated nutrients may be subsequently removed by the dredge.

Silt curtains used at Lake Tahoe in the past have either been constructed by the contractor or purchased from commercial silt curtain manufacturers. For some applications contractors have rigged their own curtains. This entailed the purchase of curtain material from a manufacturer and installation of flotation in a sleeve at the top of a curtain and anchor chain into a sleeve at the bottom of the curtain for ballast. Choice of material suitable for use underwater has been very important. Some laminated plastic materials used in past dredging operations have not been designed for use in the water and delaminated during wave activity, causing the curtain to fail.

Commercial silt curtains are typically constructed of nylon reinforced PVC which affords great strength and durability for underwater use. These curtains include flotation sewn into the top of the curtain and ballast chain sewn into the bottom of the curtain, and a means for attaching sections of curtains together. They may also have tension cables to provide additional strength. Commercial silt curtains may withstand conditions which would cause lighter-weight curtains to fail. They may cost more than contractor-constructed curtains, however, they may potentially be reused or resold due to their durability. A commercial polyester-reinforced vinyl silt curtain proved largely effective in preventing escape of water from the dredge area at Fleur Du Lac. This curtain was constructed by Containment Systems of Cocoa, Florida (commercial curtains are also available from several other manufacturers). Lakeward anchoring of the curtain was provided by placement of temporary pilings to affix the curtain . The curtain was held to the bottom by the ballast anchor chain and formed a relatively good seal. The curtain performed well during operations except on one date during which strong winds and wave activity caused the curtain to pull free from one bulkhead. Further consultation with the manufacturers of commercial silt curtains may provide information on the most effective anchorage.

Careful evaluation should be done with respect to the severity of conditions likely to be encountered at the dredging site in order to choose an appropriate silt curtain. In some operations, silt curtains are used in areas protected from wave activity (i.e. inside protected harbors). There may be less of a need for the strongest silt curtain available in such applications and lightweight commercial or contractor-constructed curtains may be sufficient. In more exposed areas, subject to rougher lake conditions, heavier commercial silt curtains are recommended due to their greater strength and durability. For dredging in very large, exposed areas of the lake, much larger curtains are needed to surround a project. The use of heavy commercial silt curtains under such situations may provide protection against possible curtain failure, however there are considerable costs associated with such large curtains. Under severe storm conditions, even these heavy curtains may be damaged and fail resulting in escape of turbid into the lake. For some very large dredging projects in very exposed areas, it may be prudent to spend more resources on low-sediment-resuspension dredging technology and methodology (i.e. reduce the amount of resuspension at the dredge) and consider not using a silt curtain.[1] When silt curtain use is not feasible, open-lake dredging should be restricted to low-resuspension dredges.

Silt curtain use in harbors with inputs of stream water, or with very rocky, uneven bottom substrate over which the curtain is to be deployed, requires special considerations. In a previous project, unexpected high flows from a stream entering the harbor during dredging forced turbid, nutrient-rich dredge area water past the curtains. This problem may be remedied by diverting stream inputs around or through the curtain via piping. When curtains are deployed over very rocky bottoms, some dredge area water may seep through the spaces between the curtain and the rocks. These spaces should be sealed. In the past, sand bags have been used to seal such spaces with a moderate degree of success (some leakage was still observed past the sand bags placed along the base of the curtain used at Crystal Shores East). The disruption of bottom sediments when filling and emptying such bags in the lake may create additional sediment and nutrient resuspension. Further development of an environmentally effective means to seal the gaps between rocky substrate and silt curtains is needed.

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1 - See also the follow-up report titled: "Cost and Effectiveness Analysis for Implementation of Recommendations in: Impacts of Marina Dredging on Lake Tahoe Water Quality" (Hackley et al., 1996) for additional discussion of silt curtain costs and effectiveness and low resuspension dredging technology.

9.4. Disposal of Dredge Area Water to the Regional Sewer System or Other Suitable Area Outside the Lake

Pumping of dredge-impacted water to the regional sewer system has been used effectively in projects at Homewood High and Dry Marina and at Fleur Du Lac to reduce nutrient concentrations and turbidity within a dredge area. After completion of dredging the silt curtains are required to be left in place until natural settling has caused the levels of turbidity and nutrients in the dredge area to decline below discharge standard levels. As a result of removal of dredge area water by pumping and replacement with clear lake water, dredge areas were cleared rapidly and a portion of the sediments and nutrients remaining in the water following dredging were removed from the lake. Several utility districts around Lake Tahoe have indicated pumping into the sewer may be feasible (however, such inputs are not feasible in the Douglas County Sewer Improvement District system) depending on the capability of their system to accept additional flows and providing certain conditions are met. Discharge into the sewer is required to meet water quality requirements of the utility district(s), including a requirement that suspended solids concentration not exceed 300-350 mg/l (the specific limit varies with the particular utility district). Project proposals will undergo careful review by the utility district(s) and there are fees required associated with the permit and amount of water to be discharged.

The overall benefit of pumping into the sewer should be weighed carefully against potential impacts of input of suspended solids into the sewer system and costs. The water quality benefit is the amount of suspended material and associated nutrients which may be removed from the lake at the end of dredging through such pumping. This amount is closely related to several factors including: the amount of settling which must occur prior to pumping (in order to decrease suspended solids below the discharge limit), the capacity of the sewer system at the site and pumping rate feasible, and the volume of the area to be pumped. Such pumping may have an impact on the sewer system. The utility districts generally have expressed concern about the potential for wear on the sewer system due to settling of solids and abrasion in the system.[2]

A potential alternative to pumping of dredge-impacted water to the sewer system is pumping into a settling basin or other acceptable area outside the lake where solids and

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2 - See also the follow-up report titled: "Cost and Effectiveness Analysis for Implementation of Recommendations in: Impacts of Marina Dredging on Lake Tahoe Water Quality" for additional discussion of costs and effectiveness of pumping dredge-impacted water into the sewer system.

associated nutrients may be retained. There may or may not be limits on suspended solids in discharge or pumping rate, depending on the specific area into which such water is pumped.

9.5. Use of Flocculents to Enhance Sedimentation and Nutrient Removal in Spoils Impoundment Basins

The use of small quantities of alum and polymer flocculents can improve the turbidity and nutrient removal capabilities of spoils impoundment basins. Alum (hydrated aluminum sulfate) when mixed into lake water (of higher pH) hydrolyzes and forms fluffy gelatinous precipitates of aluminum hydroxide which enmesh small particles and associated nutrients, into larger particles or floc. The floc with associated sediments and nutrients then settles out of solution. Water soluble polymers, such as polyacrylamides, are organic flocculating agents often used in conjunction with alum. They also remove small particles from solution by flocculation. The combination of alum and polymer proved very effective in reducing turbidity, TRP, TKN, and TP when used in the Tahoe Keys spoils impoundment basins.

Alum is commonly used in water treatment as a flocculent to remove particulates and phosphorus. It also has been successfully applied in large volumes to lakes, to deter phosphorus release from the sediments. Some concerns over the use of alum involve the potential toxicity of certain forms of aluminum and the effects alum may have on pH in water in which it is applied. However, aluminum species are not normally considered toxic at pH values between 5.5 and 9.0. Lake Tahoe pH is usually near 7.8 and pH in the Tahoe Keys is usually between 8-9. The precipitates formed by administration of alum in aquatic systems are also non-toxic. However, the addition of large quantities of alum to unbuffered lake water can lower pH and potentially impact biota.

Alum and polymer flocculent are effective for reducing turbidity and nutrient levels in spoils settling basins outside the lake. Since the floc largely is retained within these basins, the potential for any detrimental impacts on areas receiving discharge from the basins, is greatly reduced. Although, alum could also potentially be effective in reducing nutrient levels and turbidity within silt curtain enclosed areas in the lake, the floc produced would settle to the lake or harbor bottom rather than in settling basins outside of the lake. The ultimate fate of this floc and associated nutrients, and potential impacts would require much further study before its general use in flocculation within dredged harbors could be recommended. Preferred methods of clarification of dredge areas following dredging are through natural settling or pumping (see Section 9.4). Until further study can be made of the impacts of alum on sediment-nutrient interactions in the lake and on lake biota, agency approval of the use of alum, should be made with caution, and limited to impoundment basins outside of the lake. The effects of various dosages of alum on elutriate test water, and lake water pH, turbidity, and nutrient levels should be included in predredging testing for future projects, where the use of alum is proposed. We strongly recommend that special provisions for monitoring also be placed on projects using alum.

9.6. Location of Spoils Dewatering Areas

In mechanical dredging operations, the spoils are usually piled in a designated basin or enclosed area, and the excess water allowed to drain from the sediments. This water is typically a combination of overlying lake water, sediment pore water, and elutriate-type water laden with sediments, which contains elevated levels of nutrients and other contaminants. Sediments are typically dewatered briefly (during a period ranging from several hours to several days), then loaded onto trucks for removal from the site. The water produced during dewatering may either percolate into the ground water or drain into the adjacent surface water. Consequently, nutrient loading to the lake will also occur from this process.

Spoils dewatering areas should be located such that drainage of nutrient and silt-laden water directly into the lake is prevented. Spoils dewatering on land within the area enclosed by silt curtains, or upgradient of the silt curtain enclosed area can help minimize impacts. Within such areas, the pore water draining from the sediments will remain within the confines of the dredge area. If feasible, this water may later be removed from the lake. Although percolation of spoils water into the ground water can afford some nutrient removal by sorption to the sediments and filtering of particulates, it is recommended such percolation occur away from the lake. Ideally, complete interception and removal of spoils water prior to reaching the lake will minimize potential impacts.

9.7. Final Disposal of Dredge Spoils

Predredging analysis of heavy metals, and TPH in the sediments should be done and will aid in decisions on the ultimate fate of spoils material. Where levels of heavy metals or TPH are high, consideration should be given to disposal outside the basin. In the absence of other contaminants, such as metals and TPH, the presence of high levels of nutrients in the sediments may not warrant mandatory disposal outside of the basin. Much of the nitrogen and phosphorus present in the sediments is often strongly bound to the sediments or bound in particulate organic matter. These forms of nutrients may take long periods of time to degrade and inorganic degradation products could potentially be utilized by terrestrial vegetation. The finer sediments associated with the dredge material however may be easily mobilized during surface runoff of rain or snowmelt. When dredge spoils are disposed of within the basin, it is recommended that the disposal is well away from the lake and surface water bodies such as streams and lakes. Further, it is recommended the sediments be stabilized via revegetation and other Best Management Practices once deposited within the basin. Further study should be done regarding the impacts of in-basin disposal of dredge spoils in association with agencies involved in administration and protection of natural resources and water quality at Lake Tahoe.

9.8. Additional Mitigation

Measures which would reduce the need for future dredging should be evaluated by Lahontan and TRPA. Marina owners could be asked to provide an evaluation of the causes of sediment accumulation within their harbor and propose methods to slow this accumulation as part of the permit application process. These could be evaluated by TRPA and Lahontan with respect to potential for reducing future dredging.

As new, environmentally efficient dredging technology becomes available, this technology should be considered for evaluation at Lake Tahoe. The levels of sediment and nutrient resuspension produced by new technology should be evaluated and contrasted with levels produced by previous dredging systems in Lake Tahoe. If superior, low sediment and nutrient resuspension characteristics are demonstrated for a new technology, this technology should be considered the standard for future choices of dredge technology relative to a particular sediment type. Perhaps a mitigation fee could be imposed to obtain environmentally sensitive dredging equipment for general use within the basin. This equipment would be available from Lahontan or TRPA for loan to dredging projects.

Finally, the marinas could be involved in a program to make boaters aware of ways to safeguard lake water quality. Perhaps marinas could be encouraged to post signs regarding proper fueling, cleaning, waste and garbage disposal procedures.

Summary - Section 9

1) Dredging should be done during the summer when the lake tends to be calmer

2) Use of silt curtains is recommended to control the dispersion of turbidity and nutrients released during dredging. Commercial silt curtains, which are constructed of reinforced PVC or similar material are strong and durable. These curtains should be used when feasible. In very protected areas (i.e. inside protected harbors), lighter-weight commercial curtains or contractor-constructed curtains may be sufficient. When silt curtain use is not feasible, open-lake dredging should only be done using low-sediment-resuspension dredges.

3) Pumping of dredge-impacted water from silt curtain enclosed areas to the sewer or other suitable area outside the lake after completion of dredging may be beneficial in reducing the nutrient loading from the project and also help "clear" water in the area rapidly.

4) Alum and polymer flocculents are effective in enhancing settling of particulates and associated nutrients in hydraulic dredging spoils impoundment basins outside the lake. Until further study can be made of the impacts of alum on sediment-nutrient interactions in the lake and on lake biota, agency approval of the use of alum, should be made with caution, and limited to impoundment basins outside of the lake.

5) Spoils dewatering areas should be located such that drainage of nutrient and silt-laden water directly into the lake is prevented. Spoils dewatering on land within the area enclosed by silt curtains, or upgradient of the silt curtain enclosed area can help minimize impacts. Ideally, complete interception and removal of spoils water prior to reaching the lake will minimize potential impacts.

6) Predredging analysis of heavy metals, and TPH in the sediments should be done and will aid in decisions on the ultimate fate of spoils material. Where levels of heavy metals or TPH are high, consideration should be given to disposal outside the basin.

7) Use of optional equipment which may reduce resuspension of sediments during operations should also be considered. Such equipment may include a flap valve in the discharge line of hydraulic dredges, additional shrouds around the cutter and real-time turbidity monitoring equipment.

8) The dredge operator should be familiar with and skilled in use of operational controls to minimize turbidity.

10. Monitoring and Discharge Standards

Water quality monitoring during dredging operations is important to assure minimal release of sediments and nutrients from dredge areas into the lake. Through ongoing monitoring, excessive releases of turbidity and nutrients around the dredge or past silt curtains can be detected and steps taken to reduce such releases. Monitoring required during dredging projects by Lahontan and TRPA has typically included water quality samples taken on a schedule defined by the regulatory agencies and self-monitoring of turbidity by the contractor or project manager. Lahontan has typically required turbidity, nitrate, total Kjeldahl nitrogen, total phosphorus and total iron in water quality samples. The number of water quality samples required has varied depending on the specific characteristics of each project and duration of the project ranging from fewer than 10 samples on some projects to 100 samples. The chemistry results obtained from monitoring have provided the agencies with data with which project compliance with permit requirements can be assessed. Self-monitoring for turbidity by the contractor or project manager provides daily information on levels of turbidity being produced. With this knowledge the manager may take corrective action if necessary to reduce levels to within permit standards.

The regulatory agencies have expressed concern that although the results of chemical analyses provide a means to assess project compliance, such assessment generally does not occur until after dredging has occurred for a couple of days or more. This is because the standard turn-around-time between collection of a sample and completion of multiple chemical analyses is typically more than one or two days (rapid chemical analysis may be possible but usually this results in significantly increased analytical costs). At standard turn-around-times, the results of chemical analysis may not provide the regulatory agencies and contractor with information on *nutrient* levels sufficiently rapidly to allow same-day, or even next-day correction of sources of excessive nutrient discharge. Further, enforcement action may not necessarily occur after exceedances of permit requirements are identified (for instance the exceedances may be found to have been produced by factors out of the dredge operator's control). Thus a large volume of chemistry may be generated which may be used to verify whether conditions of the permit are met, but this information may have limited impact on reducing discharge as dredging is occurring.

Turbidity may be easily and rapidly measured on site. Turbidity measurements have been used by the regulatory agencies in past projects to make a rapid assessment of when to require corrective measures to address excessive discharge of *turbid* water from a project. We investigated the relationships between turbidity and nutrients in dredge-impacted water to see to what extent turbidity may also be used as an rapid indicator of *nutrient levels* resuspended in the water around dredging projects. This information is presented in Section 10.1. In Section 10.2 we present recommendations for monitoring of dredging projects. Finally, in Section 10.3 we evaluate present standards for release of turbidity and nutrients with respect to maintaining minimal impact.

10.1. Relationships Between Turbidity Levels and Nutrient Levels in Dredge-impacted Water in Lake Tahoe

All TRG inlake and marina monitoring data collected during the dredging study was statistically compared against turbidity (Table 10.1) to determine the relationships between these parameters. In addition, data for Lahontan-required monitoring of projects done during this study were analyzed in Table 10.2. Finally, all historical data for TRPA and Lahontan-required monitoring done during 1988-1992 were analyzed in Table 10.3.

Strong associations were found for BAFe and TFe with turbidity in both historical monitoring and monitoring done during this study. In monitoring done during this study BAFe was associated with turbidity ($r^2 = 0.742$ TRG data) and TFe was associated with turbidity ($r^2 = 0.873$ Lahontan-required monitoring data). For historical monitoring data BAFe and TFe were also associated with turbidity ($r^2 = 0.683$ and 0.709 respectively). TP was also found to be highly associated with turbidity in monitoring done for the current study ($r^2 = 0.75$ TRG data; $r^2 = 0.82$ Lahontan-required monitoring data), however TP was not highly associated with turbidity in historical monitoring ($r^2 = 0.126$). The association between turbidity and other nutrients, especially the dissolved fractions, were weaker.

The results of the regression analysis suggest that turbidity may be used to estimate levels of TFe and BAFe in the water. For instance, a turbidity of 20 NTU would predict BAFe concentration of 1544 μg/l (Table 10.1 equation) and a TFe concentration of 1735 μg/l (Table 10.2 equation). Values estimated in this manner may provide an approximation of the nutrient level for BAFe, and TFe which may then be compared with monitoring standards to have an rapid indication that the project may or may not be in compliance with these standards. Action could then be taken to correct any sources of leakage of high turbidity or nutrients in a timely matter after analyzing turbidity. TP appeared to be well associated with turbidity for project sites monitored during this study, however it was poorly associated with turbidity in the historical data. Without a more detailed accounting of the methodology used for the historical data, the reason for this low association remains

Table 10.1. Regression equations, r^2, and regression coefficient p values, for associations between turbidity and nutrients. All TRG monitoring data from Fleur Du Lac (1993), Tahoe Keys lagoons (1993) and Tahoe Keys East Channel (1992), Tahoe Keys Impoundment Basins (1992), and Crystal Shores East (1993) dredging was used to determine regression equations.

Regression Between Turbidity and:	Regression Equation where x = Turbidity (NTU) y = Nutrient (μg/l)	r^2	n	p ≤	Range for Turbidity Data Used to Calculate Regression
NO_2NO_3-N	y = 0.173x + 2.763	0.179	250	.0001	0-110 NTU
NH_4-N	y = 3.6x - 4.768	0.528	284	.0001	
TKN	y = 7.848x + 177.06	0.451	233	.0001	
SRP	y = 0.067x + 2.073	0.120	173	.0001	
DP	y = -0.047x + 25.423	0.006	83	.4867	
TRP	y = 0.482x + 6.034	0.367	239	.0001	
TP	y = 2.437x + 24.955	0.745	286	.0001	
Soluble BAFe	y = 1.408x + 91.02	0.052	83	.0389	
Total BAFe	y = 58.489x + 374.701	0.742	81	.0001	

Table 10.2. Regression equations, r^2, and regression coefficient p values, for associations between turbidity and nutrients. Lahontan-required monitoring data from Fleur Du Lac (1993), Tahoe Keys lagoons (1993), Tahoe Keys East Channel (1992) and Crystal Shores East (1993) dredging was used to determine regression equations.

Regression Between Turbidity and:	Regression Equation where x = Turbidity (NTU) y = Nutrient (μg/l)	r^2	n	p ≤	Maximum Turbidity Value Used to Calculate Regression
TKN	$y = 7.406x + 200.92$	0.600	112	.0001	103
TP	$y = 1.964x + 19.011$	0.820	86	.0001	
TFe	$y = 76.019x + 215$	0.873	88	.0001	

Table 10.3. Regression equations, r^2, and regression coefficient p values, for associations between turbidity and nutrients for Lahontan and TRPA-required monitoring data obtained for historical dredging projects 1988-92. These projects included: Homewood High and Dry Marina (1988, 1989), Lake Forest Boat Ramp (1991), North Tahoe Marina (1988, 1989), Obexer's Marina (1988,1991), Sierra Boat Co. (1991), Star Harbor (1990), Sunnyside Marina (1992), Tahoe Boat Co. (1988), Tahoe Keys West Channel and Lagoons (1990, 1991), Tahoe Keys East Channel (1988).

Regression Between Turbidity and:	Regression Equation where x = Turbidity (NTU) y = Nutrient (μg/l)	r^2	n	p ≤	Maximum Turbidity Value Used to Calculate Regression
TKN	$y = 2.794x + 194.9$	0.286	100	.0001	119
TP	$y = 0.974x + 80.41$	0.126	85	.0009	
BAFe	$y = 83.549x + 7.303$	0.683	48	.0001	
TFe	$y = 34.474x + 382.2$	0.709	54	.0001	

speculative. As monitoring is done at future project sites the relationship between turbidity and TP should be further investigated. At this point in time, we cautiously recommend using the relationship between turbidity and TP that we found in this study.

Discharge standards and water quality objectives have been established for turbidity, TN and TP, while a discharge standard has also been established for TFe (see Table 10-4, section 10.3). Same-day analysis of turbidity may provide an indication of whether turbidity, TFe and perhaps TP are likely to be in compliance with monitoring standards, so that corrective action may be taken if necessary. Since TN is not always associated with turbidity, rapid analysis of this parameter should be done to assess compliance. When it is suspected the levels of TN being resuspended are near maximum permitted levels, next-day analysis of TN might be required.

It is interesting to note that from the relationship between turbidity and TFe (Table 10-2), a relatively low turbidity of 3.7 NTU would equate to a TFe value of 500 μg/l using the linear equation calculated from the data above. The Lahontan discharge standard for TFe is 500 μg/l while the discharge standard for turbidity is 20 NTU. This indicates that samples which have turbidities over 3.7 NTU may often exceed the TFe discharge standard. The discharge standards for these two parameters might deserve further evaluation. Since TFe and turbidity appear to be closely associated, discharge standards could be chosen which more closely reflects this association (i.e. compliance with the turbidity standard for a sample, will also reflect compliance with TFe). TRPA and Lahontan have indicated a need to further evaluate the iron discharge standards. This data seems to further confirm the need for such a re-evaluation.

10.2 Recommendations for Monitoring

An effective monitoring plan should provide the agencies with data with which to assess project compliance, as well as identify in a timely manner sources of excessive levels of turbidity and nutrients during dredging. Where these sources are controllable, action could be taken to control them rapidly. We recommend the following aspects be included in monitoring protocols developed by the regulatory agencies, additional measures may also be added.

First, we recommend that more focus be placed on turbidity in monitoring programs. Turbidity may be rapidly measured on-site. As indicated above, we found good statistical relationships between the levels of turbidity and total or biologically available iron and total phosphorus resuspended during dredging. By using the statistical relationships we found, the level of total or biologically available iron and total phosphorus might be approximated from the measured turbidity level. Thus a rapid approximation of two (TP, TFe) of the three nutrients of primary concern to Lahontan could be made using turbidity. Through rapid assessment of turbidity during dredging, sources of excessive levels of resuspension or discharge could be rapidly identified. Where these sources are controllable, action could be taken to correct them rapidly. When exceedance of the TN standard is suspected, next-day analysis of TN could be requested by the regulatory agencies.

During the dredging operations, frequent self-monitoring of project turbidity by the contractor or project manager and maintenance of daily records should be done as in the past. Compliance monitoring for turbidity should be done in addition to self-monitoring. Such compliance turbidity monitoring might be substituted for extensive water chemistry monitoring on a portion of the days on which a full water chemistry monitoring might have been required in the past. Occasional water quality samples should be taken on a schedule outlined by the regulatory agencies, however, the frequency of extensive chemistry samples might be reduced. The turbidity measurements obtained in compliance monitoring must provide reliable data to the regulatory agencies for use in assessment of project compliance. Turbidity data collected as part of compliance monitoring should also provide measurements with which the contractor could compare his daily turbidity measurements. Automated turbidity monitoring equipment could also be employed to provide real-time turbidity monitoring during open-lake dredging. A turbidity sensor could be deployed for instance at a set distance from the cutter. Data from the sensor would be received in the dredge cab instantaneously and allow the operator to adjust controls as necessary to stay within permitted levels. Data received could also be stored in a data logger and provide a continuous record of turbidity levels for later review by the regulatory agencies.

Sites chosen for monitoring by Lahontan and TRPA in past projects have been well-selected for identifying major impact areas. The following indicates sites which are particularly important to include in future monitoring programs. Monitoring locations should include a site just outside of silt curtains or 10 feet away from the cutterhead in open water dredging to document the release of sediments and nutrients to the lake during dredging. In the past, monitoring outside the silt curtain has been done from 1-10 feet from the silt curtain at the surface. We recommend samples be collected both at the surface and near the bottom outside the silt curtain at multiple points along the entire border or perimeter of the curtain (as leakage may occur along the bottom of the curtain). Sample collections should be as close to the curtain as is possible without jeopardizing the integrity of the curtain. A monitoring site should also be selected within the silt curtain enclosed dredge area. Surface water sampling at several locations within 10 ft. of the cutter during hydraulic dredging is recommended as in the past. It should be recognized though, that levels of turbidity and nutrients may be higher along the bottom than at the surface (see Section 4.1) and this should be taken into account when assessing whether the project is in compliance with discharge standards and water quality objectives. Discharge from spoils settling basins or solids separation systems should be monitored. Areas where mixing of marina water with the lake may occur (such as at the outer end of the channels leading from Tahoe Keys) should also be monitored.

Pre-project analyses of sediments collected from the area to be dredged should continue to be done. Sediment samples should be collected well in advance of the project (several months but not more than a year in advance). It is recommended that an elutriate test (which simulates the potential release of nutrients from the sediments during dredging) be done on sediments, as well as analysis of the raw sediments. The specific analyses which should be done have been described in Section 8.5.1. The results obtained from raw sediment analysis and elutriate tests will be useful in decisions on dredge type, mitigation and monitoring. Permits should not be granted until these analyses and evaluations are completed.

Pre-project water quality samples should also be collected from the dredge area just prior to the project. Within a week before project set-up begins, background water samples should be collected within the proposed dredge area and in the approximate area which will be just outside the silt curtain. These samples should be analyzed for: turbidity, NO_2NO_3, TKN, TP, and TFe and will serve as baseline conditions from which to evaluate impacts during the operational phase.

10.3. Evaluation of Current Standards for Release of Turbidity and Nutrients

Lahontan has established specific "water quality objectives" for the protection of water quality in Lake Tahoe. These objectives are described in the Water Quality Control Plan for the Lahontan Region. In addition to the water quality objectives, Lahontan also establishes discharge standards (or effluent limitations), which must be met within the discharge permits for dredging projects. Table 10-4 presents water quality objectives and typical discharge standards for turbidity, TN, TP, and TFe in Lake Tahoe.

A comparison was made between concentrations measured during monitoring of the dredging projects and the levels for lake water quality objectives and discharge standards. The levels of turbidity, TN, TP, and TFe observed within silt curtain enclosed areas, outside the silt curtains, and near the dredge cutter during open lake operations were compared with the discharge standards and regulatory objectives.

Within silt curtain enclosed areas at Crystal Shores East and Fleur Du Lac, median levels of turbidity, TN and TP exceeded the water quality objectives for Lake Tahoe. This is one reason why silt curtains are required around dredging projects. Combining data collected within silt curtain areas for Crystal Shores East and Fleur Du Lac, the levels of each constituent presented as (median; 90th percentile value; n) were: turbidity (28 NTU; 122 NTU; n=42); TN (375 μg/l; 886 μg/l; n=27); TP (107 μg/l; 224 μg/l; n=31); TFe (2000 μg/l; 7060 μg/l; n=12). These median values also exceeded the discharge standard for turbidity, TP, and TFe. When levels of turbidity, TN, TP, or TFe exceeded the discharge standards within the enclosed area, any escape of this water past the silt curtain (detected as a concentration above background outside the curtain), constituted a violation of the discharge standard, *vis-a-vis*, the main lake.

An assessment of the significance of such leakage to localized lake water quality may be made by comparing concentrations observed outside the silt curtain with the water quality objectives for the lake. This was done for data collected 10 feet or less outside of the silt curtains at Crystal Shores East, and Fleur Du Lac. (Note: we are comparing median concentrations and not single value concentrations to the water quality objectives). For the TRG and agency monitoring data collected from these two sites, the following median and 90th percentile values were calculated: turbidity (0.33 NTU; 1.37 NTU; n=48); TN (105.5 μg/l; 150 μg/l; n=36); TP (11 μg/l; 23.8 μg/l; n=37); TFe (50 μg/l; 173 μg/l; n=22). The water quality objective for TP (8 μg/l) was slightly exceeded by the median value (11 μg/l), while the water quality objectives for turbidity (1 NTU), and TN (150 μg/l) were achieved outside the silt curtain in at least 50% of the samples. Comparison of concentrations 10 feet outside of the silt curtain with the lake water quality objectives would appear to be the most direct comparison to help assure minimal impact.

The resuspension of nutrients and production of turbidity at the cutter during open-lake dredging, is similar to new discharge in that these constituents are being introduced into the surface water where they are available for algal utilization. The measurement of discharge concentrations in such open-lake dredging however, is not possible, since the nutrients are mixed directly into the surrounding lake waters. Only the net effect of such releases may be determined through monitoring near the cutter. We calculated the median and 90th percentile values for samples collected 10 feet away from the cutter at the surface to be: turbidity (8.7 NTU; 39.5 NTU; n=28); TN (350 μg/l; 728 μg/l; n=23); TP (34 μg/l; 86 μg/l; n=25); TFe (790 μg/l; 4000 μg/l; n=21). The median values for all parameters were intermediate between the water quality objectives and the discharge standards. In the best situation, the levels of these constituents were less than the water quality objectives, in the worst, the levels exceeded the discharge standards. Typically however, the water

Table 10-4. Lahontan water quality objectives for turbidity, TN, TP, and TFe in Lake Tahoe and discharge standards for surface waters entering Lake Tahoe.

Parameter	Lahontan Water Quality Objective	Lahontan Discharge Standard
Clarity	3 NTU [1] 1 NTU [2]	20 NTU
TN	150 μg/l	500 μg/l
TP	8 μg/l	100 μg/l
TFe	-	500 μg/l

1 - In shallow lake waters directly influenced by stream discharges

2 - In shallow lake water not directly influenced by stream discharges

quality objectives were exceeded during such open water operations.

Our testing of the VMI 612 dredge under different settings of auger pressure and engine RPM, indicated the level of turbidity produced around the dredge may be reduced significantly at low auger pressures. However, the efficiency of sediment removal of the dredge was also reduced at lower auger pressures. The standard auger pressure used by the dredge operator during this project was approximately 700 PSI (the high pressure setting used in our testing). At this setting, a maximum turbidity of 16 NTU was measured at the surface during the dredge test, which is lower than the permitted level of 20 NTU. This, and the fact that the median turbidity level around this dredge at the surface was 8.7 NTU, may indicate that the permitted level of 20 NTU allows too much flexibility in the levels of turbidity around the dredge.

With the goal to minimize impacts on the lake, further evaluation of environmentally sensitive dredges should be done as the opportunity arises. Based on the results of such evaluation, monitoring standards for open lake dredging might be further refined.

<u>Summary - Section 10</u>

1) Turbidity was found to be statistically associated with the levels of total or biologically available iron and total phosphorus resuspended during dredging. Same-day measurement of turbidity may provide a rapid means to approximate levels TFe, BAFe and TP. By providing a rapid assessment of the levels of turbidity and these nutrients, sources of excessive levels of resuspension or discharge during dredging can be rapidly identified. Where these sources are controllable, action could be taken to correct them rapidly. Increased focus on turbidity in monitoring programs is recommended.

2) TN is not well associated with turbidity. Rapid assessment of whether a project is likely to be in compliance with respect to TN may be made through next day laboratory analysis.

3) Sites selected for monitoring by the regulatory agencies in the past have been well selected. However, it was recommended future monitoring outside silt curtains also include multiple points along the bottom of the curtain. Consideration should also be given to using automated turbidity monitoring equipment during hydraulic dredging to provide real-time turbidity measurements to the dredge operator. The use of a data-logger with such equipment would also provide a continuous record of turbidity generation for the regulatory agencies.

4) Preproject analysis of sediments to be dredged should include an elutriate test to assess potential nutrient and contaminant release from the sediments.

5) Further evaluation of the discharge standard for iron is warranted by Lahontan and TRPA. The linear relationship between turbidity and TFe found in this study predicted that the TFe discharge standard of 500 $\mu g/l$ would be exceeded when turbidity exceeded 3.7 NTU. The discharge standard for turbidity is 20 NTU however. Projects in compliance with the 20 NTU standard may well exceed the discharge standard for TFe.

11. Summary

From 1992-1994 the U.C. Davis Tahoe Research Group conducted a study which looked at the impacts of dredging on Lake Tahoe. To assess the potential impact of sediment resuspension during dredging, we studied both the total levels of nitrogen and phosphorus in marina and harbor sediments and the levels of different fractions of nitrogen and phosphorus released during elutriate tests (which simulated the mixing of sediments with lake water which occurs during dredging). Relatively small percentages of TN and TP present in raw sediments were released to the elutriate supernatant solution. TN in the elutriate supernatant solution ranged from 1-19% of original sediment TN with a median level of 3.9%, and TP in the elutriate supernatant ranged from less 1-7% of the original TP with a median level of 1.2%. The majority of TN in the elutriate supernatant consisted of organic N (which is not immediately available to algae, although microbial degradation of this material may increase N availability through time). The DIN fraction of TN was often small, however, this fraction is considered to be all bioavailable to algae. Generally, from 1-6% (median level 3.6%) of the TP measured in the elutriate supernatant solution was found to be bioavailable phosphorus using a NaOH extraction procedure. Much of the remaining P was organic P and other forms of P not immediately available to the algae. These results suggest that within a dredge area, disruption of the sediments can release small amounts of immediately bioavailable N and P. These results were confirmed in monitoring within dredge areas during operations. The maximum dredge area concentrations were often within an order of magnitude of concentrations observed in the elutriate tests. To the extent other forms of N and P remain available to microbial and algal activity, some additional N and P may become available to algae.

The impact of nutrients in the sediments on algal growth was also investigated using bioassay procedures. A majority of the marina sediments were also shown to stimulate algal growth when added to Lake Tahoe water as a 1% solution of elutriate test supernatant. Calculation of the dissolved inorganic nitrogen (DIN) and biologically available phosphorus in the 1% solutions of elutriate and comparison with statistically significant growth responses, indicated significant growth responses were measured at DIN levels as low as 0.05 μg/l and 0.12 μg/l BAP. These sediment solutions not only contained DIN and BAP, but also some available N sorbed to particulates and organic N, as well as iron possibly other trace metals and growth factors potentially stimulatory to algal growth. Tahoe phytoplankton thus appeared to be sensitive to additions of very small amounts of nutrients (on the order of tenths of μg/l of DIN and BAP) when added in concert with the dredged sediments.

Extensive monitoring was done in the vicinity of dredging projects during operations to determine actual levels of turbidity and nutrients resuspended. Turbidity and nutrient resuspension created around a hydraulic dredge was investigated. Localized plumes (extending 25-200 ft. from the dredge) of increased turbidity and nutrient levels were observed around the hydraulic dredge (VMI 612 horizontal cutter suction dredge) during operations in the Tahoe Keys Marina and Tahoe Keys East Channel. Although the plumes extended quite a distance, the highest levels of turbidity and nutrients were localized within 10-20 feet around the dredge itself. The median values for turbidity, TN, and TP 10 feet away from the cutter at the surface exceeded Lahontan water quality objectives for Lake Tahoe. The monitoring data was used to estimate the load of nutrients suspended in plumes around the dredge during operations both in the open lake and in a land-locked (bounded on the sides by land) section of channel. We estimated that 0.13 kg TP was in suspension in a plume around the dredge in the open-lake after one-half day of dredging. 2.4 kg TN and 0.17 kg TP were estimated to be suspended in a plume in the land-locked section of the channel, a portion of this load may have accumulated as a result of previous days of dredging.

Mechanical dredging was done at both Fleur Du Lac (dragline and clamshell dredging) and Crystal Shores East (excavator dredging). Mechanical dredging has a high potential to resuspend turbidity and nutrients. This was demonstrated by increased levels of turbidity and nutrients which developed within silt curtain enclosed areas. An estimate of dragline dredging loading of N and P to the areas enclosed by silt curtains was made from monitoring samples collected from Fleur Du Lac. Within the main harbor, one-day totals were 1.08 kg TKN (NO_3-N data not available to calculate TN) and 0.51 kg TP released within the silt curtain enclosed area. Since the nutrients released from sediments are held in place within silt curtain enclosed areas, the potential for increased algal growth is greater within these areas. Increased chlorophyll in response to elevated nutrients produced by dredging was, in fact, seen within the harbor at Fleur Du Lac (which increased from a predredging level of 0.07 μg/l to 10.15 μg/l). Since silt curtains were used to isolate the dredge area water from Lake Tahoe for projects at Fleur Du Lac and Crystal Shores East, the loading of nutrients to the lake was dependent on the integrity of the silt curtain seal.

The effectiveness of silt curtains in isolating dredge area water from Lake Tahoe was assessed through monitoring outside of the silt curtains. A commercially constructed polyester reinforced vinyl silt curtain was generally effective in retaining turbidity and nutrients within the dredge area at Fleur Du Lac. Monitoring indicated leakage past the silt curtain at Fleur Du Lac was small. Turbidity levels at the surface rarely exceeded 1 NTU, 10 ft. outside the silt curtain and levels of TN and TP 10 ft away from the curtain were generally near, or slightly exceeded the background level. A lighter plastic material, contractor-constructed curtain originally installed at Crystal Shores East failed during strong wind and wave activity resulting in the escape of some dredge area water. We estimated the maximum potential nutrient release from Crystal Shores East curtain failure area based on concentrations of nutrients reestablished in the harbor after installation of the new curtain and the approximate harbor volume. A conservatively high estimate of TN (3.5 kg) and TP (2.5 kg) could have been released to the lake if the curtain failure occurred during maximum dredge area concentrations of N and P and all dredge area water escaped to the lake.

Silt curtains are an important mitigation method to minimize the impacts of dredging on Lake Tahoe. Through use of a silt curtain, the area over which a plume of turbid water extends can be minimized and levels of turbidity and nutrients outside the curtain may potentially be maintained near the water quality objectives for Lake Tahoe. By controlling dispersion, some sediments which otherwise would move beyond the dredging area into the lake will settle out within the enclosed dredging area. A portion of these settled sediments and associated nutrients may be potentially subsequently removed by the dredge. Use of silt curtains in extremely exposed portions of the lake have the potential for failure during strong wind and wave activity, however. Careful evaluation should be done with respect to the severity of conditions likely to be encountered at the dredging site in order to choose an appropriate silt curtain.

The potential water quality impacts of sediments newly exposed by dredging was also investigated. A initial decrease in interstitial-water NO_3-N and NH_4-N concentrations in sediments newly exposed, 16 days after dredging, provided evidence that nutrient release may occur from newly exposed sediments during or following dredging. Nutrient releases from underlying sediments, which occur <u>during</u> dredging may have less impact on the lake (then releases after dredging) as the dredge may remove some portion of the nutrients released. The data also indicated dredging may increase the potential for nutrient release over a long period of time. High concentrations of NH_4-N developed in shallow sediments near the surface of Tahoe Keys lagoons sediments, over the course of the year following dredging. This increase may have been associated with ammonification of previously deeply buried organic matter in the sediments which became located near the surface upon removal of the overlying sediments. The proximity of such high concentrations of NH_4-N to the surface indicated there was potential for release to the lake through disruption of the sediments or mixing during turbulence in the overlying water, and possibly through diffusion. Determination of the magnitude of such long term releases would require additional detailed study.

The potential impacts of spoils dewatering practices was investigated. Dewatering of spoils at Crystal Shores East was done on a section of sandy beach adjacent to the lake. High NO_3-N concentrations were detected in very shallow shoreline water downgradient of the spoils pile. NO_3-N appeared to move quite rapidly through the sands into the lake. To minimize the potential impacts associated with dewatering and input of soluble nutrients to the lake, dewatering adjacent to the open lake is not recommended. When site conditions permit, a preferred approach to spoils dewatering would be to dewater spoils on land within an area enclosed by silt curtains, or upgradient of the silt curtain enclosed area. Heavy metal concentrations in marina sediments were observed to be generally low based on historical data. The potential mobilization of high levels of metals from these sediments would therefore appear to be low.

Dredge operators, manufacturers, and researchers involved with studying the impacts of dredging were contacted and information compiled on environmentally efficient dredging technology and operational practices to minimize sediment resuspension during dredging. Extremely low sediment resuspension dredges have been developed in other countries for removal of toxic contaminated sediments, however, much of this technology is not available in the USA. A special low-resuspension bucket dredge called the Cable Arm Clamshell is available in the USA. This dredge might have application in softer sediments to be dredged at Lake Tahoe and should be considered for future testing in Lake Tahoe. A new type of hydraulic dredge called the Eddy Pump is also available in the USA. This dredge has capability to remove high concentrations of solids (> 70%) while apparently creating very low turbidity. The Eddy Pump can dredge unconsolidated sediments including sand and small gravel and should be considered for testing of its ability to remove sediments while causing low resuspension in Lake Tahoe.

Operational controls are also important to minimize the sediment resuspension during dredging. We investigated the impact of operational controls relative to turbidity and nutrient release around the VMI 612 dredge during a test at Tahoe Keys. The impacts of varying engine RPM and auger pressure were investigated. Of these two controls, auger pressure was the primary factor affecting turbidity and nutrient release. Several other operational controls may be applied to hydraulic, as well as mechanical dredging to minimize sediment resuspension.

The contributions of N and P from individual dredging projects are low relative to contributions from other sources such as stream inputs and atmospheric inputs and internal loading of nutrients from the hypolimnion of the lake. However, they are comparable to other inputs produced by man's activities within the basin which are regulated (e.g. runoff from residential, commercial and other urbanized areas). The management strategy at Tahoe is to minimize all incremental sources of nutrients and thereby minimize the potential cumulative input of nutrients to the lake. The additive contributions of individual dredging projects over several years of allowed dredging, constitute non-natural inputs which, when combined with other man-derived sources of nutrients (e.g. land disturbance, runoff from impervious surfaces on individual parcels, fertilizer usage, etc.) have a cumulative, additive effect on the levels of nutrients available in the lake to support algal growth. Management of Lake Tahoe as an Outstanding National Resource Water requires that all practical measures be taken to minimize any allowed short-term degradation associated with projects such as dredging. Long-term degradation of the lake is not allowed.

The use of environmentally efficient dredging technology, operational controls, and appropriate silt curtains, combined with an effective monitoring program and adherence to discharge standards and water quality objectives, can all help minimize the impacts of dredging on the lake. Open-lake dredging (in which silt curtains are not used) may have the greatest potential for impact on the lake. These impacts are primarily short-term and occur in the immediate vicinity of the dredge operation. Localized plumes of turbidity are produced around the dredge and with each day of open-lake dredging, the load of nutrients resuspended in the lake increases. The impacts of such open-lake dredging can be reduced by selecting dredges which produce low levels of sediment resuspension and by reducing the number of days spent dredging in open-lake areas. As new low-sediment resuspension dredging technology becomes available, this technology should be evaluated for use at Tahoe. Finally, causes of sediment accumulation within specific harbors and marinas should be evaluated, and measures taken where possible to reduce the need for future dredging.

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Appendix A-1. Results of TRG monitoring around VMI 612 horizontal cutter suction dredge during 1992 dredging of the Tahoe Keys East Channel (refer to App. B Map 2).

Transect(s) / Conditions	Dist. from dredge (ft)	Front or Back of dredge	Dist. from Top/Bottom	Turbidity (NTU)	SRP (µg/l)	DP (µg/l)	TRP (µg/l)	TP (µg/l)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	DBAFe (µg/l)	BAFe (µg/l)
7/14/92- Predredging	(East Channel near Metal Bulkhead)		Surface	2.5	N/A	14	8	30	2	11	174	48	147
Background Samples	(Lake Tahoe outer East Channel)		Surface	0.25	N/A	10	3	17	2	2	37	4	12
9/12/92 Transect/	15	Front	Top - 1 ft	1.2	2	24	3	26	2	3	58	7	149
transect depth approx. 5 ft.	15	Front	Bottom - 1 ft	19	3	22	22	143	2	41	572	89	4478
windy, rough lake conditions	25	Front	Top - 1 ft	0.3	2	22	3	26	1	2	4	3	32
	25	Front	Bottom 2-3 ft	0.4	2	18	3	23	1	1	54	4	33
9/15/92 Transect/	50	Front	Top - 1 ft	8	2	24	10	56	3	19	204	77	1068
transect depth approx. 4-5 ft.	50	Front	Bottom - 1-2 ft	11	2	24	11	70	3	24	289	86	1529
slight S/W breeze	20	Front	Top - 1 ft	11	3	26	23	57	3	27	N/A	89	1346
	20	Front	Bottom - 1-2 ft	13	2	26	14	73	3	31	242	94	1837
	10	Front	Top - 1 ft	17	3	22	12	86	3	44	392	116	2317
	10	Front	Bottom - 1-2 ft	23	3	26	16	137	3	45	640	127	3670
	25	Back	Top - 1 ft	13	2	21	14	76	3	53	339	136	1613
	25	Back	Bottom - 1-2 ft	17	2	21	12	87	3	58	309	143	2314
9/24/92 Transect/	400	Front	Top - 1 ft	5	1	12	5	32	2	1	430	37	653
transect depth approx. 2-2.5 ft.	200	Front	Top - 1 ft	11	2	12	10	54	3	49	467	61	1287
15-25 mph S/W wind	100	Front	Top - 1 ft	10	2	12	9	52	3	56	570	55	1254
	50	Front	Top - 1 ft	13	3	13	13	84	3	90	521	54	1559
	20	Front	Top - 1 ft	11	3	10	7	64	2	56	516	55	1215
	10	Front	Top - 1 ft	11	2	11	6	51	3	70	443	57	1338
	0	mid-dredge	Top - 1 ft	11	2	11	7	51	3	75	506	64	1403
	20	Back	Top - 1 ft	16	3	12	8	77	2	71	659	66	1713
	50	Back	Top - 1 ft	14	2	10	11	85	4	80	698	159	1580
	100	Back	Top - 1 ft	10	2	12	6	59	3	31	514	51	1015
	200	Back	Top - 1 ft	5	3	12	5	24	3	1	429	35	616
	400	Back	Top - 1 ft	3	2	9	4	30	3	1	346	35	446
10/2/92 Transect/	400	Front	Top - 1 ft	8	N/A	N/A	7	57	N/A	1	N/A	N/A	N/A
transect depth approx. 6 ft.	200	Front	Top - 1 ft	11	N/A	N/A	7	52	N/A	1	N/A	N/A	N/A
moderate S/W wind	100	Front	Top - 1 ft	11	N/A	N/A	13	49	N/A	1	N/A	N/A	N/A
	50	Front	Top - 1 ft	11	N/A	N/A	11	60	N/A	1	N/A	N/A	N/A
	50	Front	Bottom - 1-2 ft	12	N/A	N/A	11	69	N/A	2	N/A	N/A	N/A
	20	Front	Top - 1 ft	12	N/A	N/A	10	66	N/A	1	N/A	N/A	N/A
	20	Front	Bottom - 1-2 ft	12	N/A	N/A	13	67	N/A	2	N/A	N/A	N/A
	10	Front	Top - 1 ft	15	N/A	N/A	13	75	N/A	2	N/A	N/A	N/A
	10	Front	Bottom - 1-2 ft	14	N/A	N/A	14	70	N/A	1	N/A	N/A	N/A
	0	mid-dredge	Top - 1 ft	13	N/A	N/A	10	65	N/A	1	N/A	N/A	N/A
	20	Back	Top - 1 ft	8	N/A	N/A	9	45	N/A	1	N/A	N/A	N/A
	20	Back	Bottom - 1-2 ft	19	N/A	N/A	11	82	N/A	2	N/A	N/A	N/A
	50	Back	Top - 1 ft	7	N/A	N/A	9	41	N/A	2	N/A	N/A	N/A
	50	Back	Bottom - 1-2 ft	10	N/A	N/A	10	52	N/A	7	N/A	N/A	N/A
	100	Back	Top - 1 ft	4	N/A	N/A	9	27	N/A	1	N/A	N/A	N/A
	200	Back	Top - 1 ft	3	N/A	N/A	8	24	N/A	1	N/A	N/A	N/A

D.4. Conclusions

a) Strong linear relationships were observed between turbidity and suspended sediment for sediments from the two sites. The slope of the lines describing suspended sediment as a function of turbidity level varied slightly for sediments from the two different locations.

b) The linear relationships describing suspended sediment as a function of turbidity may be cautiously used to estimate suspended sediment levels produced around the dredging projects at Tahoe Keys and Crystal Shores East. It should be recognized the data are very limited and provide only a rough approximation of the actual suspended sediment level. Since the relationship appeared to vary slightly for sediments from the two different locations, we used the relationship found using Tahoe Keys sediments (Figure D-1) to estimate suspended sediment levels around the VMI 612 dredge during operations at Tahoe Keys. These values were compared with suspended sediment levels measured around a Mud Cat dredge that were reported in the literature. Similarly, the turbidity vs. suspended sediment relationship found using Crystal Shores East sediments may cautiously be used to estimate suspended sediment levels from the measured turbidities at this site.

Table D-2. Turbidity and suspended sediment levels in samples of lake water following resuspension and brief settling (for 10 seconds) of variable quantities of Crystal Shores East Harbor sediments in 250 ml of lake water.

Wet Weight Sed. Added (mg)	Turbidity (NTU)	Suspended Sediment (mg/l)
13	2.25	4
13	2.75	5
28	5	24
71	13	59
73	13	67
141	22	122
270	45	208
476	62	376

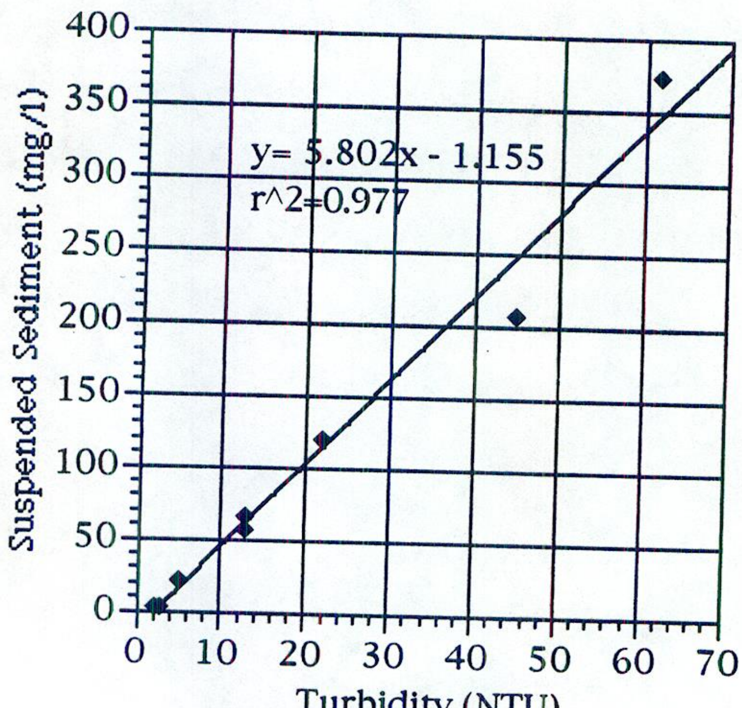


Figure D-2. Relationship between turbidity and suspended sediment for variable amounts of Crystal Shores East Harbor sediments resuspended in lake water.

D.3. Results

Table D-1. Turbidity and suspended sediment levels in samples of lake water following resuspension and brief settling (for 10 seconds) of variable quantities of Tahoe Keys Marina sediments in 250 ml of lake water.

Wet Weight Sed. Added (mg)	Turbidity (NTU)	Suspended Sediment (mg/l)
15	0.80	2
20	0.77	2
61	1.75	2.4
451	9.1	33
873	16.8	49
1242	25	92
2916	53	220

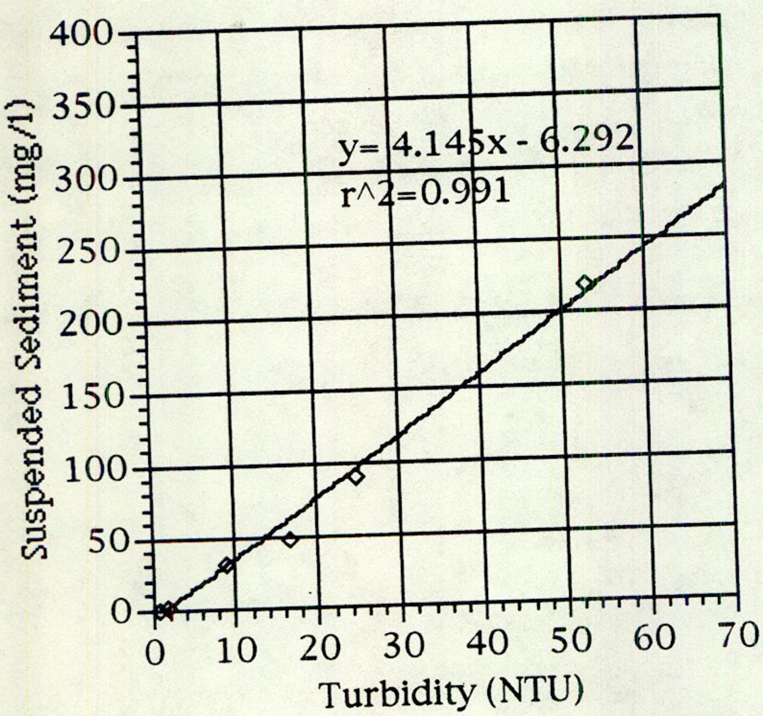


Figure D-1. Relationship between turbidity and suspended sediment for variable amounts of Tahoe Keys Marina sediments resuspended in lake water.

Appendix D. Turbidity vs. Suspended Sediment Relationships

D.1. Purpose

Monitoring around dredges and inside and outside of silt curtain enclosed areas was limited to turbidity and certain nutrients. Suspended sediment was not measured, however suspended sediment is commonly reported in the literature for assessment of particulate resuspension around dredging operations. To make very general comparisons between turbidity measurements made as part of this study and suspended sediment concentrations reported in the literature, a limited experiment was done which related turbidity produced by suspension of lake sediments from two different sites to measured suspended sediment concentration.

D.2. Methods

Small quantities (ranging from 0.1-3.0 grams) of wet lake sediments from either Tahoe Keys or Crystal Shores East were added to 250 ml of 0.45 μm filtered lake water in a 250 ml graduated cylinder. The cylinder was capped with parafilm and inverted 20 times to mix. The large particles were then allowed to settle out of solution for 10 seconds. The remaining solution was poured off rapidly into a 500 ml bottle and the turbidity and suspended sediment determined. Suspended sediment was determined by filtering a known volume of sample through a pretared GF/F filter, drying the filter overnight at 105 C, then measuring the weight of material on the filter.

7) The potential impacts of many of the projects during dredging was appeared to be low as indicated by near background nutrient concentrations outside the turbidity curtains. However, escape of dredge area water into the lake occurred in several projects. Projects in which some escape of dredge water occurred during dredging could be divided into three categories: (a) projects in which short-term releases occurred due to minor failures of the turbidity curtains; (b) projects which had ongoing releases due to continued failures of the curtains; (c) projects which had complete failure of curtains and release of much of the dredge area water. Categories (b) and (c) had the greatest potential for impact.

asphalt plant. Though the solids removal system initially slowed the dredging by causing the dredge to operate at less than capacity, modifications were made which allowed the dredge to operate at capacity.

- Lake Forest Boat Ramp (1991) - following dredging, pumps were used to pump out the dredge area to the sewer system and a depression by a field. This decreased the amount of time until turbidity curtain removal and reduced the amount of nutrients released to the lake once the curtains were removed.
- Homewood High and Dry Marina (1991) - used pumps to pump dredge area water into the sewer system. This decreased the amount of time until turbidity curtain removal and replaced marina water with low nutrient lake water.
- Sierra Boat Co. Marina (1991) - used pumps to pump dredge area water to settling ponds. Water from these ponds was then pumped to the sanitary sewer system.
- Coon St. Boat Ramp (1989) - removed solids from suction dredging in a solids removal system. The water was disposed in the sewer system.

<u>Summary - Appendix C</u>

1) During dredging, levels of Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), Biologically Available Iron (BAFe), Total Iron (TFe) and turbidity increased within dredged areas in nearly all projects in which they were monitored. TKN, TP, BAFe, and TFe consist of both a soluble and particulate fraction of the nutrient analyzed. Thus as levels of particulates and turbidity increased during dredging, the levels of these nutrients also tended to increase. The magnitude of increase for these parameters varied by project and frequency of sampling.

2) The levels of oxidized nitrogen (NO_2+NO_3-N), ammonium nitrogen (NH_4-N) and ortho-phosphorus increased within dredged areas during dredging in some but not all projects in which they were monitored.

3) Turbidity was found to be statistically associated with BAFe and TFe, but not TP and TKN in the historical data.

4) Increased algal growth as indicated by increased chlorophyll a concentrations was observed within dredged areas during or following dredging in several projects. This increased growth was likely a result of increased nutrient levels resulting from dredging.

5) The turbidity curtains used to confine water in the dredging areas appeared to be effective in isolating dredge area impacted water of high turbidity and nutrient content from the main lake in many of the historical projects. Maximum turbidity and nutrient concentrations outside the turbidity curtains were often near or only slightly higher than background for many projects.

6) Time elapsed between completion of dredging and permission to remove turbidity curtains ranged up to 17 days. Projects which utilized pumping and removal of dredge area water were able to remove silt curtains much sooner.

C.6. Problems or Delays During Historical Dredging Projects

Upon reviewing the historical data, it became apparent that several projects experienced problems or delays. In some cases these problems were preventable, others were associated with non-preventable causes such as the weather. Familiarity with these problems may prove beneficial to future potential dredge operators. The following presents a summary of the some of the problems which developed during historical projects.

- Coon St. Boat Ramp (1988) - Rough lake conditions caused turbidity curtain to pull away from bottom anchorage. Turbidity plume escaped into Lake Tahoe.
- Coon St. Boat Ramp (1989) - Sand content in water discharged from solids separation system to sewer was too high; potential problems with abrasion in sewer line.
- North Tahoe Marina (1988) - Rough lake conditions caused some leakage through turbidity curtains.
- Tahoe Boat Co. Marina (1988) - Rough lake conditions caused some turbidity curtain problems and delays.
- Tahoe Keys East Channel (1988) - Some dredge spoils escaped through a poor gasket seal in the pipeline.
- Star Harbor (1990) - Inclement weather and unanticipated runoff increased stream inputs into harbor being dredged. Permeable screens designed to contain sediments and allow water to pass through clogged. Increased streamflows caused spillage over the screens and escape of turbidity plume into lake. Time delays associated with fixing problems moved project into possible fish spawning season, construction of a fish ladder was required.
- Obexer's (1991) - Turbidity curtain "blow out" and escape of turbidity plume.
- Sunnyside (1992) - Clamshell loader unable to dig through bottom material, had to use backhoe. East wind and rough lake conditions caused some leakage through curtains.

C.7. Innovative Dredging Techniques

Finally, in the course of reviewing the files, it became evident that certain projects were innovative in the methods that were used to help reduce lake impacts. The following summarizes some the innovative techniques associated with historical dredging projects.

- Tahoe Keys (1991) - suction dredged the west channel. Dredged material solids were separated in a solids removal device, then removed for use at an

When significant flows into a dredge area from streams exist, provision for diverting the flows around impermeable silt curtains should be done prior to commencing the project.

Obexer's 1991 is an example of project in which a complete failure of the turbidity curtain occurred causing the release of much of the dredge area water to the lake. During dredging at Obexer's Marina the turbidity curtain was "blown out" on 10 May 1991. Much of the dredge area water was also released during this "blow out" as evidenced by the decreases in turbidity and nutrients within the marina from 9 May to 10 May. Turbidity decreased from 23 NTU on 9 May to 2.6 NTU on 10 May; TKN decreased from 80 μg/l to 50 μg/l; TP from 60 μg/l to < 20 μg/l; and BAFe from 1260 μg/l to 170 μg/l. Increases in concentrations outside the marina from 9 May to 10 May provide further evidence of release of dredge area water: turbidity outside increased from 0.62 NTU on 9 May to 3.1 NTU on 10 May; TKN from < 50 μg/l to 70 μg/l; BAFe from < 50 μg/l to 300 μg/l. A similar complete failure of the silt curtain occurred during the 1988 Coon St. Boat Ramp project (no data available). Rough lake conditions during this project caused the turbidity curtain to pull away from its bottom anchorage releasing the majority of the dredge area water into the lake. For both projects the failures of the silt curtains occurred 1-2 days following completion of dredging during the settling period. The amount of turbidity and nutrients released were probably greater than levels which would have been released had the curtains remained in place for the week or more usually required following the end of dredging.

Direct visual evidence dredging impact on the lake may be seen in increased turbidity and decreased clarity as well as in increased growth of floating algae (phytoplankton) or algae attached to the rocks (periphyton) outside the marina during or following dredging. Turbidities were elevated above background outside the marinas in only a few projects above. Only in one project was the turbidity elevated for an extended period creating potential visual impacts for a long period of time. Chlorophyll a as an indicator of algal biomass was monitored outside marinas for only two projects: North Tahoe Marina 1988 and Tahoe Boat Co. 1988. At North Tahoe Marina, the chlorophyll a increased outside the dredge area only slightly from a predredging level of .06 μg/l to .34 μg/l prior to removal of the turbidity curtain. At Tahoe Boat Co. the chlorophyll a concentration outside the dredge area just prior to curtain removal had increased from a predredging concentration of 0.34 μg/l to 0.93 μg/l. The escape of some nutrients from the dredge area may have caused these increases in chlorophyll a and corresponding phytoplankton growth.

concentrations of nutrients outside the silt curtain indicating some escape of dredge area water had occurred. These projects could be separated into three categories: projects for which short-term releases occurred due to minor failures of the turbidity curtains, projects which had ongoing releases due to continued failure of the curtains, and projects which had complete failure of the curtains and releases of dredge water.

An example of a project which had relatively minor short-term releases of turbidity during dredging was Sunnyside Marina 1992. On 9 May 92, strong east winds and 2 ft. waves caused some leakage of dredge area water past the curtains following high winds and rough lake conditions. Turbidity concentrations outside the turbidity curtains were noted to be 3.1 NTU (about 6 times the background concentration). The dredging was stopped and repairs made to the curtains soon after the leak was detected. Turbidity outside the curtain was 4.06 NTU the following day then decreased to 1.55 NTU (3 times background) by 11 May. Since repairs were made to the curtains relatively soon after the leaks were detected, the time period over which turbidity and nutrients were allowed to escape was reduced and potential for impact minimized. Other projects which experienced short term, wind related curtain problems included Tahoe Boat Co. 1988 and North Tahoe Marina 1988.

Star Harbor is an example of a project which experienced ongoing releases of nutrients during dredging and as a result had a potentially greater impact on the lake than short term releases. Since streams flow into Star Harbor, complete isolation of the waters using silt curtains was difficult to achieve. Permeable silt screens were used during dredging in 1990 to allow movement of water out of the harbor and retain particulates and associated nutrients within the dredge area. Unanticipated increases in runoff during dredging in 1990 however, increased the movement water out of Star Harbor. The permeable screens designed to contain sediments and allow water to pass through clogged, causing spillage over the screens and escape of turbidity and particulate associated nutrients, as well as soluble nutrients into the lake. Turbidities outside the dredge area ranged up to 105 NTU. Concentrations of TKN, TP outside the curtains were relatively high on single dates in March, April and May: TKN ranged to 520 μg/l, TP ranged to 230 μg/l. BAFe ranged to 7100 μg/l on dates sampled in April and May. Data collected outside the silt curtain was very limited during March and April for this project preventing assessment of the duration of the elevated concentrations. However the longer the concentrations of nitrogen and phosphorus remained elevated outside the dredge area in the open lake, the greater the potential impact on the lake. Partial diversion of the stream around the silt curtain was eventually done to relieve the pressure on the turbidity screens.

Table C-4. Number of samples exceeding predredging background levels of turbidity, oxidized N, TKN, and TP outside of silt curtain enclosed areas during historical dredging projects. Also shown are the range of levels outside the silt curtain, and median value (where sufficient data was available to calculate).

Dredging Project	Turbidity (NTU) [#of samples > backgrd.] (range; median)	Oxidized N ($\mu g/l$) [#of samples > backgrd.] (range; median)	TKN ($\mu g/l$) [#of samples > backgrd.] (range; median)	TP ($\mu g/l$) [#of samples > backgrd.] (range; median)
Homewood High & Dry Marina 1991	[17 of 22 samp. > 0.3] (rg. 0.2-3.5; med. 0.45)		[2 of 22 samp. > 170] (rg. <50-300; -)	[10+ of 22 samp. > 20] (rg. <20-80; -)
Lake Forest Boat Ramp 1991	[4 of 4 samp. > 0.65] (rg. 0.8-4.7; med. 2.5)	[0 of 1 samp. > (<20)] (rg. <20; -)	[No background] (rg. 110; -)	[No background] (rg. 92; -)
North Tahoe Marina 1988	[1 of 2 samp. > (<1)] (rg. <1-12; -)	[0 of 2 samp. > (<20)] (rg. all <20; -)	[0 of 2 samp. > (<100)] (rg. all <100; -)	[0 of 2 samp. > (<50)] (rg. all <50; -)
North Tahoe Marina 1989	[2 of 3 samp. > 0.46] (rg. 0.22-1.1; med. 0.8)	[0 of 1 samp. > (<10)] (rg. all <10; -)	[0 of 1 samp. > 200] (rg. <100; -)	[1 of 1 samp. > 10] (rg. 30; -)
Obexer's Marina 1991	[5 of 5 samp. > 0.33] (rg. 0.5-17; med. 0.8)	[0 of 5 samp. > 30] (rg. all <20; -)	[1 of 5 samp. > 90] (rg. <50-140; -)	[1 of 5 samp. > (<20)] (rg. <20-40; -)
Sierra Boat Co. Marina 1991	[No background] (rg. 0.1-7.5; med. 0.41)	[No background] (rg. all <10; -)	[No background] (rg.<10-<100; -)	[No background] (rg. all <40; -)
Star Harbor 1990	[No background] (rg. 5.5-105; med. 14)	[No background] (rg. <20-420; -)	[No background] (rg. 160-520; med. 390)	[No background] (rg. 47-230; med. 165)
Sunnyside Marina 1992	[No background] (rg. 0.37-4.06;md. 0.94)			
Tahoe Boat Co. 1988	[4 of 6 samp. > (<1)] (rg. 1.5-12; med. 2.13)	[0 of 6 samp. > (<20)] (rg. all <20)	[2 of 6 samp. > (<100)] (rg. <100-140; -)	[1 of 6 samp. > (<50)] (rg. <50-80; -)

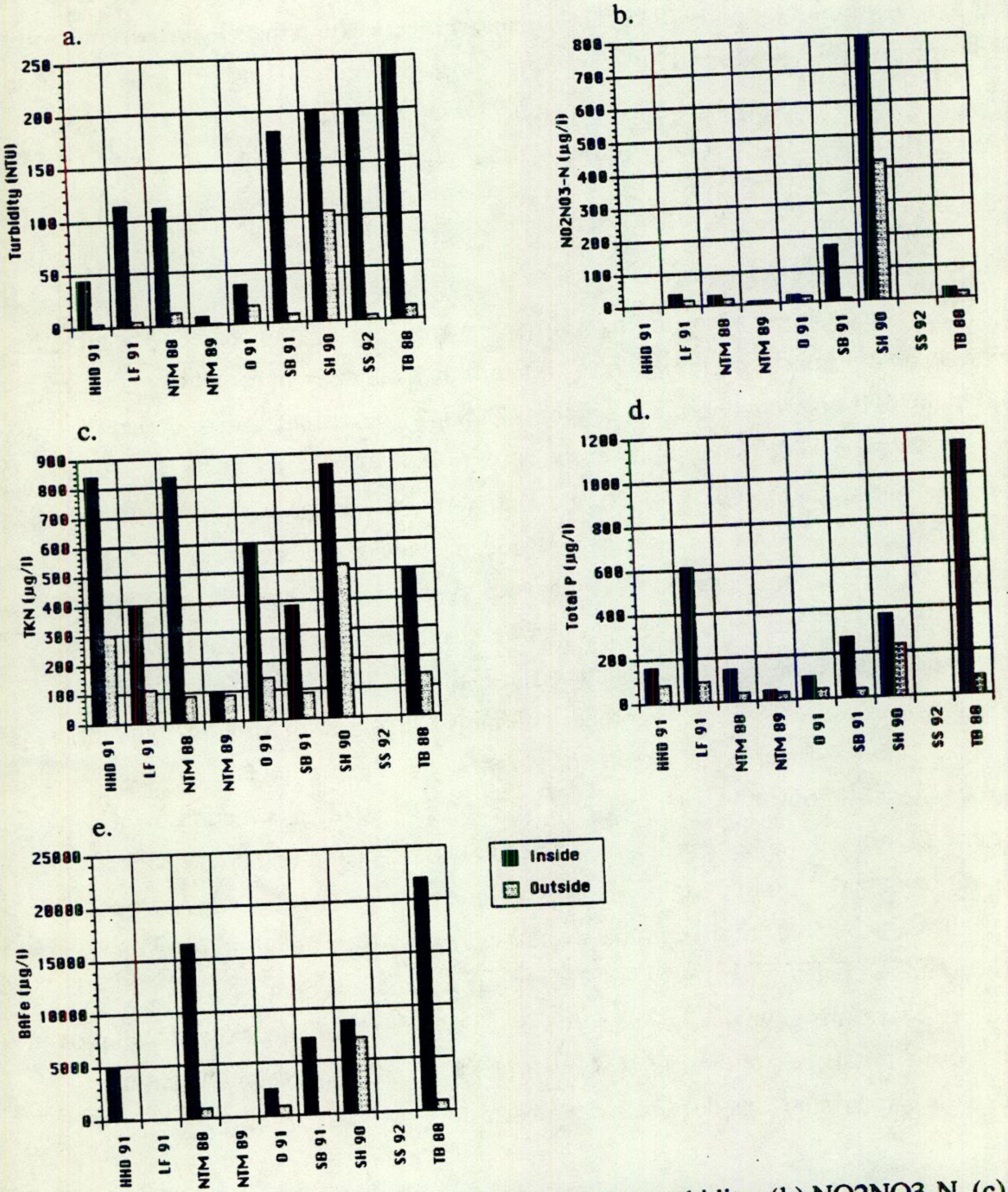


Figure C-4. Comparison of maximum observed levels of (a) turbidity, (b) NO2NO3-N, (c) TKN, (d) Total-P, (e) BAFe within and outside of silt curtain enclosed areas during historical dredging projects (HHD=Homewood High and Dry Marina, LF=Lake Forest Boat Ramp, NTM=North Tahoe Marina, O=Obexer's Marina, SB=Sierra Boat Co. Marina, SH=Star Harbor, SS=Sunnyside Marina, TB=Tahoe Boat Co. Marina).

ranged from a few to 17 days. Where very high turbidities were observed during dredging, the time to curtain removal tended to be longer. For instance, Tahoe Boat Co. which had the highest turbidity (825 NTU) of any projects within the silt curtain enclosed area during dredging, required 17 days prior to removal of silt curtains. Projects which utilized pumping of dredged area to the regional sewer system or other area were able to remove curtains much sooner i.e. within 3-4 days following dredging end.

C.4. Silt Curtain Efficiency

The silt curtains used to confine water in the dredging areas appeared to be effective in isolating dredge area impacted water of high turbidity and nutrient content from the main lake in many of the historical projects. Figures C-4 (a-e) present maximum observed values inside and outside the turbidity curtains for turbidity, oxidized N, TKN, TP and BAFe. As can be seen for most projects, maximum turbidity and nutrient concentrations were much higher inside the curtains than outside. However, in a few projects, high turbidities or nutrient concentrations were also observed outside the silt curtain enclosed area. At Obexer's Marina in 1991 the curtains were "blown out" resulting in increased turbidity levels outside the silt curtain and at Star Harbor in 1990 inputs from streams into the dredging area caused spillage over the silt curtains and release of turbidity and nutrients to the lake. Table C-4 shows the number of samples which exceeded predredging background levels of turbidity, oxidized N, TKN, and TP outside of silt curtain enclosed areas during historical dredging projects. Turbidity was often higher than the background concentration outside the silt curtains. However, though increased above background, the levels of turbidity outside the silt curtains overall were low. Median turbidity levels outside the silt curtains were less than 1 NTU in 5 of 8 projects, and less than 3 NTU in 7 of 8 projects. At Star Harbor the median was 14 NTU. Oxidized N did not exceed background outside the silt curtain in 5 of 5 projects. Levels of TKN and TP occasionally slightly exceeded the background outside the silt curtains.

C.5. Potential Impacts of Dredging Projects

A very general assessment of the potential impacts of historical dredging projects may be made by comparing the relative levels of nutrients outside the silt curtains. Many of the projects had concentrations which were close to background outside the silt curtains (see Table C-2) indicating little leakage of dredge area water to the lake. These projects had low potential for impact on lake water quality. However, several projects had elevated sparse nature of data in Figure C-3 compared to Figure C-2 limits the interpretation that may be drawn from this data.

Through monitoring chlorophyll a, the response of phytoplankton within or near the dredge area to nutrients released by dredging operations can be evaluated. As phytoplankton increase in numbers the concentration of chlorophyll a typically increases. Certain nutrients i.e. particularly nitrogen and phosphorus are known to increase the growth of phytoplankton in Lake Tahoe. As the levels of these nutrients increase in the marinas during dredging, the potential exists for increased algae growth. Very limited chlorophyll a data was available in 5 of 15 projects. Predredging concentrations at the project sites ranged from 0.04-0.66 μg/l. Concentrations inside silt curtain enclosed areas increased during or following completion of dredging in 3 of 5 projects. Measured chlorophyll a increases included: from 0.07 μg/l to 1.24 μg/l at Obexer's in 1988; from 0.04 μg/l to 0.38 μg/l at North Tahoe Marina 1988; and from 0.66 μg/l to 3.23 μg/l at Tahoe Boat Co. 1988. At Homewood High and Dry 1988, the chlorophyll a values following completion of dredging (0.45 μg/l, 0.31 μg/l) were close to the predredging level of 0.41 μg/l. Only a single chlorophyll a sample was taken in the other project.

C.3. Turbidity and Nutrient Changes Within Dredged Areas Following Completion of Dredging

Levels of turbidity and BAFe within the silt curtain enclosed area showed a general decline over time following the end of dredging (at sites where the end of dredging was noted in the data). The levels of other nutrients monitored also often decreased within the silt curtain enclosed areas following the end of dredging, however, at some sites the levels fluctuated before ultimately declining. For instance the levels of oxidized nitrogen and TP at Sunnyside in 1992 remained elevated for several days after dredging ended before finally decreasing. Chlorophyll a showed an increase within a silt curtain enclosed area after completion of dredging at one site monitored (the data was too limited to determine whether such increases occurred at other sites). At the Tahoe Boat Co. Marina chlorophyll a increased from 0.29 μg/l four days after completion of dredging to 3.23 μg/l eleven days after dredging. Chlorophyll a subsequently declined to 0.98 μg/l seventeen days following completion of dredging.

In these historical projects, turbidity curtain removal was generally allowed when turbidity and nutrient levels in the enclosed area had decreased below the Lahontan discharge standards (these are: turbidity 20 NTU, TP 100 μg/l, TN 500 μg/l, TFe 500 μg/l). The number of days elapsed to curtain removal following completion of dredging

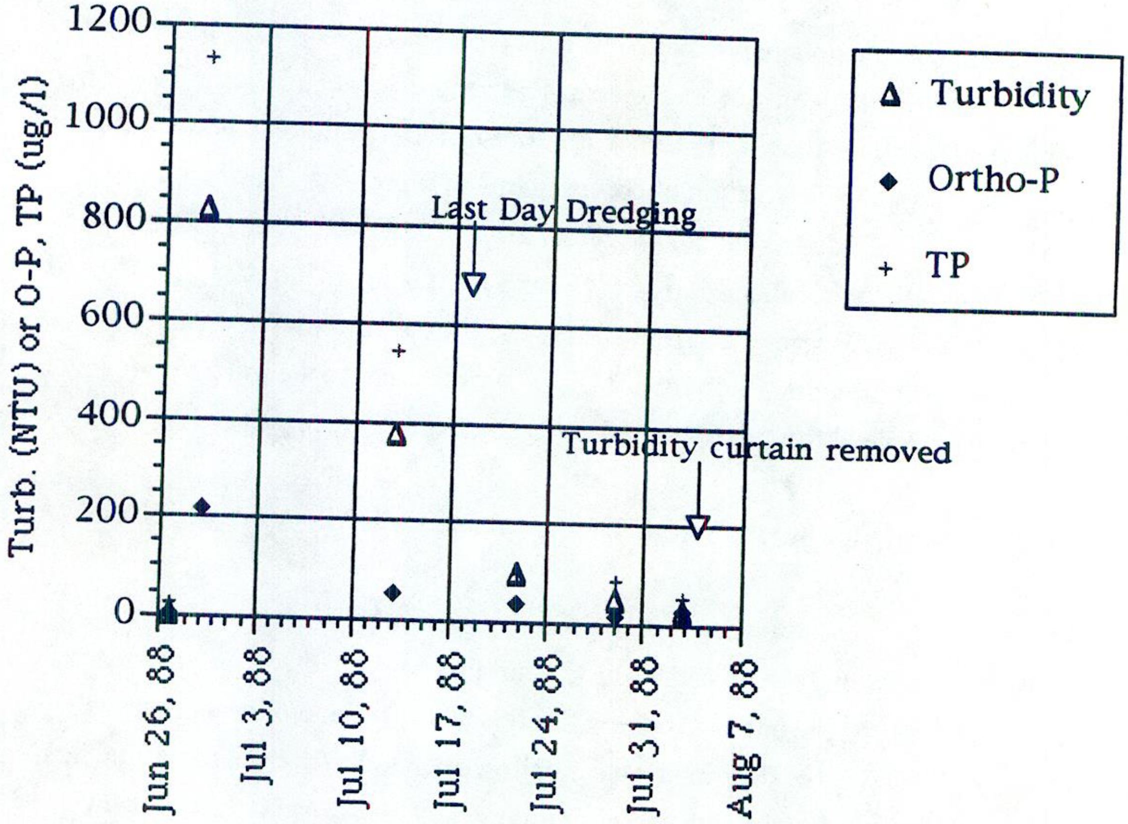


Figure C-3. Levels of turbidity, Ortho-P and TP within the silt curtain enclosed area during dredging at the Tahoe Boat Co. Marina, 1988.

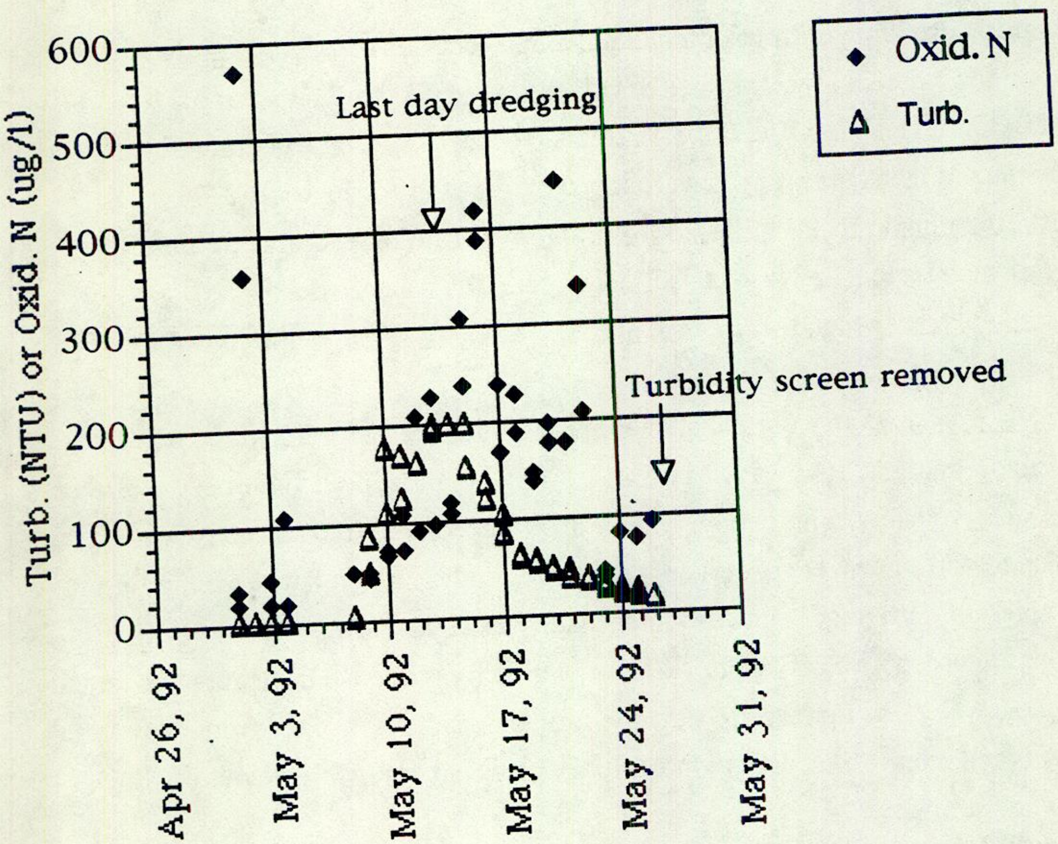


Figure C-2. Levels of turbidity and oxidized nitrogen (NO2+NO3) within the silt curtain enclosed harbor during dredging at Sunnyside Marina 1992.

projects. The very high turbidities observed within the Tahoe Boat Co. Marina dredging area may have resulted from resuspension of very fine particles during dredging. Sediment cores collected from the Tahoe Boat Co. marina bottom as part of the current study indicated some layers to be high in the clay and silt sediment size classes.

C.2.2. NO_2+NO_3-N, NH_4-N, Ortho-P, Chlorophyll a

Soluble inorganic oxidized nitrogen (NO_2+NO_3-N), ammonia (NH_4-N) and ortho-P increased during dredging during some but not all projects. Predredging values within areas to be dredged were all low. Ranges for values among all sites included: oxidized nitrogen (< 20-30 μg/l), NH_4-N (< 20 μg/l), ortho-P (< 20-40 μg/l). Maximum observed values within the dredged areas ranged as follows: oxidized nitrogen (< 10-2200 μg/l), NH_4-N (< 20-50 μg/l), ortho-P (< 20-220 μg/l). Sources for these soluble nutrients during dredging may include: release of sediment interstitial water to the overlying water, desorption from the resuspended sediments, nutrients released through biologically mediated reactions.

Figure C-2 presents an example of changes through time in turbidity and oxidized nitrogen during dredging at Sunnyside Marina in 1992. Sporadic high values of oxidized nitrogen were observed almost immediately after dredging commenced and consistently high values (up to 450 μg/l) were observed just prior to and for about a week following dredging completion. Turbidity began low and steadily increased to a peak near the final day of dredging, then dropped off again. While not directly related to the level of sediment particulates in the water, the increased oxidized nitrogen may have resulted from disruption of the sediments and release of sediment interstitial water containing high levels of NO_3-N into the water column.

Ammonia (NH_4-N) and Ortho-P were monitored inside the dredge areas in only four of the projects . NH_4-N was near or below the 20 μg/l level of detection in 3 of the projects. At Tahoe Boat Co. NH_4-N was monitored in the dredge area only after dredging was completed and found to be as high as 50 μg/l. It is possible NH_4-N levels were even higher during dredging at Tahoe Boat Co. Samples for Ortho-P analysis were collected both during and following dredging at Tahoe Boat Co. Figure C-3 shows changes through time in turbidity, TP and ortho-P at Tahoe Boat Co. during and following dredging 1988. A maximum Ortho-P level of 220 μg/l occurred soon after dredging commenced. This corresponded with the maximum turbidity and TP levels. All three parameters decreased prior to the final day of dredging, and decreased further prior to removal of the silt curtains. The removal of ortho-P from the water may have occurred as a result of adsorption to settling particulates and possibly coprecipitation with hydrous iron oxide compounds. The

Table C-3. Regression equations, r^2, and regression coefficient p values, for associations between turbidity and nutrients for Lahontan and TRPA-required monitoring data obtained for historical dredging projects 1988-92. These projects included: Homewood High and Dry Marina (1988, 1989), Lake Forest Boat Ramp (1991), North Tahoe Marina (1988, 1989), Obexer's Marina (1988,1991), Sierra Boat Co. (1991), Star Harbor (1990), Sunnyside Marina (1992), Tahoe Boat Co. (1988), Tahoe Keys West Channel and Lagoons (1990, 1991), Tahoe Keys East Channel (1988).

Regression Between Turbidity and:	Regression Equation where x = Turbidity (NTU) y = Nutrient (μg/l)	r^2	n	$p \leq$	MaximumTurbidity Value Used to Calculate Regression
TKN	y = 2.794x + 194.9	0.286	100	.0001	119
TP	y = 0.974x + 80.41	0.126	85	.0009	
BAFe	y = 83.549x + 7.303	0.683	48	.0001	
TFe	y = 34.474x + 382.2	0.709	54	.0001	

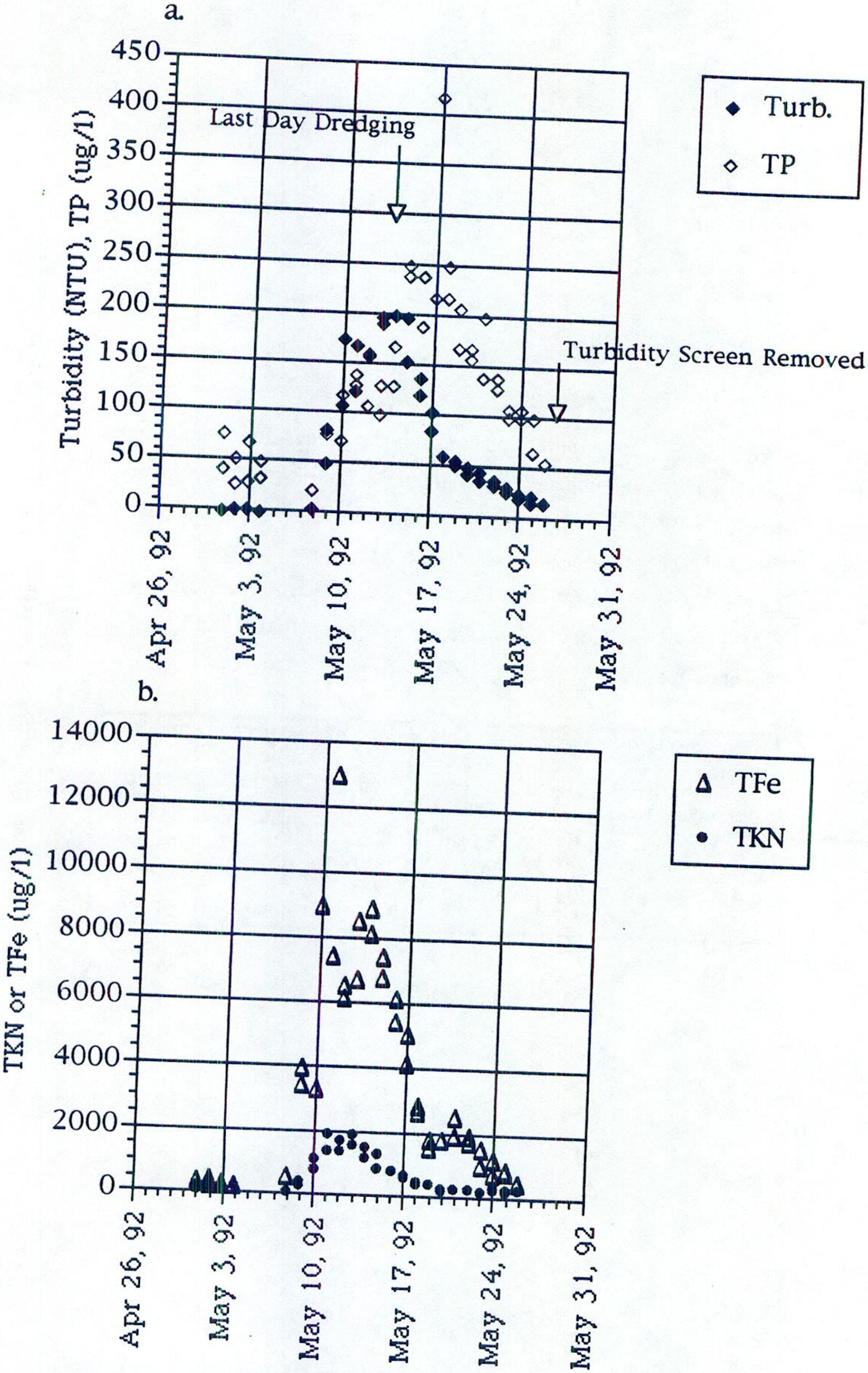


Figure C-1. Levels of (a) turbidity and TP; (b) TKN and TFe within the silt curtain enclosed harbor during dredging at Sunnyside Marina 1992.

During dredging within silt curtain enclosed areas, turbidity levels typically increase as sediments are mixed into the water column. For many of the historical projects monitored, turbidity levels increased to a maximum near the final day of dredging. In a few projects the turbidity peaked earlier.

When levels of turbidity increased in the dredge area, levels of TKN, TP, BAFe and TFe also tended to increase. Figures C-1 (a) and (b) present examples of changes in turbidity, TKN, TP and TFe through time during dredging for one marina which was monitored intensively, Sunnyside 1992. The pattern for TKN, TP, and TFe increase tended to be similar to turbidity i.e. a general increase during dredging to a peak near the final day of dredging. It is interesting to note that TP remained high for a while as turbidity declined. The sustained high concentration of TP after completion of dredging likely related to sustained levels of slowly settling clays and silt in the water. These smaller particles can have more adsorbed TP per unit weight than larger sized particles (this was verified in sediment studies as part of the current dredging study).

Turbidity was found to be statistically associated with BAFe and TFe, but not TP and TKN in the historical data. Table C-3 presents the results of statistical analysis for associations between turbidity and TKN, TP, BAFe, TFe data (this table is also presented in the main body of the report as Table 10-3). Turbidity was well associated with BAFe ($r^2 = 0.683$) and TFe ($r^2 = 0.709$); however turbidity was weakly associated with TP ($r^2 = 0.126$) and TKN ($r^2 = 0.286$).

Variability was observed in background levels of parameters at the project sites prior to dredging. Predredging ranges among all project sites were: TKN (< 50-480 μg/l), TP (< 20-160 μg/l), TFe (20-380 μg/l), BAFe (< 50-460 μg/l). Background turbidities were less than 2 NTU. The maximum observed levels for turbidity, TKN, TP, BAFe, and TFe within the dredging area varied by project. Maximum observed values for the projects during dredging operations ranged as follows: turbidity (8-825 NTU), TKN (100-1900 μg/l), TP (40-1140 μg/l), TFe (80-1300 μg/l), BAFe (1350-22000 μg/l). Among all projects, maximum observed concentrations for turbidity, TP and BAFe occurred during the Tahoe Boat Co. dredging project, and maximum observed concentrations for TKN and TFe occurred at Sunnyside in 1992.

Several factors may affect the maximum turbidity and nutrient concentration level observed during dredging. These factors may include: type of dredging done, duration of dredging, size of containment area, nutrient content of the sediments, proportions of silt and clay in the dredged sediments. Mechanical dredging was done both Sunnyside and Tahoe Boat Co. using an excavator. Such mechanical dredging has a high potential for sediment resuspension and contributed to the high dredge area turbidities observed in these

Table C-2 cont'd.

(m) cont'd. T. Keys West Channel Entrance, Inner Lagoons1991 (contain. area)

Date	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside TFe	Outside TFe
8/1/91		30		230		110		1700
8/1/91		31		170		64		1100
8/2/91		<20		150		38		590
8/2/91		2000		150		74		2300
8/3/91		<20		130		62		1100
8/5/91		<20		180		66		630
8/5/91		<20		150		140		5600
8/8/91		<20		230		81		660
8/9/91		180		150		83		940
8/9/91		400		170		85		800
8/12/91		20		180		68		710
8/12/91		<20		400		68		610
8/13/91		30		140		66		1700
8/13/91		<20		87		98		500
8/14/91		<20		370		59		680
8/14/91		<20		240		54		610
8/15/91		68		210		88		2100
8/15/91		380		340		88		1800
8/19/91		140		410		66		390
8/19/91		410		360		68		400
8/20/91		51		160		76		860
8/20/91		140		120		56		910
8/21/91		63		400		68		620
8/21/91		41		<50		71		890
8/22/91		98		62		67		970
8/22/91		89		51		62		950
8/23/91		180		<50		62		670
8/23/91		120		<50		62		720
8/29/91		880		160		56		620
8/30/91		240		<50		54		800
8/30/91		320		220		54		690
9/4/91		2400		140		51		850
9/4/91		1000		70		54		450
9/5/91		1100		50		64		800
9/5/91		230		280		67		810
9/7/91		100		170		59		470
9/7/91		110		80		62		430

(n) Tahoe Keys West Channel Entrance, Inner Lagoons1991, (at dredge)

Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside BAFe	Outside BAFe
6/17/91	15		<20		480		40		1290	
6/21/91	27.5		<10		540		60		1820	
7/22/91	1.6		11		270		<40		300	
8/5/91	13	2.7	11	16	350	430	<40	<40	1390	400
8/8/91	6.2	7.2	15	14	300	310	<40	<40	840	750
8/16/91	18	6.3	11	13	310	260	60	<40	2050	790
8/23/91	16	8.8	<10	<10	340	340	50	<40	1390	830
8/26/91	8.9	3.7	<10	<10	330	320	<40	<40	780	340

(o) Tahoe Keys East Channel 1988 (note no turbidity screens, E. Channel)

Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside NH4	Outside NH4	Inside TKN	Outside TKN	Inside O-P	Outside O-P	Inside TP	Outside TP	Inside BAFe	Outside BAFe
7/18/88		2		<20		<20		140		<20		<50		330
8/10/88		<1		<20				180		<20		<50		<50

Table C-2 cont'd.

(l) Tahoe Keys West Channel 1990 (at dredge)

Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside BAFe	Outside BAFe
5/16/90		3		<20		<80		<80		500
5/21/90		3.5				<80				
8/1/90		4.1		<20		180		<80		

(m) Tahoe Keys West Channel Entrance, Inner Lagoons1991, (contain. area)

Date	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside TFe	Outside TFe
B 6/10/91	450		<50		95		380	
6/10/91	150		240		180		1000	
6/11/91	<20		54		71		420	
6/13/91	20		230		86		260	
6/14/91	23		160		50		610	
6/14/91	23		160		50		610	
6/15/91	<20		190		83		200	
6/17/91	<20		250		86		450	
6/17/91	<20		53		120		250	
6/18/91	<20		300		81		300	
6/19/91	<20		430		57		350	
6/20/91	25		200		97		520	
6/21/91	22		<50		55		500	
6/24/91	<20		390		60		310	
6/25/91	23		340		83		330	
6/26/91	45		320		55		330	
6/27/91	<20		130		99		590	
6/27/91	70		890		88		960	
6/28/91	<20		300		74		500	
6/28/91	570		120		64		410	
7/1/91	<20		88		60		550	
7/1/91	<20		81		53		480	
7/2/91	<20		87		41		390	
7/2/91	<20		<50		57		430	
7/3/91	95		190		50		270	
7/3/91	59		<50		38		220	
7/5/91	29		68		46		260	
7/5/91	350		150		38		210	
7/6/91	2200		<50		60		220	
7/8/91			170		43		150	
7/8/91	55		710		52		250	
7/9/91	48		350		82		190	
7/11/91	94		250		55		250	
7/11/91	52		220		50		230	
7/12/91	46		440		79		650	
7/12/91	530		370		110		520	
7/15/91	360		<50		72		240	
7/16/91	81		490		67		350	
7/16/91	84		310		84		280	
7/17/91	96		400		270		3400	
7/17/91	78		380		77		860	
7/18/91	160		59		60		620	
7/18/91	860		210		60		320	
7/19/91	830		51		110		370	
7/19/91	0.11		53		87		820	
7/20/91	500		270		60		290	
7/20/91	510		<50		87		360	
7/22/91	97		200		67		760	
7/22/91	50		410		45		350	
7/22/91	640		<50		42		330	
7/24/91		1600		150		54		840
7/24/91		290		350		69		810
7/22/91	<20		55		67		290	
7/26/91		<20		130		62		490
7/26/91	63	90	1100	110	210	71	190	190
7/27/91	24		190		47		320	
7/29/91	<20		440		81		260	
7/29/91	430		380		64		210	
7/30/91	34		410		57		280	
7/30/91	280		330		40		210	
7/31/91	38		450		47		260	
7/31/91	<20		490		40		200	

Table C-2 cont'd.

(i) cont'd. Star Harbor 1990 (Turbidity curtain removed 7/2)

Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside NH4	Outside NH4	Inside TKN	Outside TKN	Inside O-P	Outside O-P	Inside TP	Outside TP	Inside BAFe	Outside BAFe
5/26/90		12												
5/27/90		11												
5/28/90		11												
5/29/90		9												
5/30/90		9												
6/1/90		7		<20		84		160		6		47		
6/28/90		5.5												

(j) Sunnyside Marina 1992 (Last day dredging 5/14; turbidity curtain removed 5/26)

Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside TFe	Outside TFe	Inside SFe	Outside SFe
B			<21	<20	172	120	71	76			66	<25
5/1/92	1.36		<20		200		42		330			
5/1/92	1.96	0.45	34		100		79		350			
5/2/92	2.6		570		300		52		410			
5/2/92	2.92	0.52	360		100		27		220			
5/3/92	2.5		<20		<100		30		270			
5/3/92	2.02	1.08	45		200		69		220			
5/4/92	1.75		110		200		35		250			
5/4/92	1.65	0.72	<20		200		50		220			
5/8/92	5.46	0.61	52		100		23		570			
5/9/92	85.2		46		400		80		3400			
5/9/92	50.2	3.1	52		300		80		3900			
5/10/92	109.4		74		800		73		3300			
5/10/92	175.8	4.06	69		1100		120		9000			
5/11/92	169		75		1400		140		7400			
5/11/92	124.4	1.55	110		1900		130		13000			
5/12/92	161.3		210		1400		110		6500			
5/12/92	160.2	1.82	93		1700		160		6100			
5/13/92	192.7		99		1600		100		6700			
5/13/92	199.7	0.65	230		1900		130		8500			
5/14/92	>200		110		1500		130		8900			
5/14/92	>200	1.96	120		1200		170		8100			
5/15/92	198.5		240		1300		250		7400			
5/15/92	154.6	0.37	310		900		240		6800			
5/16/92	137.6		390		800		190		6100			
5/16/92	121.9	0.53	420		800		240		5400			
5/17/92	105.5		240		700		220		5000			
5/17/92	86.2	0.6	170		600		420		4100			
5/18/92	61.9		230		400		220		2800			
5/18/92	60.7	0.76	190		500		250		2600			
5/19/92	58		150		400		210		1500			
5/19/92	53.4	1.72	140		400		170		1800			
5/20/92	50		200		300		160		1800			
5/20/92	45	2.45	180		200		170		1800			
5/21/92	47		180		300		200		2500			
5/21/92	39.2	1.21	450		300		140		1900			
5/22/92	38		340		300		140		1700			
5/22/92	34.6	1.05	210		300		130		1900			
5/23/92	31.7		46		200		110		1000			
5/23/92	27.1	0.83	41		200		100		1500			
5/24/92	26.5		<20		300		100		1200			
[illegible]	22.4	0.55	86		400		110		770			
[illegible]	24.2		80		300		100		880			
[illegible]	18.1	1.45	<20		200		67		780			
[illegible]	16.6		95		300		57		470			

(k) Tahoe Boat Co. 1988 (Last day dredging 7/18; turbidity curtains removed 8/3-8/5)

Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside NH4	Outside NH4	Inside TKN	Outside TKN	Inside O-P	Outside O-P	Inside TP	Outside TP	Inside BAFe	Outside BAFe	Inside Chl a	Outside Chl a
B 6/27/88	1.5	<1	<20	<20			140	<100	<20	<20	<50	<50	<100	<100	0.66	0.34
6/29/88	825	12	30	<20			490	<100	220	20	1140	<50	3180	900		
6/29/88		1.75		<20				<100		<20		<50		<100		
7/13/88	375	2.5	<20	<20	40	<20	190	140	60	<20	550	<50	22000	350		
7/22/88	95	1.5	<20	<20	50	<20	230	<100	40	<20	100	<50	5160	70	0.29	0.1
7/29/88	45	<1	<20	<20	<20	20			20	<20	90	80	2190	550	3.23	0.34
8/3/88	24	<1	<20	<20			140	110	30	<20	60	<50	1390	<50	0.98	0.93

Table C-2 cont'd.

(e) North Tahoe Marina 1989 (Turbidity curtain removal 5/22/89)

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside TFe	Outside TFe
B	4/19/89	0.32	0.46	<10	<10	400	200	10	10	20	10
	5/10/89	1.3	1.1								
	5/11/89	0.63	0.22								
	5/17/89	2									
	5/18/89	4.7									
	5/19/89	4.5									
	5/22/89	6.3									
	5/22/89	7.9	0.8	<10	<10	100	<100	40	30	80	10

(f) Obexer's Marina 1988 (Turbidity curtain removal 6/22)

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside NH4	Outside NH4	Inside TKN	Outside TKN	Inside O-P	Outside O-P	Inside TP	Outside TP	Inside BAFe	Outside BAFe	Inside Chl a	Outside Chl a
B	6/1/88	<1	<1	<20	<20	<20	<20	<100	<100	<20	<20	<50	<50	150	<100	0.07	0.06
	6/6/88	21		<20		<20		150		20		<50		1350		1.24	
	6/13/88	20		<20		30		120		20		<50		1200		0.28	
	6/21/88	4		<20		<20		<100		<20		<50		430		0.35	
	6/23/88	<1		<20		<20		220		<20		50		<100			

(g) Obexer's Marina 1991 (Last day dredging 5/8; turbidity curtain blown out 5/10; removed 5/13)

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside BAFe	Outside BAFe
B	5/6/91	0.34	0.33	30	30	120	90	<20	<20	<50	<50
	5/7/91	37	0.8	14	18	170	60	100	<20	2490	<50
	5/8/91	33	17	20	<20	590	140	80	40	1760	940
	5/8/91	34	0.5	<20	<20	150	80	70	<20	1580	<50
	5/9/91	23	0.62	<20	<20	80	<50	60	<20	1260	<50
	5/10/91	2.6	3.1	<20	<20	50	70	<20	<20	170	300

(h) Sierra Boat Co. 1991 (Last day dredging 10/15; turbidity curtain removed 11/1)

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside BAFe	Outside BAFe	Inside SFe	Outside SFe	Inside Chl a	Outside Chl a
B	9/19/91	1.5		<10		420		<40		378					
	9/20/91	74													
	9/21/91	28													
	9/21/91	41	0.46	<20		54		35				840			
	9/22/91	10	0.4	<20		120		44				520			
	9/23/91	1.1	0.15	22	<10	250	<100	<40	<40	130	<50				
	9/24/91														
	9/24/91	2.4	0.85	<20		<50		39				220			
	10/3/91	16		45		240		<40		1080					
	10/16/91	180	7.5	170		<100		270				12000			
	10/16/91	119	0.41	170		<50		18				11000			
	10/16/91	112		22		380		160		7240					
	10/17/91	52		100		<50		18				2000			
	10/17/91	31		<20		<50		21				1900			
	10/18/91	9	0.1	12	<10	<100	<10	<40	<40	830	<50				
	11/1/91	1.3	0.15	<10		<10	<10	<40	<40	200	<50			0.424	

(i) Star Harbor 1990 (Turbidity curtain removed 7/2)

Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside NH4	Outside NH4	Inside TKN	Outside TKN	Inside O-P	Outside O-P	Inside TP	Outside TP	Inside BAFe	Outside BAFe
3/22/90	198	105	800	420			770	420			370	150		
4/23/90	160	99	40	20			860	520			210	180	8710	7100
5/14/90		16												
5/15/90		17												
5/16/90		16												
5/17/90		16												
5/17/90		12		<20				360				230		1190
5/18/90		16												
5/19/90		15												
5/20/90		15												
5/21/90		16												
5/22/90		14												
5/23/90		13												
5/24/90		13												

Table C-2. Summary of 1988-92 dredging project turbidity (NTU), nutrient and chlorophyll values (μg/l) observed inside and outside the silt curtains, or near dredge. "B" is predredging background level. Data courtesy of Lahontan.

(a) Homewood High and Dry 1988 (Last day dredging 6/11; turbidity curtain removed 6/22)

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside NH4	Outside NH4	Inside TKN	Outside TKN	Inside O-P	Outside O-P	Inside TP	Outside TP	Inside BAFe	Outside BAFe	Inside Chl a	Outside Chl a
B	6/6/88	0.93	0.45	<20	<20	<20	<20	<100	400	40	20	<50	<50	140	<50	0.41	0.23
	6/13/88	52		<20		20		320		<20		100		3000		0.45	
	6/21/88	6.3		<20		<20		120		<20		<50		540		0.31	
	6/23/88	1	<1	<20	<20	<20	<20	200	160	<20	<20	<50	60	<100	<100		

(b) Homewood High and Dry 1991 (Last day dredging 6/24; turbidity curtain removed 6/28)

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside BAFe	Outside BAFe	Inside TFe	Outside TFe
B	6/12/91	1.25	0.3	<20	<20	130	170	<20	<20	460	<50		
	6/14/91		0.5				<50		80				
	6/15/91		2.2				<50		80				<100
	6/15/91		1.1				<50		80				<100
	6/16/91		1.1				300		40				<100
	6/16/91		1.1				250		50				<110
	6/17/91		0.5				<50		40				<100
	6/17/91		1.4				<50		40				110
	6/18/91		0.5				<50		80				120
	6/18/91		2.7				<50		70				160
	6/19/91		0.5				<50		80				160
	6/19/91	45	0.4	20		840	<50	160	<50	4880			150
	6/20/91		0.2				<50		<50				<100
	6/20/91		0.2				<50		<50				<100
	6/21/91		0.4				<50		<50				<100
	6/21/91		0.4				<50		<50				<100
	6/22/91		0.4				<50		<50				<100
	6/22/91		0.2				<50		<50				<100
	6/23/91		0.4				<50		<50				<100
	6/23/91		3.5				<50		<50				<100
	6/24/91		0.4				<50		<50				180
	6/24/91		0.2				<50		<50				<100
	6/28/91	0.8	0.3	<10		60	90	<20	<20	<50	<50		<100

(c) Lake Forest Boat Ramp 1991 (Last day dredging 6/11; turbidity curtain removed 6/14)

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside TKN	Outside TKN	Inside TP	Outside TP	Inside TFe	Outside TFe
B	6/10/91	0.8		<20		<50		160		110	
B	6/10/91	1.6	0.65	<20	<20	150		120		200	
	6/11/91	15		<20		<50		610		2000	
	6/11/91	18	3	390		390		200		2300	
	6/12/91	85		<20		280		190		2800	
	6/12/91	114	4.7	<20	<20	240	110	250	92	2900	740
	6/13/91	9.1		<20		86		190		1000	
	6/13/91	70	2	35		60		380		2900	
	6/14/91	19		<20		80		260		4400	
	6/14/91	8.4	0.8	<20		62		180		470	
	6/15/91	6.1		24		290		91		460	
	6/15/91	4.1		750		360		95		1200	

(d) North Tahoe Marina 1988

	Date	Inside Turb.	Outside Turb.	Inside Oxid. N	Outside Oxid. N	Inside NH4	Outside NH4	Inside TKN	Outside TKN	Inside O-P	Outside O-P	Inside TP	Outside TP	Inside BAFe	Outside BAFe	Inside Chl a	Outside Chl a
B	5/31/88	<1	<1	<20	<20	<20	<20	<100	<100	20	<20	<50	<50	<100	<100	0.04	0.06
	5/31/88	33	12	<20	<20	<20	<20	320	<100	40	30	<50	<50	4340	860		
	6/1/88	112						830				140					
	6/3/88	88		<20		<20		250		40		110		16540			
	6/6/88	3.5	<1	30	<20	<20	<20	<100	<100	50	<20	<50	<50	360	<100	0.38	0.34

Table C-1. Summary of historical dredging project files 1988-92 reviewed, N/A indicates data not available.

Project Name	Year	Dredge Type	Data Include in Summary?
Coon St. Boat Ramp	1988	Excavator	N/A
Coon St. Boat Ramp	1989	Suction	N/A
Fleur Du Lac Harbor	1988	Suction	N/A
Homewood High and Dry Marina	1988	Suction	Yes
Homewood High and Dry Marina	1991	Suction	Yes
Lake Forest Boat Ramp	1991	Excavator	Yes
Lakeside Marina	1990	Excavator	N/A
North Tahoe Marina	1988	Excavator + suction	Yes
North Tahoe Marina	1989	Excavator	Yes
Obexer's Marina	1988	Excavator	Yes
Obexer's Marina	1991	Excavator	Yes
Sierra Boat Co.	1991	Excavator	Yes
Ski Run Marina	1988	Excavator + suction	N/A
Star Harbor	1990	Suction	Yes
Sunnyside Marina	1992	Excavator	Yes
Tahoe Boat Co.	1988	Excavator	Yes
Tahoe Keys Marina and East Channel	1988	Suction	Yes
Tahoe Keys Lagoons and West Channel	1990	Suction	Yes
Tahoe Keys Lagoons and West Channel	1991	Suction	Yes

Appendix C. Summary of Historical Dredging Data 1988-92

C.1. Approach and Objectives of Review of Historical Data

Prior to the current study, some water quality data had been collected during dredging projects (1988-92). This data was collected to satisfy monitoring requirements imposed by T.R.P.A. and Lahontan. The following presents much of this available data which included files from a total of 19 dredging projects (Table C-1). Turbidity and chemistry data was available for 15 of these projects.

Though specific monitoring requirements varied among the projects, certain sampling protocols were common for most of the projects. Only data obtained using these common sampling protocols, was included in this summary:

- Predredging data from within and outside the areas to be dredged.
- Data from inside the dredged area and outside the silt curtain enclosed area during dredging.
- Postdredging data from inside and outside the contained area .

To make meaningful comparisons for changes in a parameter through time, the data was further limited to include only consistent sampling locations within and outside the marina. The data were analyzed with respect to the following:

(1) Turbidity and nutrient changes within contained areas during dredging, magnitude of increase of these parameters, and associations between turbidity and the nutrients.

(2) Changes once dredging is ended and turbidity is allowed to decrease.

(3) Efficiency of the turbidity curtains.

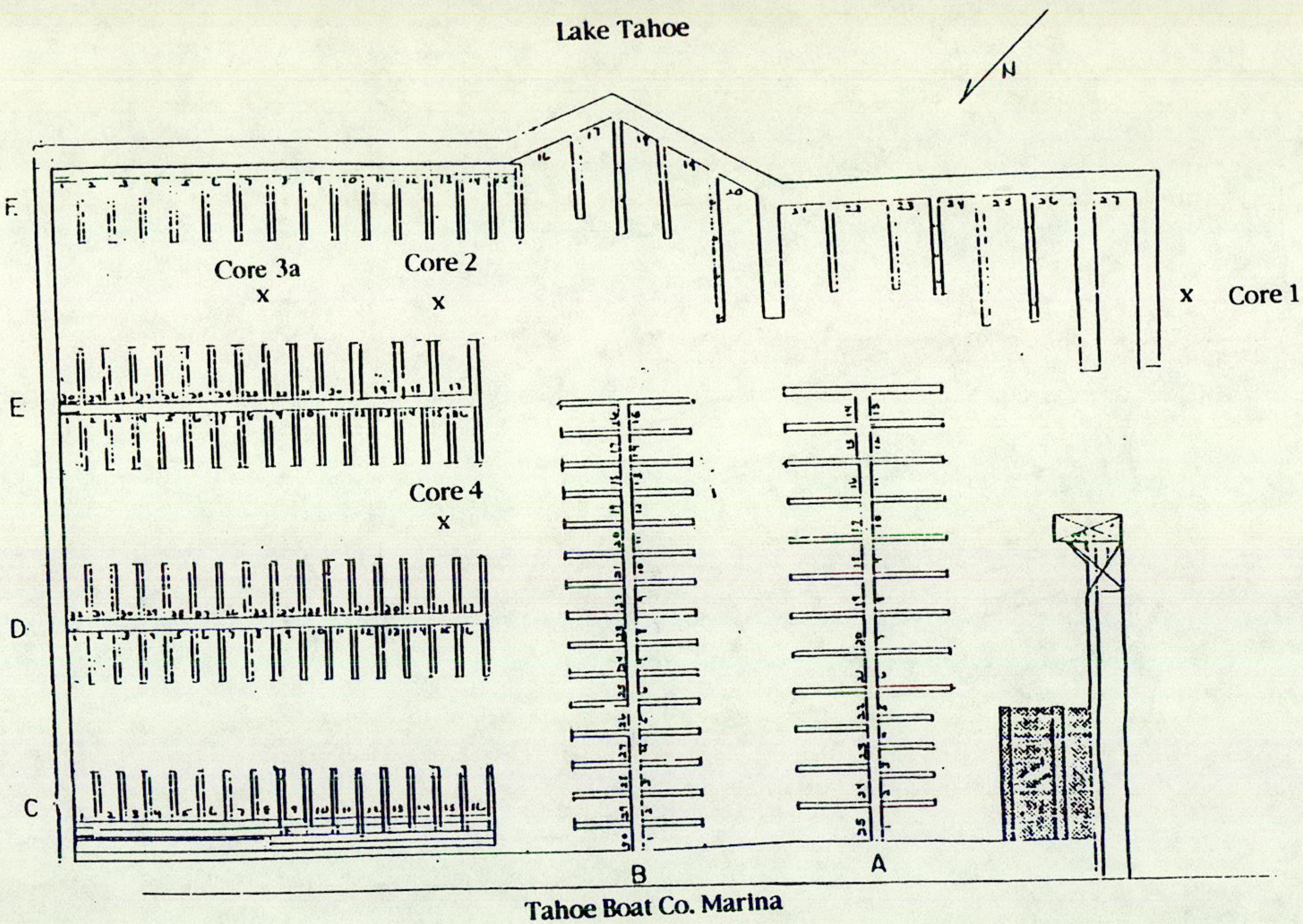
(4) Potential impacts to Lake Tahoe of the dredging and demonstrations of lake impacts.

(5) Problems which occurred during the dredging projects and innovative dredging methods.

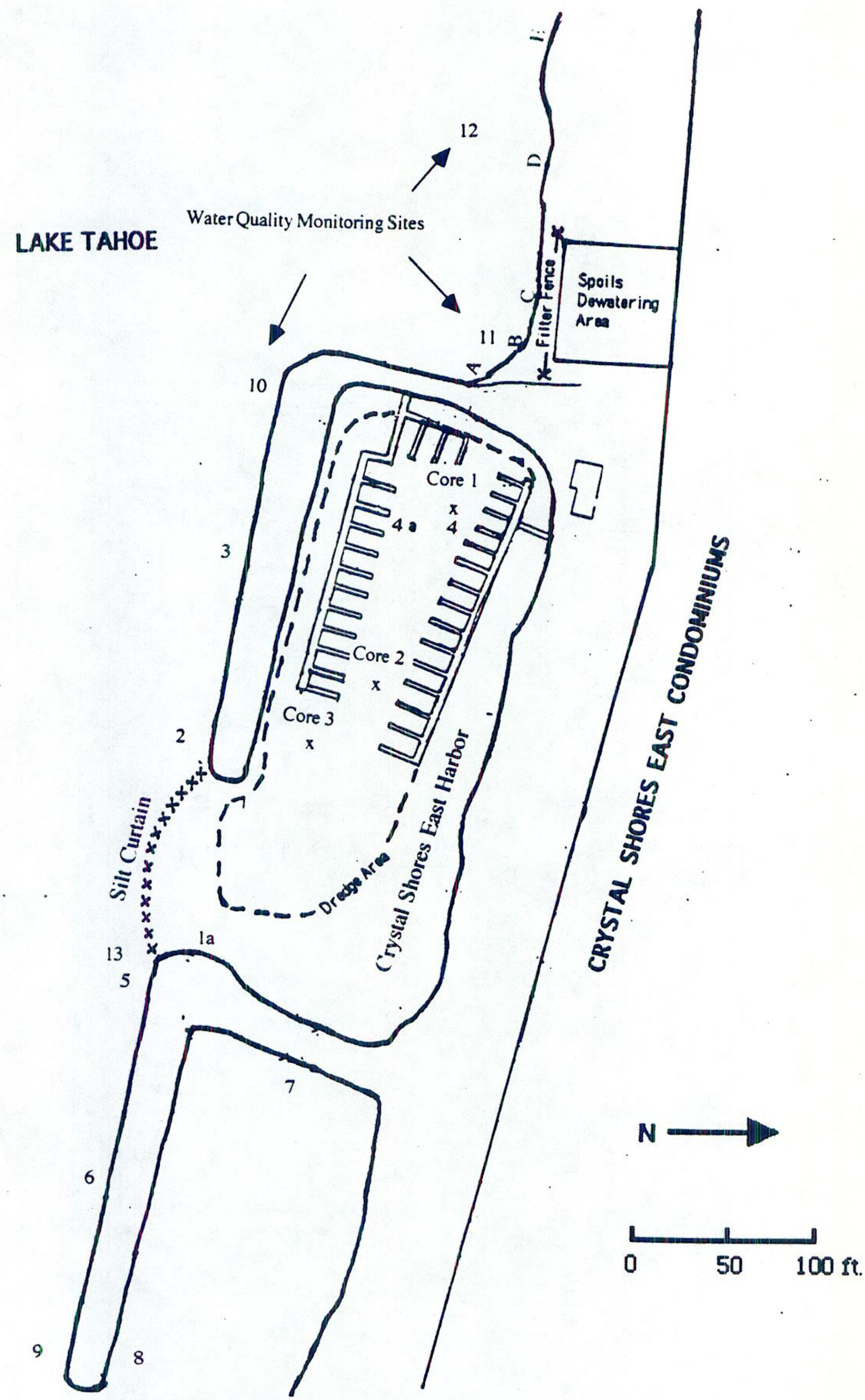
C.2. Turbidity and Nutrient Changes Within Containment Areas During Dredging

C.2.1. Turbidity, TKN, TP, BAFe, TFe

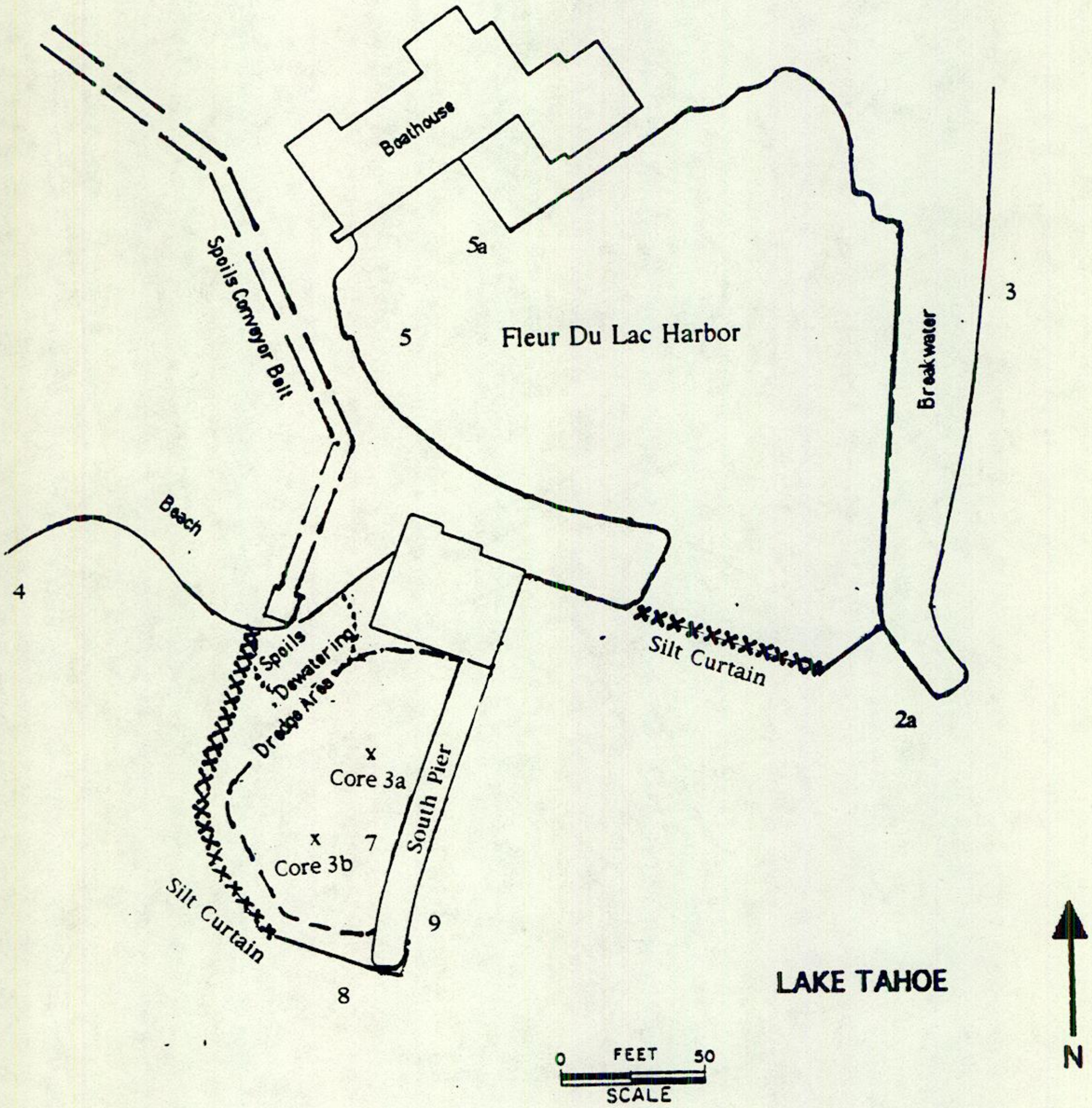
Table C-2 presents the pre-, during-, and postdredging turbidity and water quality data for within and outside the silt curtain enclosed areas. Turbidity, Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), Biologically Available Iron (BAFe) and Total Iron (TFe) concentration increased during dredging for nearly all projects for which sampling was done within enclosed areas. Oxidized Nitrogen (NO_2-N+NO_3-N), Ammonium Nitrogen (NH_4-N), and Ortho-Phosphorus (Ortho-P) increased in some but not all projects in which they were analyzed.



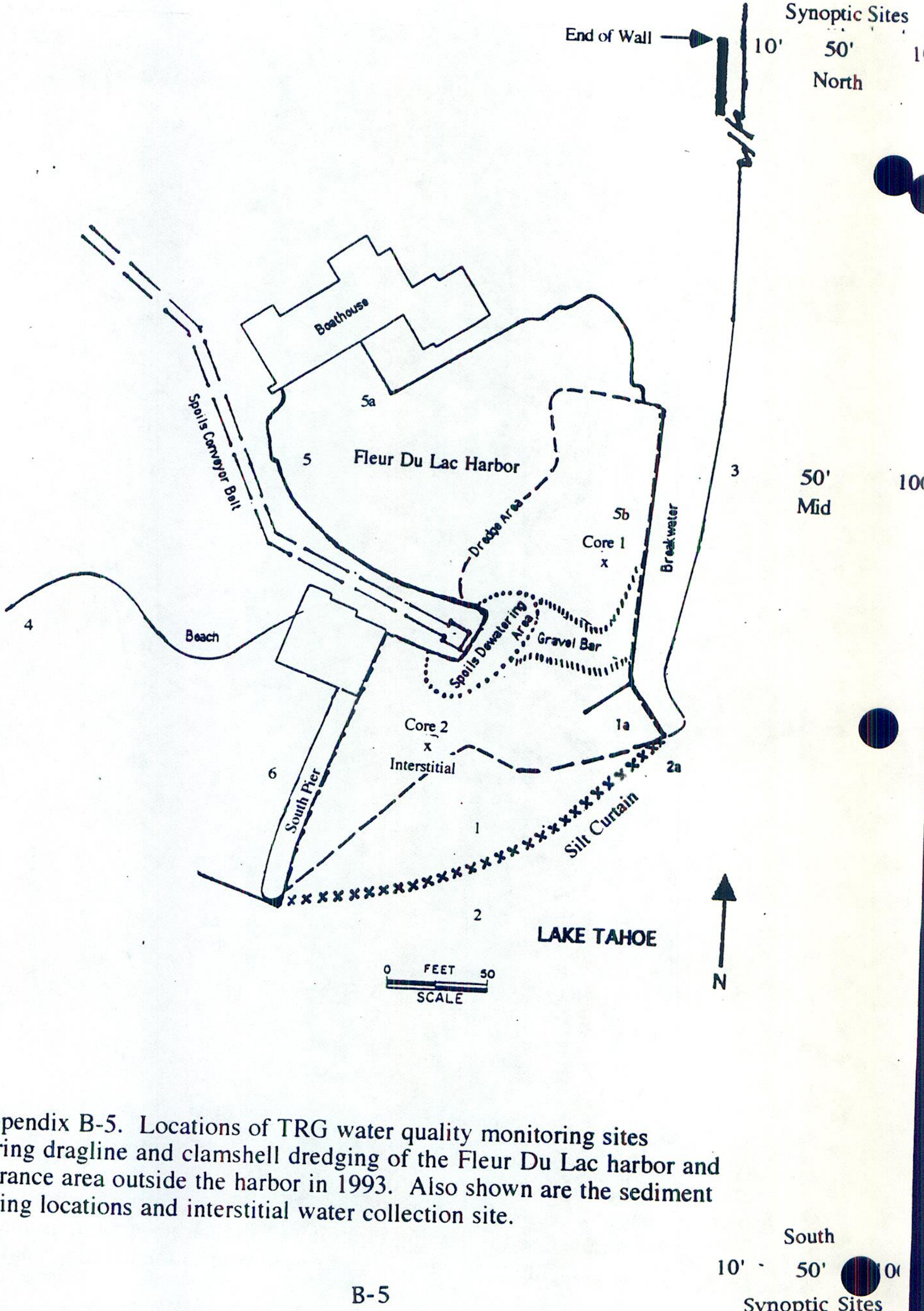
Appendix B-8. Locations of TRG sediment coring locations in the Tahoe Boat Co. Marina, 1994.



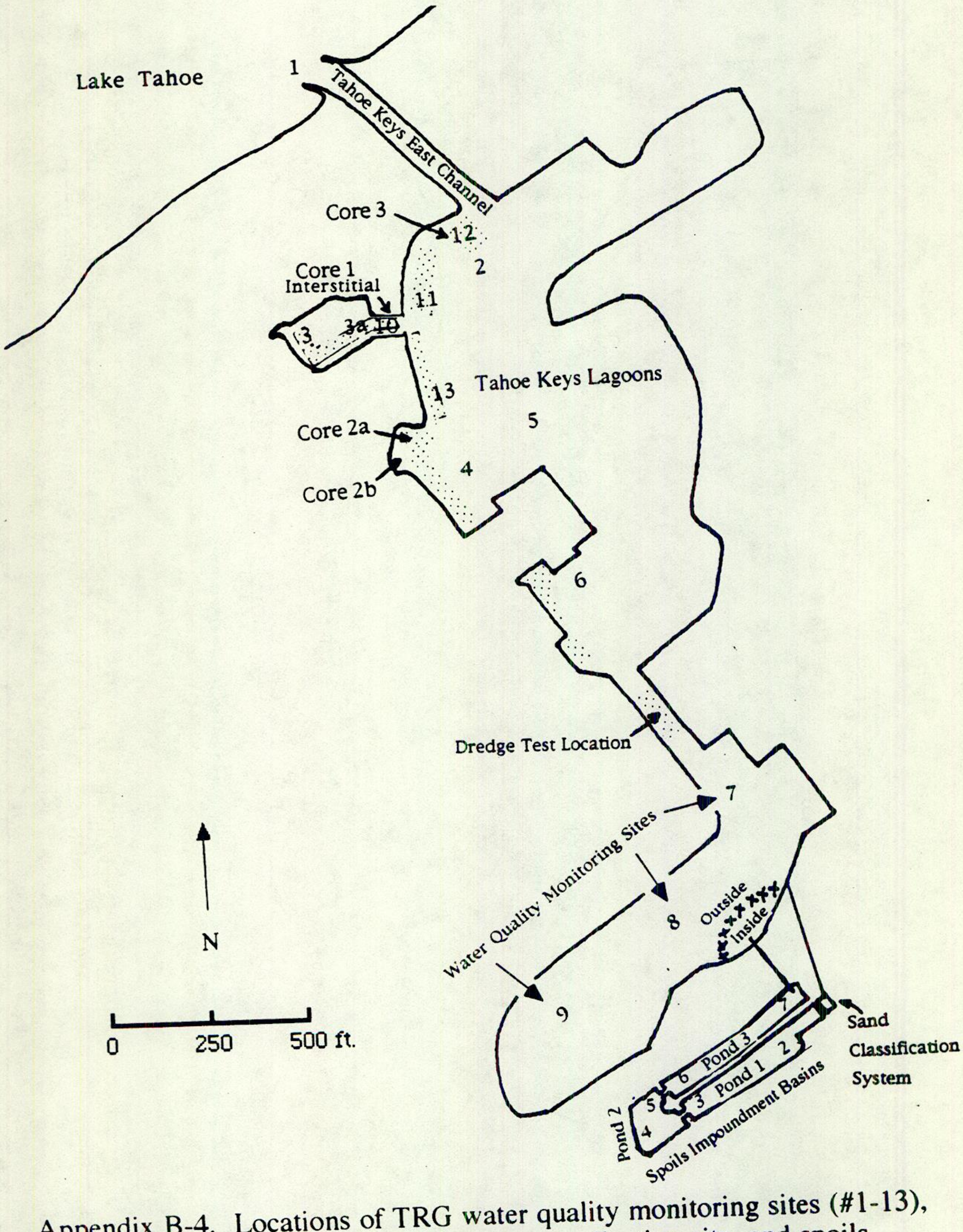
Appendix B-7. Locations of TRG water quality monitoring sites (#1-13), and shallow nearshore water collection sites (A-E) during excavator dredging at Crystal Shores East in 1993. Also shown are sediment coring locations.



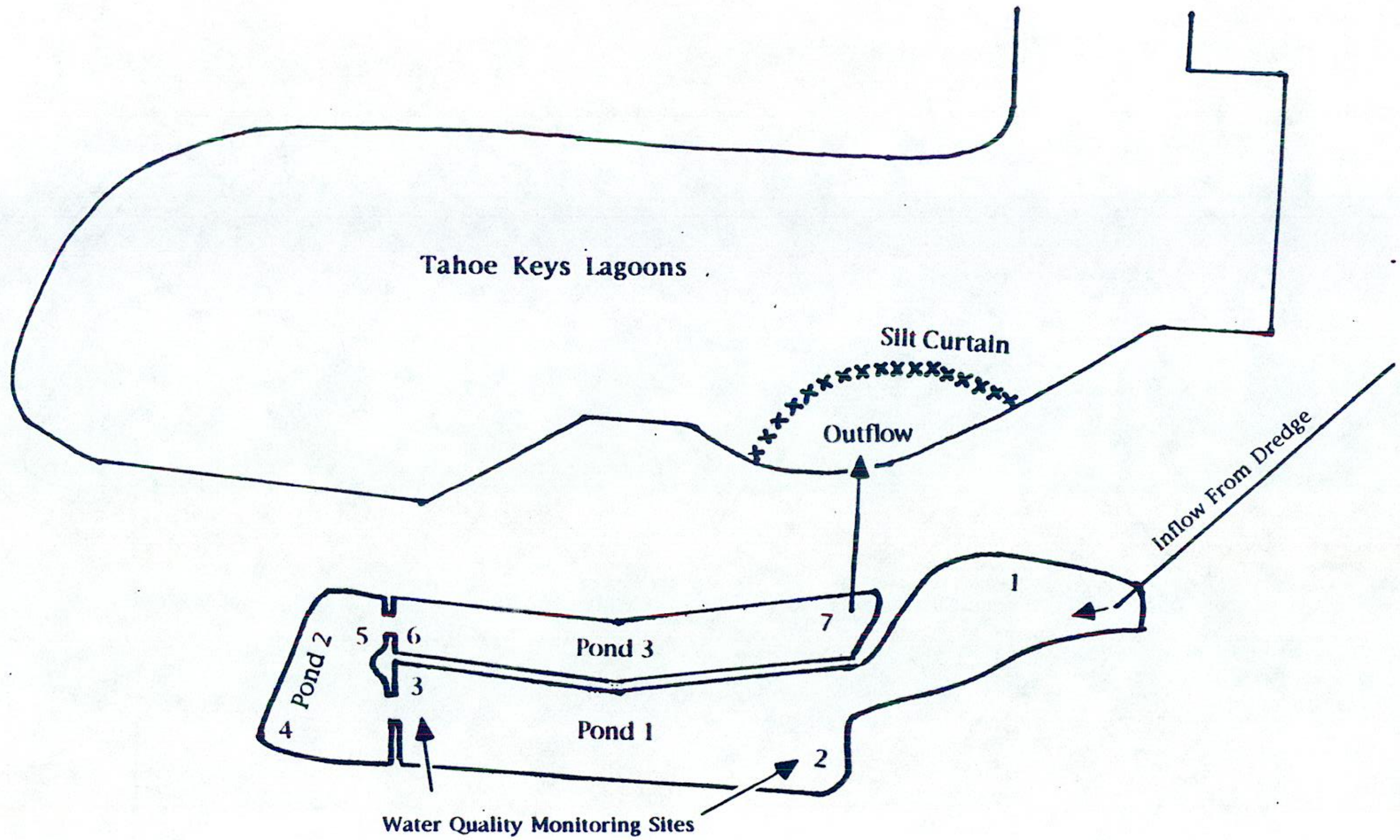
Appendix B-6. Locations of TRG water quality monitoring sites (#2a-9) during dragline and clamshell dredging of the area adjacent to the south pier at Fleur Du Lac. 1993. Also shown are sediment coring locations. This dredging occurred following dredging of the harbor area; note that the silt curtain isolating the harbor has been moved to the harbor mouth.



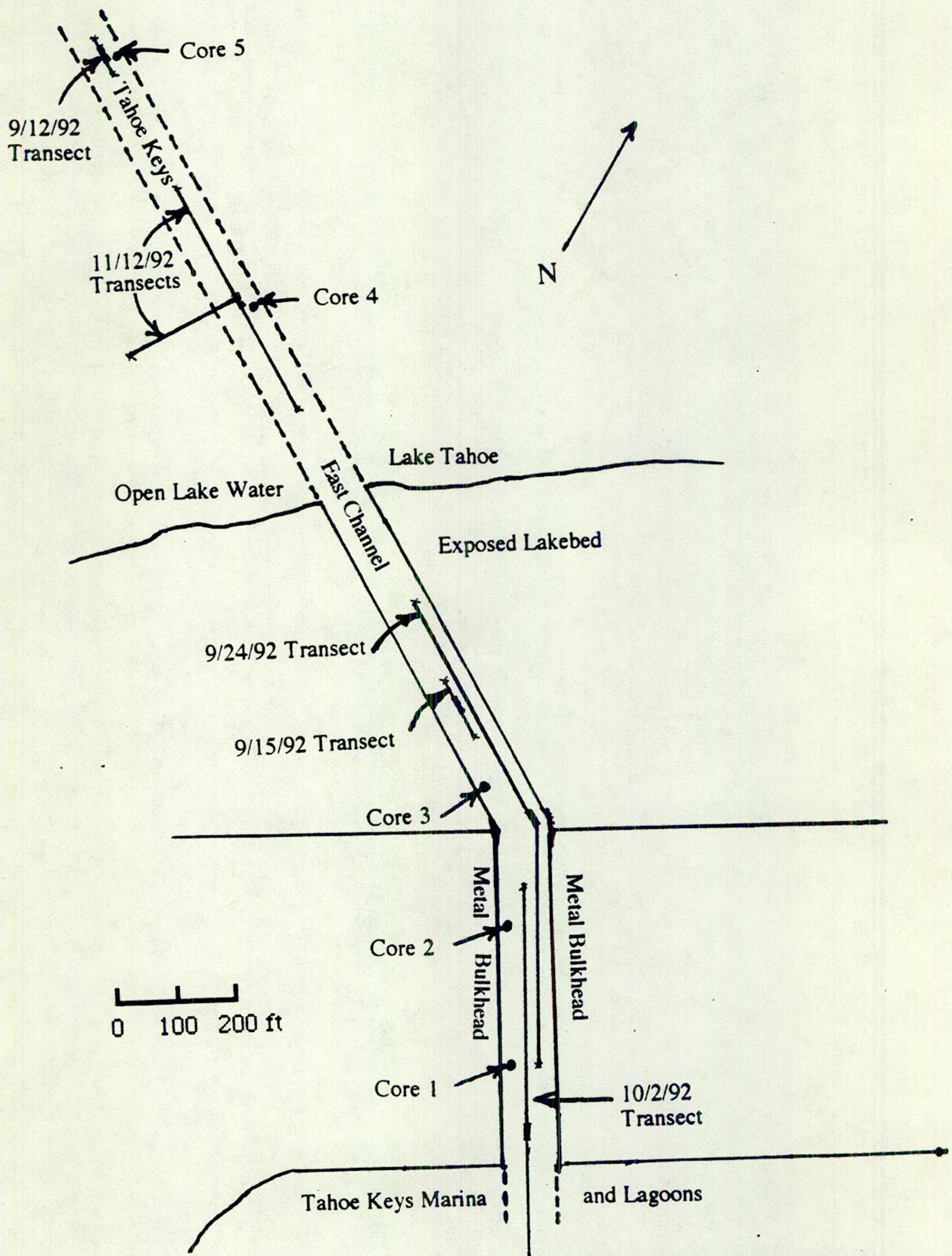
Appendix B-5. Locations of TRG water quality monitoring sites during dragline and clamshell dredging of the Fleur Du Lac harbor and entrance area outside the harbor in 1993. Also shown are the sediment coring locations and interstitial water collection site.



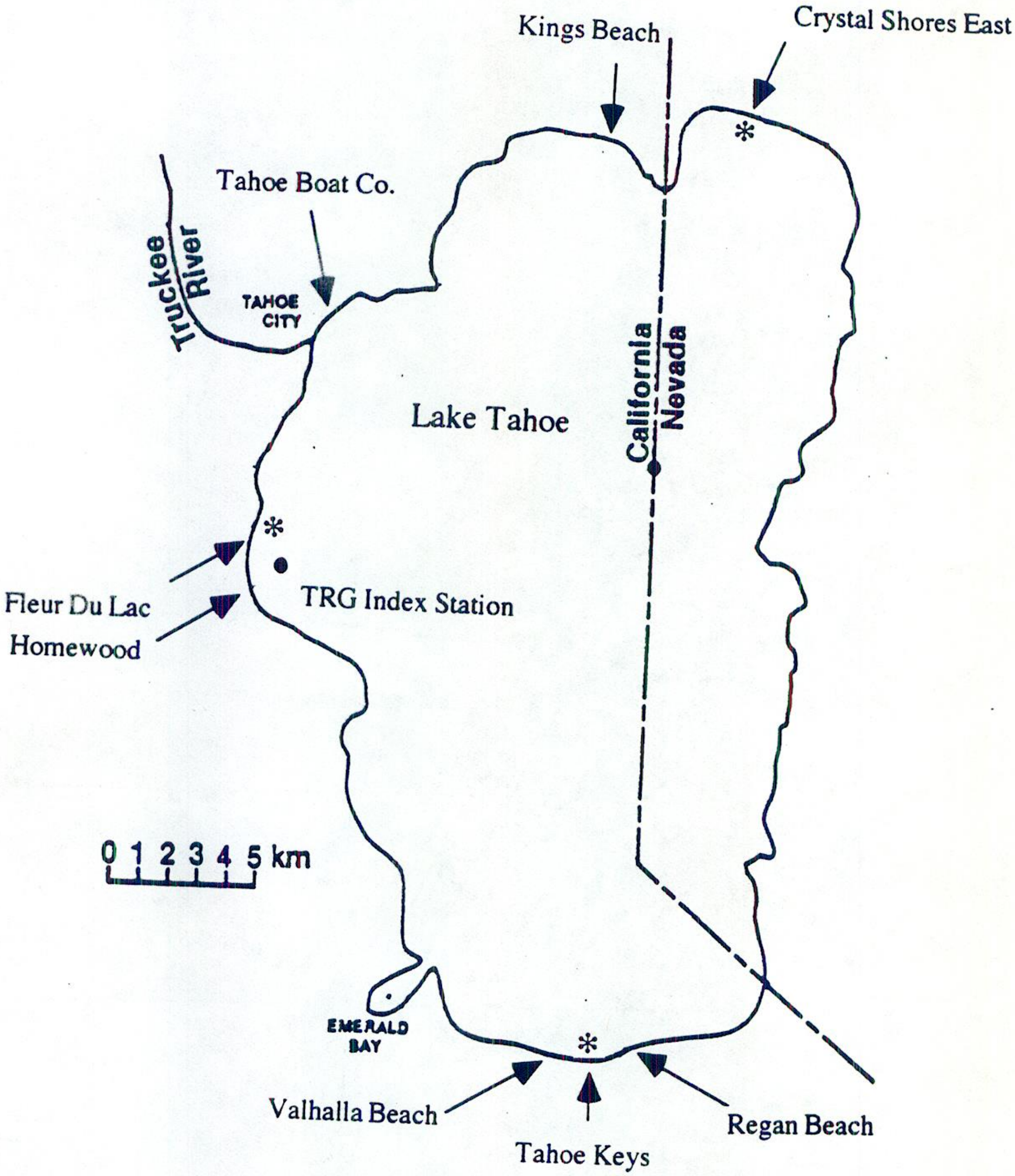
Appendix B-4. Locations of TRG water quality monitoring sites (#1-13), sediment coring locations, interstitial water collection site, and spoils impoundment basin monitoring sites during 1993 hydraulic dredging project in the Tahoe Keys Marina and lagoons. Also shown is the "Dredge Test Location" where sediment and nutrient resuspension produced by the VMI 612 dredge at varied operational control settings was monitored.



Appendix B-3. Location of the dredge spoils impoundment basins (Ponds 1-3) used to settle solids from hydraulic dredging spoils during dredging of the Tahoe Keys East Channel in 1992. TRG water quality monitoring sites: #1-7, "inflow", and "outflow" are shown.



Appendix B-2. Locations of water quality monitoring transects around the VMI 612 horizontal cutter during operations in the Tahoe Keys East Channel in 1992. Also shown are locations of predredging sediment cores collected by Chemax Labs, Sparks, Nv. and the TRG on 7/8/92.



Appendix B-1. Locations of dredging projects studied (Tahoe Keys 1992,93; Fleur Du Lac 1993; and Crystal Shores East 1993). Also shown are additional sites where lake sediment samples were collected for analysis.

Appendix A-29. Pre- and postdredging profiles of sediment interstitial water NO2NO3-N, NH4-N, and SRP at TRG core site 2 at Fleur Du Lac.

Date	Elevation of Sed. Surface	Depth in sed. (cm)	NO2NO3-N (μg/l)	NH4-N (μg/l)	SRP (μg/l)
8/4/93	1896.47 m	5	13	2	8
Predredge	(6222.03 ft)	10	60	1	10
		10	84	4	14
		15	90	2	15
		20	90	2	15
		25	84	1	16
		30	84	4	17
		30	80	2	18
		40	108	2	49
		50	93	4	18
		80	15	12	27
		110	12	8	17
9/20/93	1895.13 m	0	3	1	1
Postdredge	(6217.60 ft)	5	4	1	7
		10	3	0	8
		15	7	1	10
		20	10	1	11
		25	7	3	3
		30	7	1	10
		40	10	25	11
11/8/93		5	24	2	2
Postdredge		10	3	2	2
		15	4	4	5
		20	3	8	2
		25	4	5	2
		30	9	1	15
		40	6	5	9

Appendix A-28. Pre- and postdredging profiles of sediment interstitial water NO2NO3-N, NH4-N, and SRP at TRG core site 1 in the Tahoe Keys lagoons.

Date	Elevation of Sed. Surface	Depth in sed. (cm)	NO2NO3-N (µg/l)	NH4-N (µg/l)	SRP (µg/l)
8/11/93	1896.30 m	0	7	0	2
Predredge	(6221.44 ft.)	5	24	2	30
		10	33	147	5
		15	142	996	17
		20	108	808	48
		25	198	1335	85
		30	209	1601	66
		40	184	1498	83
		50	219	1752	20
		100	270	1805	10
9/16/93	1895.86 m	0	5	0	2
Postdredge	(6220.01 ft)	5	8	212	4
		5	9	155	5
		15	30	394	5
		20	38	550	15
		25	23	414	7
		30	68	1154	33
		40	36	1292	2
		50	173	1474	16
1/12/94		0	2	0	1
Postdredge		5	101	521	1
		10	131	378	31
		10	91	483	4
		15	109	397	20
		20	55	361	1
		25	53	443	1
		30	47	652	1
		40	49	1275	1
		50	180	1364	1
5/11/94		0	1	0	1
		5	5	911	0
		10	6	881	1
		10	6	338	0
		15	8	385	1
		20	9	430	1
		25	8	444	1
		30	9	831	1
		40	10	1475	3
		50	9	1580	2
8/4/94		0	2	1	3
		5N	42	1281	13
		10	33	1053	3
		10	32	834	3
		10N	74	1211	45
		15	17	428	2
		20	11	307	3
		25	10	372	3
		30	7	2228	3
		30N	8	1168	1
		40	10	1843	2
		40N	15	1560	2
		50	9	1961	3

Appendix A-27. Results of bioassay which tested additions dried core #1 sediments from Tahoe Keys lagoons, Fleur Du Lac harbor, and Crystal Shores East harbor to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at p≤0.05, "**" is significant at p≤0.01, "***" is highly significant at p≤0.001. Bioassay was run 10/31-11/6/94.

Flask	Treatment	11/2/94 Day 2 d Fluor. f.u. (30x)	11/2/94 Day 2 mean d Fluor. f.u. (30x)	11/4/94 Day 4 d Fluor. f.u. (30x)	11/4/94 Day 4 mean d Fluor. f.u. (30x)	11/6/94 Day 6 d Fluor. f.u. (30x)	11/6/94 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. Control vs. Treatment	11/6/94 Day 6 d Chl a (µg/l)	11/6/94 Day 6 mean d Chl a (µg/l)	Stat. Signif. Day 6 Chl a Control vs. Treatment	11/6/94 Day 6 d Pheo. (µg/l)	11/6/94 Day 6 mean d Pheo. (µg/l)
1	Control	0.9		1.8		1.8			0.05			0.05	
2		1.7	1.20	1.3	1.33	1.3	1.30		-0.01	0.01		0.06	0.04
3		1		0.9		0.8			0			0	
4	0.1 g/l 8/93 T.Keys Lagoons 1-1	1.1	1.60	1.8	1.95	3	2.25	NS	0.18	0.14	NS	0.07	0.09
5		2.1		2.1		1.5			0.09			0.11	
6	0.1 g/l 8/93 T.Keys Lagoons 1-2	1.5	1.95	2.6	2.90	3	3.00	*	0.15	0.17	NS	-0.01	0.01
7		2.4		3.2		3			0.19			0.02	
8	0.1 g/l 8/93 T.Keys Lagoons 1-3	1.5	1.50	1.9	1.80	2.2	2.10	NS	0.11	0.12	NS	0.04	0.03
9		1.5		1.7		2			0.12			0.02	
10	0.1 g/l 8/93 T.Keys Lagoons 1-4	0.9	0.80	1.8	1.75	2.6	2.35	NS	0.2	0.21	*	0.01	0.01
11		0.7		1.7		2.1			0.21			0.01	
12	0.1 g/l 8/93 Fleur Du Lac 1-1	1.4	1.35	3.1	2.75	4.4	4.75	***	0.45	0.37	**	-0.01	0.02
13		1.3		2.4		5.1			0.29			0.05	
14	0.1 g/l 8/93 Fleur Du Lac 1-2	0.5	0.50	0.9	1.00	1.8	2.30	NS	0.07	0.14	NS	0.03	0.05
15		0.5		1.1		2.8			0.2			0.07	
16	0.1 g/l 8/93 Fleur Du Lac 1-3 + 1-4	0.7	0.85	1.7	1.85	3.5	3.25	*	0.26	0.23	*	0.03	0.06
17		1		2		3			0.2			0.09	
18	0.1 g/l 8/93 Fleur Du Lac 1-5 + 1-6	0.6	0.30	2.6	1.95	2.8	2.50	NS	0.1	0.12	NS	0.03	0.04
19		0		1.3		2.2			0.13			0.05	
20	0.1 g/l 9/93 Crystal Shores E. 1-1	1.2	1.10	3	3.10	6.5	6.80	***	0.38	0.48	**	0.1	0.10
21		1		3.2		7.1			0.57			0.09	
22	0.1 g/l 9/93 Crystal Shores E. 1-2	0	0.00	3	3.25	5.8	5.25	***	0.45	0.42	**	-0.02	0.04
23		0		3.5		4.7			0.38			0.09	
24	0.1 g/l 9/93 Crystal Shores E. 1-3	0.6	0.55	4.2	3.80	6.8	5.80	***	0.5	0.38	**	0.1	0.12
25		0.5		3.4		4.8			0.25			0.13	
26	0.1 g/l 9/93 Crystal Shores E. 1-4	0.1	-0.05	3.8	3.35	6.4	5.10	***	0.49	0.33	**	0.08	0.09
27		-0.2		2.9		3.8			0.17			0.09	

Appendix A-26. Results of bioassay which tested additions of different levels of N, P, or N+P to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at p≤0.05, "**" is significant at p≤0.01, "***" is highly significant at p≤0.001. Bioassay was run 10/31-11/6/94.

Flask	Treatment	11/2/94 Day 2 d Fluor. f.u. (30x)	11/2/94 Day 2 mean d Fluor. f.u. (30x)	11/4/94 Day 4 d Fluor. f.u. (30x)	11/4/94 Day 4 mean d Fluor. f.u. (30x)	11/6/94 Day 6 d Fluor. f.u. (30x)	11/6/94 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. Control vs. Treatment	11/6/94 Day 6 d Chl a (ug/l)	11/6/94 Day 6 mean d Chl a (ug/l)	Stat. Signif. Day 6 Chl a Control vs. Treatment	11/6/94 Day 6 d Pheo. (ug/l)	11/6/94 Day 6 mean d Pheo. (ug/l)
1	Control	3.2		3.1		3.45			-0.04			0.02	
2		2.9	3.00	3.1	3.13	4.05	3.73		0	-0.02		0.02	0.02
3		2.9		3.2		3.7			-0.03			0.02	
4	4µg/l N	4.1	3.60	3	3.30	3.1	3.45	NS	-0.03	0.00	NS	0.02	0.03
5		3.1		3.6		3.8			0.03			0.03	
6	10µg/l N	3.2	3.05	3.7	3.85	3.3	3.20	NS	0.02	0.03	NS	0.02	0.03
7		2.9		4		3.1			0.03			0.04	
8	20µg/l N	3.3	3.15	4.1	4.55	3.5	3.40	NS	0.03	0.05	NS	0.03	0.04
9		3		5		3.3			0.06			0.04	
10	2µg/l P	3.8	3.95	4.5	4.25	4.7	4.60	NS	0.1	0.05	NS	0.06	0.05
11		4.1		4		4.5			-0.01			0.03	
12	5µg/l P	4.8	4.35	4.7	4.75	3.9	3.95	NS	0.01	0.03	NS	0.04	0.03
13		3.9		4.8		4			0.05			0.01	
14	10µg/l P	4	3.75	4.2	4.55	4.1	4.10	NS	0.04	0.03	NS	0.02	0.02
15		3.5		4.9		4.1			0.01			0.01	
16	4µg/l N + 2µg/l P	3.3	3.65	4.8	4.80	4.9	5.35	***	0.12	0.17	***	0.02	0.03
17		4		4.8		5.8			0.21			0.03	
18	10µg/l N + 5µg/l P	4	3.85	6	6.15	8	7.45	***	0.22	0.22	***	0.06	0.07
19		3.7		6.3		6.9			0.22			0.07	
20	20µg/l N + 10µg/l P	3.9	4.05	6	6.00	8.1	8.20	***	0.27	0.28	***	0.08	0.09
21		4.2		6		8.3			0.28			0.1	

Appendix A-25. Results of bioassay which tested 1% by volume additions of postdredging Crystal Shores East, and natural nearshore sediment elutriate test supernatant water, or N, P, N+P to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. Postdredging sediment samples were collected from Crystal Shores East on 7/15/94, nearshore sediment samples were collected 7/18/94. "d" is change in value from initial (Day 0) value; Stat. Signif. is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at p≤0.05, "**" is significant at p≤0.01, "***" is highly significant at p≤0.001. Bioassay was run 7/28-8/3/94.

Flask	Treatment	7/30/94 Day 2 d Fluor. f.u. (30x)	7/30/94 Day 2 mean d Fluor. f.u. (30x)	7/31/94 Day 3 d Fluor. f.u. (30x)	7/31/94 Day 3 mean d Fluor. f.u. (30x)	8/1/94 Day 4 d Fluor. f.u. (30x)	8/1/94 Day 4 mean d Fluor. f.u. (30x)	8/2/94 Day 5 d Fluor. f.u. (30x)	8/2/94 Day 5 mean d Fluor. f.u. (30x)	8/3/94 Day 6 d Fluor. f.u. (30x)	8/3/94 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. 1% Control vs. Treatment	8/3/94 Day 6 d Chl a (µg/l)	8/3/94 Day 6 mean d Chl a (µg/l)	Stat. Signif. Day 6 Chl a 1% Control vs. Treatment	8/3/94 Day 6 d Pheo. (µg/l)	8/3/94 Day 6 mean d Pheo. (µg/l)
1	1% Control	2.2		4.2		4.3		5.1		5.4			0.27			0.11	
2		2.4	2.43	3.7	3.97	4.5	4.50	5	4.87	5.7	5.53		0.24	0.28		0.1	0.11
3		2.7		4		4.7		4.5		5.5			0.32			0.11	
4	20 µg/l N	2.3	3.15	4.2	4.25	5.3	5.20	6.3	5.75	7.1	6.65	NS	0.36	0.32	NS	0.12	0.17
5		4		4.3		5.1		5.2		6.2			0.27			0.21	
6	10 µg/l P	3.5	3.30	6.5	5.90	9.1	8.90	8.4	7.80	7.7	7.90	***	*	0.29	NS	*	0.10
7		3.1		5.3		8.7		7.2		8.1			0.29			0.1	
8	20 µg/l N + 10 µg/l P	3.5	3.70	7.1	7.65	12.4	12.45	12.7	12.95	11.9	12.30	***	0.4	0.50	***	0.29	0.29
9		3.9		8.2		12.5		13.2		12.7			0.6			0.28	
10	1% Homewood Sed.	2.9		4.4		5.6		6.2		7			0.29			0.12	
11		2.2	2.73	4.4	4.23	5.8	5.73	7	6.50	7.6	7.23	**	0.31	0.29	NS	0.15	0.14
12		3.1		3.9		5.8		6.3		7.1			0.27			0.15	
13	1% Kings Beach Sed.	2.2		3.7		5		5.4		5.9			0.36			0	
14		2.8	2.43	4.2	4.00	4.6	4.87	5.4	5.50	5.8	5.87	NS	0.37	0.35	NS	0	0.03
15		2.3		4.1		5		5.7		5.9			0.33			0.08	
16	1% Regan Beach Sed.	2.4		6.2		7.1		10.3		10.6			0.74			-0.64	
17		2.6	2.70	5.9	5.73	7.1	7.17	10.1	9.67	9	9.07	***	0.32	0.44	NS	-0.58	-0.64
18		3.1		5.1		7.3		8.6		7.6			0.27			-0.7	
19	1% Valhalla Beach Sed.	2.3		4.8		5.6		6.3		7.1			0.23			0.07	
20		2.6	2.30	4	4.30	4.6	5.13	4.8	5.90	7.1	6.77	*	0.24	0.22	NS	0.1	0.07
21		2		4.1		5.2		6.6		6.1			0.18			0.05	
22	1% 7/94 Crystal Sh. 1b-1	3.7		6.5		8		7.9		7.3			0.2			0.09	
23		4.8	3.80	6.3	6.27	7.7	7.50	7.5	7.47	6.3	6.90	*	0.22	0.22	NS	0.08	0.08
24		2.9		6		6.8		7		7.1			0.24			0.07	
25	1% 7/94 Crystal Sh. E. 2	4.2		7.8		9.6		10.1		8.1			0.32			0.05	
26		3.9	3.83	7.9	7.50	9.3	9.17	9.3	9.50	8.8	8.37	***	0.3	0.30	NS	0.15	0.11
27		3.4		6.8		8.6		9.1		8.2			0.28			0.12	

Appendix A-24. Results of bioassay which tested 1% by volume additions of postdredging Crystal Shores East, and natural nearshore sediment elutriate test supernatant water, or N, P, N+P to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. Postdredging sediment samples were collected from Crystal Shores East on 7/15/94, nearshore sediment samples were collected 7/18/94. "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at p≤0.05, "**" is significant at p≤0.01, "***" is highly significant at p≤0.001. Bioassay was run 7/20-7/26/94.

Flask	Treatment	7/22/94 Day 2 d Fluor. f.u. (30x)	7/22/94 Day 2 mean d Fluor. f.u. (30x)	7/24/94 Day 4 d Fluor. f.u. (30x)	7/24/94 Day 4 mean d Fluor. f.u. (30x)	7/26/94 Day 6 d Fluor. f.u. (30x)	7/26/94 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. 1% Control vs. Treatment	7/26/94 Day 6 d Chl a (μg/l)	7/26/94 Day 6 mean d Chl a (μg/l)	Stat. Signif. Day 6 Chl a 1% Control vs. Treatment	7/26/94 Day 6 d Pheo. (μg/l)	7/26/94 Day 6 mean d Pheo. (μg/l)
1	1% Control	1.5		2.2		3.2			0.1			0.11	
2		1.7	1.70	3.4	3.00	4.2	3.70		0.14	0.11		0.07	0.09
3		1.9		3.4		3.7			0.09			0.08	
4	20μg/l N	1.5	1.45	4.1	4.00	4.6	4.40	NS	0.14	0.15	NS	0.08	0.07
5		1.4		3.9		4.2			0.15			0.06	
6	10 μg/l P	2.2	2.70	6.1	6.00	4.45	4.93	**	0.14	0.15	NS	0.09	0.13
7		3.2		5.9		5.4			0.15			0.17	
8	20μg/l N + 10μg/l P	3.2	2.70	8.3	8.35	7.2	7.20	***	0.19	0.21	NS	0.16	0.12
9		2.2		8.4		7.2			0.22			0.08	
10	1% Homewood Nearshore Sed.	2.4		4.4		4.1			0.22			0.11	
11		3.1	2.70	3.9	4.13	4.4	4.13	NS	0.16	0.18	NS	0.07	0.09
12		2.6		4.1		3.9			0.16			0.09	
13	1% Kings Beach Nearshore Sed.	2.3		3		4.3			0.11			0.08	
14		1.8	1.90	3.6	3.53	3.6	4.00	NS	0.09	0.11	NS	0.09	0.08
15		1.6		4		4.1			0.13			0.08	
16	1% Regan Beach Nearshore Sed.	0.7		4.5		3.2			-0.5			-0.26	
17		0.9	0.77	3	3.67	2.2	2.70	*	-0.45	-0.49	***	-0.28	-0.30
18		0.7		3.5		2.7			-0.52			-0.37	
19	1% Valhalla Beach Nearshore Sed.	0.9		2.8		2.9			0.12			-0.01	
20		0.2	0.67	3.8	2.97	2.9	2.87	*	0.09	0.11	NS	0.05	0.03
21		0.9		2.3		2.8			0.12			0.06	
22	1% 7/94 Crystal Shores E. 1b-1	2.7		7.3		5.4			0.26			-0.03	
23		2.4	2.47	5.1	5.77	4.2	4.63	*	0.18	0.20	NS	-0.02	-0.03
24		2.3		4.9		4.3			0.16			-0.05	
25	1% 7/94 Crystal Shores E. 2	1.5		5.2		5.2			0.17			-0.03	
26		2.2	2.10	6.2	5.57	6	5.60	***	0.18	0.16	NS	0	0.00
27		2.6		5.3		5.6			0.14			0.03	

Appendix A-23. Results of bioassay which tested 1% by volume additions of Tahoe Boat Co. or postdredging Fleur Du Lac sediment elutriate test supernatant water to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. Postdredging Fleur Du Lac sediments were collected 6/1/94. "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at p≤0.05, "**" is significant at p≤0.01, "***" is highly significant at p≤0.001. Bioassay was run 7/6-7/12/94.

Flask	Treatment	7/8/94 Day 2 d Fluor. f.u. (30x)	7/8/94 Day 2 mean d Fluor. f.u. (30x)	7/10/94 Day 4 d Fluor. f.u. (30x)	7/10/94 Day 4 mean d Fluor. f.u. (30x)	7/12/94 Day 6 d Fluor. f.u. (30x)	7/12/94 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. 1% Control vs. Treatment	7/12/94 Day 6 d Chl a (µg/l)	7/12/94 Day 6 mean d Chl a (µg/l)	Stat. Signif. Day 6 Chl a 1% Control vs. Treatment	7/12/94 Day 6 d Pheo. (µg/l)	7/12/94 Day 6 mean d Pheo. (µg/l)
1	1% Control	3		2.5		2.2			0.1			-0.01	
2		2.6	2.80	2.9	2.70	2.2	2.33		0.08	0.09		0	0.00
3		2.8		2.7		2.6			0.1			0.01	
4	1% T. Boat Co. 1-1	2.2		2.6		1.4			0.03			0.04	
5		1.9	1.73	2.7	3.07	2.2	2.07	NS	0.08	0.06	NS	0.02	0.04
6		1.1		3.9		2.6			0.06			0.05	
7	1% T. Boat Co. 1-2	2.1		3.5		2.9			0.08			0.03	
8		2.2	2.10	3.5	3.33	3.2	3.10	NS	0.11	0.11	NS	0.05	0.05
9		2		3		3.2			0.14			0.08	
10	1% T. Boat Co. 3a-3	2		3.8		4.4			0.13			0.08	
11		2.6	2.33	3.6	3.80	4.6	4.43	**	0.14	0.16	*	0.1	0.08
12		2.4		4		4.3			0.2			0.05	
13	1% T. Boat Co. 3a-2	0.6		3.3		4.5			0.18			0.13	
14		2.3	1.30	3.7	3.93	4.8	4.60	**	0.26	0.22	***	0.1	0.10
15		1		4.8		4.5			0.21			0.08	
16	1% T. Boat Co. 3a-1	3.9		6.9		11.2			0.38			0.06	
17		4	3.77	7.6	7.47	11.9	12.00	***	0.31	0.36	***	0.01	0.02
18		3.4		7.9		12.9			0.4			-0.02	
19	1% postdr. Fleur du lac 1a	3.2		6.4		6.7			0.12			0.05	
20		4.2	3.73	7.6	7.10	7.5	7.23	***	0.21	0.18	**	0.03	0.05
21		3.8		7.3		7.5			0.2			0.07	
22	1% postdr. Fleur du lac 1a	5		11.2		18.4			0.25			-0.05	
23		4.4	4.63	11.7	11.07	17	17.67	***	0.25	0.25	***	-0.02	-0.02
24		4.5		10.3		17.6			0.24			0.02	
25	1% postdr. Fleur du lac 1b	3.4		8.7		27.9			0.43			0.29	
26		2.2	2.67	8	8.43	24.7	25.77	***	0.45	0.44	***	0	0.11
27		2.4		8.6		24.7			0.44			0.04	

Appendix A-22. Results of bioassay which tested 1% by volume additions of postdredging Tahoe Keys sediment elutriate supernatant test water, or N, P, N+P to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. Postdredging sediment was collected from core site #1 on 6/23/94. "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at $p \leq 0.05$, "**" is significant at $p \leq 0.01$, "***" is highly significant at $p \leq 0.001$. Bioassay was run 7/6-7/12/94.

Flask Treatment	7/8/94 Day 2 d Fluor. f.u. (30x)	7/8/94 Day 2 mean d Fluor. f.u. (30x)	7/10/94 Day 4 d Fluor. f.u. (30x)	7/10/94 Day 4 mean d Fluor. f.u. (30x)	7/12/94 Day 6 d Fluor. f.u. (30x)	7/12/94 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. (1%) Control vs. Treatment	7/12/94 Day 6 d Chl a (µg/l)	7/12/94 Day 6 mean d Chl a (µg/l)	Stat. Signif. Day 6 Chl a (1%) Control vs. Treatment	7/12/94 Day 6 d Pheo. (µg/l)	7/12/94 Day 6 mean d Pheo. (µg/l)
1 Control	2.4		2.6		2.5			0.12			0.04	
2	2.3	2.37	2.5	2.47	1.5	1.73		0.12	0.11		0.02	0.03
3	2.4		2.3		1.2			0.1			0.02	
4 20 µg/l N	4.8		4.9		3.2			0.11			0.06	
5	3.7	3.87	4.1	4.47	2.7	3.30	NS	0.12	0.12	NS	0.05	0.06
6	3.1		4.4		4			0.12			0.07	
7 10 µg/l P	5.4		4.9		2.4			0.09			0.04	
8	3.9	4.67	3.7	4.17	1.2	1.83	NS	0.06	0.07	NS	0.02	0.01
9	4.7		3.9		1.9			0.07			-0.02	
10 20 µg/l N + 10 µg/l P	7		10.8		14.4			0.31			0.17	
11	5.8	6.23	13.8	12.43	18.4	17.00	***	0.34	0.31	***	0.16	0.16
12	5.9		12.7		18.2			0.28			0.16	
13 1% Control	3.1		2.7		1.9			0.11			0.06	
14	2.9	3.13	2.7	2.73	2	1.97		0.08	0.08		0.05	0.15
15	3.4		2.8		2			0.05			0.33	
16 postdr. T.Keys 1-1	5.1		4.5		2.9			0.15			*	
17	3.1	4.13	2.1	3.77	0.9	1.70	NS	-0.01	0.07	NS	-0.06	-0.03
18	4.2		4.7		1.3			0.06			0	
19 postdr. T. Keys 1-2	3.4		3.6		2			0.09			0.04	
20	2.8	3.00	2.9	3.37	1.6	1.77	NS	0.03	0.07	NS	0	0.01
21	2.8		3.6		1.7			0.09			0	
22 postdr. T. Keys 1-3	3.7		5.7		3.9			0.13			0.07	
23	3.7	3.67	4.2	4.67	2.2	2.77	NS	0.08	0.09	NS	0.03	0.05
24	3.6		4.1		2.2			0.06			0.04	

Appendix A-21. Results of bioassay which tested 1% by volume additions of Crystal Shores East sediment elutriate test supernatant water, or N, P, N+P to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. "CSE" is Crystal Shores East. "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at $p \leq 0.05$, "**" is significant at $p \leq 0.01$, "***" is highly significant at $p \leq 0.001$. Bioassay was run 11/30-12/6/93.

Flask	Treatment	12/4/93 Day 4 d Fluor. f.u. (30x)	12/4/93 Day 4 mean d Fluor. f.u. (30x)	12/6/93 Day 6 d Fluor. f.u. (30x)	12/6/93 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. (1%) Control vs. Treatment	12/6/93 Day 6 d Chl a (μg/l)	12/6/93 Day 6 mean d Chl a (μg/l)	Stat. Signif. Day 6 Chl a (1%) Control vs. Treatment	12/6/93 Day 6 d Pheo. (μg/l)	12/6/93 Day 6 mean d Pheo. (μg/l)
1	Control	3.10		0.70			-0.03			-0.03	
2		1.70	1.90	3.00	1.87		0.21	0.09		0.04	0.01
3		0.90		1.90			0.08			0.03	
4	20 μg/l N	3.70		5.80			0.71			-0.07	
5		4.60	3.90	5.40	5.40	***	0.84	0.76	***	0.07	-0.01
6		3.40		5.00			0.73			-0.03	
7	10 μg/l P	0.50		-1.30			-0.28			0.03	
8		2.80	1.27	1.40	-0.03	*	-0.07	-0.16	*	0.16	0.10
9		0.50		-0.20			-0.13			0.11	
10	20 μg/l N + 10 μg/l P	3.80		12.00			0.84			0.15	
11		4.30	4.20	10.20	11.70	***	1.17	1.03	***	0.01	0.08
12		4.50		12.90			1.09			0.07	
13	1% Control	0.50		-1.20			-0.06			0.08	
14		-0.50	-0.03	-1.40	-0.90		0.13	0.02		-0.05	0.09
15		-0.10		-0.10			-0.02			0.10	
16	1% CSE C2-3 Elut.	3.90		7.70			0.99			-0.18	
17		3.90	4.07	7.90	8.17	***	0.83	0.86	***	-0.23	-0.13
18		4.40		8.90			0.76			0.01	
19	1% CSE C3-1 Elut.	3.50		6.20			0.74			-0.22	
20		4.00	3.80	7.80	6.57	***	0.76	0.66	***	-0.17	-0.18
21		3.90		5.70			0.47			-0.16	
22	1% CSE C2-4 Elut.	5.50		15.70			1.45			0.32	
23		7.70	6.60	16.40	16.20	***	1.30	1.50	***	0.04	0.18
24		6.60		16.50			1.76			0.17	
25	1% CSE C1-4 Elut.	6.00		12.40			1.09			0.27	
26		7.50	7.53	13.90	12.90	***	0.93	1.05	***	0.23	0.22
27		9.10		12.40			1.13			0.15	

Appendix A-20. Bioassay which tested 1% by volume additions of Tahoe Keys sand classification system sand or beach sand elutriate test supernatant water to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. "#120 grade" is washed sand from the sand classification system which was > 120 μm; "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at $p \leq 0.05$, "**" is significant at $p \leq 0.01$, "***" is highly significant at $p \leq 0.001$. Bioassay was run 9/7-9/14/93.

Flask	Treatment	9/10/93 Day 3 d Fluor. f.u. (30x)	9/10/93 Day 3 mean d Fluor. f.u. (30x)	9/14/93 Day 6 d Fluor. f.u. (30x)	9/14/93 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. 1% Control vs. Treatment	9/14/93 Day 6 d Chl a (µg/l)	9/14/93 Day 6 mean d Chl a (µg/l)	Stat. Signif. Day 6 Chl a 1% Control vs. Treatment	9/14/93 Day 6 d Pheo. (µg/l)	9/14/93 Day 6 mean d Pheo. (µg/l)
1	1% Control	2.90		2.30			0.08			0.02	
2		2.50	2.43	2.80	2.67		0.11	0.10		0.01	0.01
3		1.90		2.90			0.10			0.00	
4	1% #40 (beach sand) Elut.	3.60		9.70			0.50			0.11	
5		3.30	3.43	9.80	9.33	***	0.44	0.48	***	0.16	0.13
6		3.40		8.50			0.50			0.11	
7	1% #41 (beach sand) Elut.	2.30		4.40			0.09			0.23	
8		4.10	3.13	4.80	4.73	***	0.29	0.20	*	0.00	0.10
9		3.00		5.00			0.23			0.06	
10	1% #2 (#120 grade) Elut.	2.70		5.00			0.21			0.02	
11		3.00	2.93	5.20	4.80	***	0.21	0.20	*	-0.01	0.01
12		3.10		4.20			0.18			0.01	
13	1% #37 (#120 grade) Elut.	2.70		6.70			0.33			0.06	
14		2.50	2.57	6.50	6.50	***	0.29	0.34	***	0.02	0.03
15		2.50		6.30			0.39			0.02	

Appendix A-19. Results of bioassay which tested 1% by volume additions of Tahoe Keys lagoon or Fleur Du Lac sediment elutriate test supernatant water to Lake Tahoe Index Station 0-15m water containing natural phytoplankton. "FDL" is Fleur Du Lac core subsection, "TK" is Tahoe Keys lagoons core subsection, "Fluor." is In Vivo Fluorescence. "d" is change in value from initial (Day 0) value; "Stat. Signif." is statistical significance level of difference between treatment response and control response where "NS" is not significant, "*" is significant at $p \leq 0.05$, "**" is significant at $p \leq 0.01$, "***" is highly significant at $p \leq 0.001$. Bioassay was run 9/7-9/14/93.

Flask	Treatment	9/10/93 Day 3 d Fluor. f.u. (30x)	9/10/93 Day 3 mean d Fluor. f.u. (30x)	9/14/93 Day 6 d Fluor. f.u. (30x)	9/14/93 Day 6 mean d Fluor. f.u. (30x)	Stat. Signif. Day 6 Fluor. Treatment vs. 1% Control	9/14/93 Day 6 d Chl a (µg/l)	9/14/93 Day 6 mean d Chl a (µg/l)	Stat. Signif. Day 6 Chl a Treatment vs. 1% Control	9/14/93 Day 6 d Pheo. (µg/l)	9/14/93 Day 6 mean d Pheo. (µg/l)
1	1% Control	2.30		2.30			0.19			0.03	
2		1.20	1.50	2.40	2.47		0.18	0.20		-0.07	-0.04
3		1.00		2.70			0.23			-0.07	
4	1% FDL C2-1 Elut.	0.70		3.40			0.19			0.00	
5		1.40	1.37	3.60	3.63	NS	0.18	0.16	NS	0.02	0.04
6		2.00		3.90			0.12			0.09	
7	1% FDL C3b-2 Elut.	3.60		11.60			0.62			0.04	
8		3.00	3.73	8.30	9.87	***	0.42	0.51	***	0.12	0.08
9		4.60		9.70			0.49			0.07	
10	1% FDL C1-4 Elut.	4.00		7.30			0.55			-0.11	
11		3.80	3.93	9.50	8.10	***	0.41	0.46	**	0.12	0.01
12		4.00		7.50			0.42			0.02	
13	1% FDL C1-1 Elut.	2.80		10.00			0.64			-0.12	
14		3.40	3.20	9.50	9.43	***	0.57	0.54	***	-0.01	-0.05
15		3.40		8.80			0.41			-0.01	
16	1% TK C1-3 Elut.	6.00		12.50			0.63			0.11	
17		6.00	6.17	31.00	12.25	***	1.86	0.59	***	0.22	0.12
18		6.50		12.00			0.55			0.13	
19	1% TK C2b-1 Elut.	4.80		10.20			0.73			-0.55	
20		4.80	4.83	11.10	11.17	***	0.67	0.63	***	-0.32	-0.33
21		4.90		12.20			0.48			-0.11	
22	1% TK C2b-4 Elut.	5.20		10.00			0.46			0.00	
23		8.70	6.97	10.70	10.40	***	0.40	0.48	**	0.24	0.05
24		7.00		10.50			0.58			-0.08	
25	1% TK C2b-2 Elut.	4.70		9.60			0.23			0.26	
26		4.60	4.57	6.60	7.80	***	0.46	0.37	*	0.39	0.26
27		4.40		7.20			0.43			0.13	

Appendix A-18. Results of regulatory agency required predredging substrate analysis of Sierra Boat Co. Marina sediments. "Gr" is gravel, "Sd" is sand, "Sl+Cl" is silt + clay fraction; "O & G" is oil and grease. Chemical analysis was by Chemax Laboratories, Sparks, Nv. Data courtesy Lahontan.

		RAW SED																		
Core Site & (Depth)	Collected	% Gr	% Sd	%Sl+Cl	TKN Gr	TKN Sd (mg/kg)	TKN Sl+Cl	TKN Total	Oxid. N. Gr	Oxid. N. Sd (mg/kg)	Oxid. N. Sl+Cl	Oxid. N. Total	TP Gr	TP Sd (mg/kg)	TP Sl+Cl	TP Total	sBAFE Gr	sBAFE Sd (mg/kg)	sBAFE Sl+Cl	sBAFE Total
1	5/21/91	40%	58%	3%	12	16	112	17.11	<.2	<.2	*	0.20	600	730	*	677.17	8.50	0.42	*	3.70
2	5/21/91	0%	59%	41%	*	12	183	82.79	*	0.33	0.69	0.48	*	410	570	476.24	*	0.26	0.32	0.28
3	5/21/91	0%	65%	35%	*	53	397	174.09	*	0.20	0.76	0.40	*	376	580	447.81	*	0.20	0.39	0.27
4	5/21/91	1%	71%	29%	13	18	226	77.87	*	0.53	0.60	0.55	*	550	450	521.03	*	<.1	0.16	0.12
5	5/21/91	6%	88%	6%	13	26	22	24.97	0.55	0.35	0.32	0.36	620	570	320	558.30	<.1	<.1	0.27	0.11
6	5/21/91	0%	96%	4%	11	32	50	32.56	*	0.24	0.32	0.24	*	580	260	568.43	*	<.1	*	0.10

		RAW SED																		
Core Site & (Depth)	Collected	O & G Gr	O & G Sd (mg/kg)	O & G Sl+Cl	O & G Total	Cd Gr	Cd Sd (mg/kg)	Cd Sl+Cl	Cr Gr	Cr Sd (mg/kg)	Cr Sl+Cl	Pb Gr	Pb Sd (mg/kg)	Pb Sl+Cl	Zn Gr	Zn Sd (mg/kg)	Zn Sl+Cl	Sn Gr	Sn Sd (mg/kg)	Sn Sl+Cl
1	5/21/91	<10	86	*	55.12	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	0.15	*	0.18	Abs.	*
2	5/21/91	*	157	531	311.84	*	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	Abs.	*	0.18	0.29	*	Abs.	Abs.
3	5/21/91	*	227	726	402.65	*	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	Abs.	*	0.19	0.38	*	Abs.	Abs.
4	5/21/91	*	32	279	103.57	*	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	Abs.	*	0.12	0.20	*	Abs.	Abs.
5	5/21/91	*	18	*	18.00	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.
6	5/21/91	*	21	*	21.00	*	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	Abs.	*	Abs.	Abs.

Appendix A-17. Results of regulatory agency required predredging substrate analysis of Obexer's Marina sediments. "Gr" is gravel, "Sd" is sand, "Sl+Cl" is silt + clay fraction; "O&G" is oil and grease. Chemical analysis was by Chemax Laboratories, Sparks, Nv. Data courtesy Lahontan.

	RAW SED														
Core Site & (Depth)	Collected	% Gr	% Sd	%Sl+Cl	TKN Gr	TKN Sd (mg/kg)	TKN Sl+Cl	Oxid. N. Gr	Oxid. N. Sd (mg/kg)	Oxid. N. Sl+Cl	TP Gr	TP Sd (mg/kg)	TP Sl+Cl	sBAFE Gr	sBAFE Sd (mg/kg)	sBAFE Sl+Cl
In Marina - 1		*	*	*	66	250	196	<0.2	<0.2	<0.2	111	364	443	0.64	<.2	<.2
Outside Marina - 2		*	*	*	114	98	157	<0.2	<0.2	<0.2	119	371	472	0.77	<.2	0.26

	RAW SED															
Core Site & (Depth)	Collected	% Gr	% Sd	%Sl+Cl	O & G Gr	O & G Sd (mg/kg)	O & G Sl+Cl	Cd Sd (mg/kg)	Cd Sl+Cl	Cr Sd (mg/kg)	Cr Sl+Cl	Pb Sd (mg/kg)	Pb Sl+Cl	Zn Sd (mg/kg)	Zn Sl+Cl	Sn Sd (mg/kg)	Sn Sl+Cl
In Marina - 1		*	*	*	<10	340	265	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.
Outside Marina - 2		*	*	*	20	45	40	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.	Abs.

Appendix A-16. Results of regulatory agency required predredging substrate analysis of Sunnyside Marina sediments. "Gr" is gravel, "Sd" is sand, "Sl+Cl" is silt + clay fraction; "O & G is oil and grease; "LD" is analytical limit of detection. Chemical analysis was by Chemax Laboratories, Sparks, Nv. Data courtesy Lahontan.

	RAW SED										
Core Site & (Depth) Collected	% Gr	% Sd	%Sl+Cl	TKN Sd (mg/kg)	TKN Sl+Cl	Oxid. N. Sd (mg/kg)	Oxid. N. Sl+Cl	TP Sd (mg/kg)	TP Sl+Cl	sBAFE Sd (mg/kg)	sBAFE Sl+Cl
Marina No. -1	1%	82%	18%	223	571	0.21	0.24	739	925	0.93	3.10
Mid-Marina - 2	1%	41%	58%	234	150	0.09	0.41	700	970	0.17	3.30
Marina - 3	42%	47%	11%	392	663	0.25	0.20	842	1040	0.34	0.93
Outside Marina-4	0%	97%	3%	231	*	0.10	*	453	*	<.1	*

	RAW SED										
Core Site & (Depth) Collected	O & G Sd (mg/kg)	O & G Sl+Cl	Cd Sd (mg/kg)	Cd Sl+Cl	Cr Sd (mg/kg)	Cr Sl+Cl	Pb Sd (mg/kg)	Pb Sl+Cl	Zn Sd (mg/kg)	Zn Sl+Cl	Sn Sd (mg/kg)	Sn Sl+Cl
Marina No. -1	732	635	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	0.25	<0.1	<0.1
Mid-Marina - 2	526	526	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	0.13	<0.1	0.12
Marina - 3	574	619	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	0.18	<0.1	<0.1
Outside Marina-4	154	*	<0.1	*	<0.1	*	<0.2	*	<0.1	*	<0.1	*
			LD 0.1mg/kg		LD 0.1mg/kg		LD 0.2 mg/kg		LD 0.1mg/kg		LD 0.1mg/kg	

Appendix A-15. Results of regulatory agency required predredging substrate analysis of Fleur Du Lac sediments. "Gr" is gravel; "Sd" is sand; "Sl" is silt; "Sl+Cl" is silt + clay fraction; "O & G" is oil and grease; "LD" is analytical limit of detection. Chemical analysis was by Chemax Laboratories, Sparks, Nv. Data courtesy Lahontan.

		RAW SED														
Core Site & (Depth)	Collected	% Gr	% Sd	%Sl+Cl	TKN Gr	TKN Sd (mg/kg)	TKN Sl+Cl	Oxid. N. Gr	Oxid. N. Sd (mg/kg)	Oxid. N. Sl+Cl	TP Gr	TP Sd (mg/kg)	TP Sl+Cl	sBAFE Gr	sBAFE Sd (mg/kg)	sBAFE Sl+Cl
Harbor -1	5/29/90	*	*	*	5590	1600	1910	<.2	<.2	<.2	100	660	560	*	0.22	<.2
Harbor -2	5/29/90	*	*	*	96	21	60	<.2	<.2	<.2	198	306	628	<.2	<.2	<.2
East of Pier -3	5/29/90	*	*	*	103	58	21	<.2	0.51	0.64	200	520	640	<.2	<.2	*
West of Pier - 4	5/29/90	*	*	*	139	154	50	<.2	<.2	0.52	266	273	548	<.2	<.2	*
Lake -5	5/29/90	*	*	*	103	44	237	<.2	0.71	1.10	127	402	530	<.2	<.2	*

		RAW SED																				
Core Site & (Depth)	Collected	% Gr	% Sd	%Sl+Cl	O & G Gr	O & G Sd (mg/kg)	O & G Sl+Cl	Cd Gr	Cd Sd (mg/kg)	Cd Sl+Cl	Cr Gr	Cr Sd (mg/kg)	Cr Sl+Cl	Pb Gr	Pb Sd (mg/kg)	Pb Sl+Cl	Zn Gr	Zn Sd (mg/kg)	Zn Sl+Cl	Sn Gr	Sn Sd (mg/kg)	Sn Sl+Cl
Harbor -1	5/29/90	*	*	*	130	465	380	*	<.05	<.05	*	<0.2	<0.2	*	<0.2	<0.2	*	<0.2	<0.2	*	<0.2	<0.2
Harbor -2	5/29/90	*	*	*	59	110	1300	<.05	<.05	*	<0.2	<0.2	*	<0.2	<0.2	*	<0.2	<0.2	*	<0.2	<0.2	*
East of Pier -3	5/29/90	*	*	*	104	19	<10	<.05	<.05	*	<0.2	<0.2	*	<0.2	<0.2	*	<0.2	<0.2	*	<0.2	<0.2	*
West of Pier - 4	5/29/90	*	*	*	6	32	<10	<.05	<.05	<.05	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Lake -5	5/29/90	*	*	*	36	24	*	<.05	<.05	<.05	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
									LD .05mg/kg			LD .2 mg/kg			LD .2 mg/kg			LD .2 mg/kg			LD .2 mg/kg	

Appendix A-14. Results of regulatory agency required predredging substrate analysis of Tahoe Keys East Channel and lagoon sediments. "Gr" is gravel; "Sd" is sand; "Sl" is silt; "Sl+Cl" is silt + clay fraction; "O & G" is oil and grease; "LD" is analytical limit of detection. Chemical analysis was by Chemax Laboratories, Sparks, Nv. Data courtesy Lahontan.

		RAW SED														
Core Site & (Depth)	Collected	% Gr	% Sd	%Sl+Cl	TKN Sd	TKN Sl+Cl (mg/kg)	TKN Total	Oxid. N. Sd	Oxid. N. Sl+Cl (mg/kg)	Oxid. N. Total	TP Sd	TP Sl+Cl (mg/kg)	TP Total	sBAFE Sd	sBAFE Sl+Cl (mg/kg)	sBAFE Total
Channel - 1	7/8/92	1%	64%	35%	673	1380	923	<.2	<.5	0.31	<.1	243	85.97	0.47	0.60	0.52
Channel - 2	7/8/92	3%	85%	12%	592	1770	738	<.2	<.5	0.24	<.1	5	0.74	0.52	1.20	0.60
Channel - 3	7/8/92	3%	84%	13%	168	1630	364	<.2	0.50	0.24	0.16	13	1.88	0.25	0.48	0.28
Channel - 4	7/8/92	1%	84%	15%	1080	1070	1078	<.2	0.65	0.27	0.11	27	4.18	0.44	0.36	0.43
Channel - 5	7/8/92	0%	93%	7%	137	724	178	<.2	1.20	0.27	0.31	26	2.11	0.13	0.19	0.13
Lagoon - 1	6/25/92	8%	86%	6%	296	1260	359	<.04	0.29	0.06	0.04	0	0.04	0.25	0.13	0.24
Lagoon - 2	6/25/92	5%	84%	11%	149	332	170	0.13	0.25	0.14	0.01	0	0.01	0.7	2	0.85

		RAW SED															
Core Site & (Depth)	Collected	% Gr	% Sd	%Sl+Cl	O & G Sd	O & G Sl+Cl (mg/kg)	O & G Total	Cd Sd (mg/kg)	Cd Sl+Cl	Cr Sd (mg/kg)	Cr Sl+Cl	Pb Sd (mg/kg)	Pb Sl+Cl	Zn Sd (mg/kg)	Zn Sl+Cl	Sn Sd (mg/kg)	Sn Sl+Cl
Channel - 1	7/8/92	1%	64%	35%	512	928	659	<.001	<.001	<0.1	<0.1	<.01	<.01	<0.1	0.12	<0.1	<0.1
Channel - 2	7/8/92	3%	85%	12%	343	383	348	<.001	<.001	<0.1	<0.1	<.01	<.01	<0.1	0.11	<0.1	<0.1
Channel - 3	7/8/92	3%	84%	13%	143	384	175	<.001	<.001	<0.1	<0.1	<.01	<.01	<0.1	<0.1	<0.1	<0.1
Channel - 4	7/8/92	1%	84%	15%	150	252	165	<.001	<.001	<0.1	<0.1	<.01	<.01	<0.1	<0.1	<0.1	<0.1
Channel - 5	7/8/92	0%	93%	7%	<10	24	11	<.001	<.001	<0.1	<0.1	<.01	<.01	<0.1	<0.1	<0.1	<0.1
Lagoon - 1	6/25/92	8%	86%	6%	287	355	291	<.001	<.001	<0.1	<0.1	<.01	<.01	0.1	0.14	<0.1	<0.1
Lagoon - 2	6/25/92	5%	84%	11%	44	96	50	<.001	<.001	<0.1	<0.1	<.01	<.01	<0.1	<0.1	<0.1	<0.1
								LD .001mg/kg		LD .1mg/kg		LD .01mg/kg		LD .1mg/kg		LD .1mg/kg	

Appendix A-13. Results of TRG grain size analysis of selected core subsection sediments.

Sample	Section	Gravel and Cobble % > 2mm	Med-Coarse Sand % <2mm and >250μm	Fine-Very Fine Sand % <250μm and >63μm	Silt and Clay % <63μm
T. Keys Lagoons	1-3	22	58	19	2
T. Keys Lagoons	1-4	28	42	27	3
T. Keys Lagoons	2b-2	1	54	37	8
T. Keys Lagoons	2b-3	30	55	12	3
post-dr. T. Keys Lag.	1-1	2	78	18	1
Crystal Shores East	1-4	19	61	16	4
Crystal Shores East	2-2	*	24	74	2
Crystal Shores East	2-4	1	13	66	20
Crystal Shores East	3-1	12	56	31	1
post-dr. Crystal Sh. E.	1b-1	4	48	35	12
post-dr. Crystal Sh. E.	2-1	3	29	57	11
Fleur du lac	1-6	71	15	14	1
Fleur du lac	3b-2	47	49	4	0
post-dr. Fleur du lac	1b-1	5	23	55	16
post-dr. Fleur du lac	1b-2	0	2	39	59
Tahoe Boat Co.	3a-1	0	14	43	43
Tahoe Boat Co.	3a-2	0	15	41	44
Tahoe Boat Co.	3a-3	0	21	35	44

Appendix A-12. Results of TRG analysis of washed sands produced by the sand classification system used at Tahoe Keys for solids separation during the 1993 dredging of the lagoons. A #120 mesh screen (> 120μ particle size retention) or a #200 mesh screen (>75μ particle size retention) were used to separate sands into 2 piles. The two grades of sand were mixed in large storage piles on site "mixed pile". Samples of beach sand from Tahoe Keys were collected for comparison.

	RAW SED				ELUTRIATE TEST WATER CONCENTRATION								WT. IN ELUTRIATE TEST WATER PER WT. SED. SHAKEN (wt/wt sed.)								
Sand	TN	TP	BAP	LOI	S. Sed.	NO3	NH4	TKN	SRP	BAP	TRP	TP	S.Sed.	NO3	NH4	TKN	TN	SRP	BAP	TRP	TP
Sample	(µg/g)	(µg/g)	(µg/g)	(mg/g)	(g/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	(µg/l)	mg/g	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)
#1 (beach sand)	80	86	31	5.69	0.17	35	18	1684	4	55	38	700	0.48	0.10	0.05	4.72	4.82	0.01	0.15	0.11	1.96
#2 (#120 grade)	50	*	12	3.77	0.14	8	13	286	9	28	54	290	0.34	0.02	0.03	0.69	0.70	0.02	0.07	0.13	0.69
#3 (#200 grade)	80	*	16	4.16	0.15	28	12	677	6	23	34	355	0.44	0.08	0.03	1.95	2.03	0.02	0.07	0.10	1.02
#4 (mixed pile)	80	*	14	6.52	0.22	8	1	538	5	30	52	420	0.67	0.02	0.00	1.67	1.69	0.02	0.09	0.16	1.30
#5 (mixed pile)	100	*	33	6.30	0.12	8	9	390	1	25	11	196	0.35	0.02	0.03	1.17	1.19	0.00	0.08	0.03	0.59
#6 (mixed pile)	130	*	19	5.71	0.10	10	1	746	6	37	10	207	0.32	0.03	0.00	2.38	2.41	0.02	0.12	0.03	0.66
#7 (mixed pile)	100	*	15	5.97	0.28	7	10	1021	8	5	68	473	0.84	0.02	0.03	3.07	3.09	0.02	0.01	0.20	1.42
#35 (mixed pile)	130	200	60	12.02	0.53	9	79	1599	2	41	68	1292	1.54	0.03	0.23	4.65	4.67	0.01	0.12	0.20	3.76
#36 (mixed pile)	370	333	193	17.95	0.04	7	123	845	2	7	14	270	0.14	0.02	0.39	2.66	2.68	0.01	0.02	0.04	0.85
#37 (#120 grade)	90	255	26	9.30	0.32	11	11	1177	7	21	131	784	0.90	0.03	0.03	3.31	3.34	0.02	0.06	0.37	2.21
#38 (#200 grade)	100	763	12	6.20	0.10	7	13	363	2	0	18	192	0.28	0.02	0.04	1.00	1.02	0.01	0.00	0.05	0.53
#39 (beach sand)	160	173	12	2.77	0.14	896	1710	8730	140	14	214	945	0.35	2.19	4.19	21.37	23.56	0.34	0.03	0.52	2.31
#40 (beach sand)	90	110	17	1.45	0.13	528	277	1470	14	12	61	573	0.30	1.18	0.62	3.29	4.47	0.03	0.03	0.14	1.28
#41 (beach sand)	100	90	17	1.98	0.02	100	346	1583	1	0	5	107	0.05	0.23	0.78	3.58	3.80	0.00	0.00	0.01	0.24
#42 (beach sand)	90	109	14	1.79	0.03	109	331	1637	1	46	7	158	0.08	0.25	0.77	3.79	4.05	0.00	0.11	0.02	0.37
#43 (beach sand)	70	93	7	1.79	0.00	433	342	1433	9	0	15	72	0.00	0.99	0.78	3.28	4.27	0.02	0.00	0.03	0.16

Appendix A-11. Results of regulatory agency required monitoring outside the silt curtain enclosed dredging area at Crystal Shores East, NV. during 1993 excavator dredging. Data courtesy of T.R.P.A.

Station	Date	Time	Turbidity (NTU)	NO3-N (μg/l)	NO2-N (μg/l)	NH4-N (μg/l)	TKN (μg/l)	TP (μg/l)	TFe (μg/l)
Background	10/1/93	16:00	0.16	*	*	*	*	*	*
1 ft outside screen	10/8/93	9:00	0.17	*	*	*	*	*	*
	10/8/93	15:30	1.6	<20	<20	<50	120	14	150
	10/9/93	9:30	3.4	<20	<20	<50	150	26	430
	10/9/93	16:30	1.5	<20	20	<50	130	14	180
	10/10/93	9:30	0.34	<20	<20	<50	88	<10	<50
	10/11/93	9:00	0.27	<20	<20	<50	98	<10	<50
	10/11/93	16:00	1.05	<20	<20	<50	320	14	110
	10/12/93	8:50	0.16	<20	<20	<50	110	<10	<50
	10/12/93	15:50		<20	<20	<50	110	<10	56
	10/13/93	9:10	0.29	<20	<20	<50	100	<10	<50
	10/13/93	15:20	0.5	<20	<20	<50	95	<10	59
50 ft outside screen	10/8/93	9:00	0.15	<20	<20	<50	*	*	*
	10/8/93	15:30	0.18	<20	<20	<50	120	<10	<50
	10/9/93	9:30	0.35	<20	<20	<50	130	12	96
	10/9/93	16:30	0.75	290	<20	<50	91	10	69
	10/10/93	9:30	0.25	<20	<20	<50	86	<10	<50
	10/11/93	9:00	0.22	<20	<20	<50	85	<10	60
	10/11/93	16:00	1.2	<20	<20	<50	150	<10	100
	10/12/93	8:50	0.2	<20	<20	<50	100	<10	<50
	10/12/93	15:50	0.17	<20	<20	<50	130	<10	<50
	10/13/93	9:10	0.3	<20	<20	<50	100	<10	<50
	10/13/93	15:20	0.55	<20	<20	<50	95	<10	130

Appendix A-10. Results of regulatory agency required monitoring inside and outside the silt curtain enclosed dredging areas, during dragline and clamshell dredging at Fleur Du Lac, 1993. Data courtesy of Lahontan.

Station	Date	Turbidity (NTU)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	TP (µg/l)	TFe (µg/l)
Inside Harbor	8/4/93	4.5	<20	<20	<50	290	20	980
	8/12/93	103			74	820	270	7200
	8/13/93	91	<20	<20	70	810	190	7000
	8/14/93	99	<20	<20	91	880	<10	<600
	8/15/93	66	<20	<20	75	540	140	5300
	8/26/93	31	<20	<20	<50	470	100	4000
	8/28/93	35	<20	<20	<50	420	80	3300
	8/29/93	18	<20	<20	<50	720	130	2900
	8/31/93	8.3	1400	<20	<50	250	40	1100
	9/1/93	6.2	21	<20	<50	290	33	900
	9/2/93	5.2	<20	<20	<50	230	32	790
	9/3/93	8	<20	<20	<50	450	44	970
	9/7/93	4.4	23	<20	<50	450	39	780
	9/8/93	5.7	*	*	*	*	*	*
	9/9/93	35	*	*	*	*	*	*
	9/10/93	48	*	*	*	*	*	*
	9/21/93	1.9	*	*	*	*	*	*
	9/22/93	2.5	*	*	*	*	*	*
	9/23/93	2	*	*	*	*	*	*
	9/27/93	1.2	<20	<20	<50	170	22	200
10ft Outside Screen	8/12/93	0.09	<20	<20	<50	110	11	<50
	8/13/93	0.19	<20	<20	<50	90	<10	<50
	8/14/93	0.08	<20	<20	<50	79	<10	<50
	8/15/93	0.62	<20	<20	<50	110	<10	170
	8/26/93	0.24	<20	<20	<50	110	20	<50
	8/28/93	0.4	<20	<20	<50	110	<10	<50
	8/29/93	0.32	<20	<20	<50	78	<10	<50
	8/31/93	0.36	<20	<20	<50	130	14	<50
	9/1/93	0.23	<20	<20	<50	83	13	<50
	9/2/93	0.15	680	<20	<50	80	11	<50
	9/3/93	0.21	<20	<20	<50	140	10	<50
	9/7/93	0.23	<20	<20	<50	100	<10	<50
	9/8/93	0.38	*	*	*	*	*	*
	9/9/93	0.26	*	*	*	*	*	*
	9/10/93	0.33	*	*	*	*	*	*
	9/27/93	0.18	*	*	*	*	*	*
50ft Outside Screen	8/12/93	*	<20	<20	<50	87	22	<50
So. Pier Inside Screen	9/17/93	78	*	*	*	*	*	*
	9/18/93	33	*	*	*	*	*	*
	9/19/93	171	*	*	*	*	*	*
	9/20/93	192	*	*	*	*	*	*
	9/21/93	72	*	*	*	*	*	*
	9/22/93	46	*	*	*	*	*	*
	9/23/93	28	*	*	*	*	*	*
	9/27/93	7.9	<20	<20	<50	120	28	370
So. Pier 10ft Outside Screen	9/17/93	0.93	*	*	*	*	*	*
	9/18/93	0.92	*	*	*	*	*	*
	9/19/93	0.5	*	*	*	*	*	*
	9/20/93	0.93	*	*	*	*	*	*
	9/21/93	0.69	*	*	*	*	*	*
	9/22/93	0.4	*	*	*	*	*	*
	9/23/93	0.24	*	*	*	*	*	*
	9/27/93	0.3	*	*	*	*	*	*

Appendix A-9. Results of regulatory agency required monitoring outside the silt curtain enclosed discharge area, and 10 ft. away from the VMI 612 cutter at the surface, during the 1993 dredging of the Tahoe Keys lagoons. Data courtesy of Lahontan.

Station	Date	Time	Turbidity (NTU)	NO3-N (µg/l)	NO2-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	TP (µg/l)	TFe (µg/l)
Discharge Area	8/12/93		0.71	<20	<20	<50	260	21	190
C II	8/12/93		3.25	<20	<20	<50	290	17	660
Pond 3	8/26/93		11	<20	<20	<50	320	24	800
1ft Outside Screen	8/26/93		1.9	<20	<20	<50	470	23	210
	8/26/93		1.6	<20	<20	<50	240	18	200
	8/27/93		1.9	<20	<20	<50	230	26	160
	8/28/93	9:50	6.4	<20	<20	<50	230	31	470
	8/28/93	14:50	2	<20	<20	<50	220	21	230
	9/1/93		3.4	<20	<20	<50	200	92	150
	9/2/93		2	<20	<20	<50	220	21	270
	9/7/93		3	<20	<20	<50	300	19	240
	9/10/93		1.5	<20	<20	<50	230	16	330
	9/17/93		0.9	<20	<20	<50	270	26	390
	9/24/93		2.8	<20	<20	<50	200	34	440
	9/27/93		1.7	<20	<20	<50	250	17	360
	9/30/93		6.1	<20	<20	<50	310	32	970
50ft Outside Screen	8/26/93		1.6	<20	<20	<50	220	23	180
	8/27/93		1.8	<20	<20	<50	230	27	200
	8/28/93	10:00	2.1	<20	<20	<50	280	20	240
	8/28/93	14:55	1.9	<20	<20	<50	210	18	220
	9/1/93		2.5	<20	<20	<50	210	50	140
	9/2/93		1.9	<20	<20	<50	200	21	300
	9/7/93		2	<20	<20	<50	290	28	260
	9/10/93		1.8	<20	<20	<50	330	16	490
	9/17/93		2.2	<20	<20	<50	270	25	490
	9/24/93		1.3	<20	<20	<50	230	16	220
	9/27/93		1.7	<20	<20	<50	250	21	380
	9/30/93		2.7	<20	110	<50	360	19	420
10ft from Auger	8/26/93		5.8	<20	<20	<50	300	37	910
	8/26/93		11	<20	<20	<50	320	20	750
	8/27/93	9:40	19	<20	<20	<50	330	43	1500
	8/27/93	16:30	29	<20	<20	<50	380	56	3100
	9/2/93		23	<20	<20	<50	330	32	1200
	9/17/93		44	<20	<20	<50	350	86	3600
	9/24/93		25	<20	<20	<50	260	63	1900
	9/27/93		6	<20	<20	<50	260	34	640
	9/30/93		6.4	<20	<20	<50	690	27	740

Appendix A-8. Results of regulatory agency required monitoring outside the silt curtain enclosed discharge area, in the open lake near the north end of the Tahoe Keys East Channel, 10 ft. away from the VMI 612 cutter at the surface, and at the discharge pipe from the spoils settling ponds during the 1992 dredging of the Tahoe Keys East Channel. Data courtesy of Lahontan.

Station	Date	AM/PM	Turbidity (NTU)	Oxidized N (µg/l)	TKN (µg/l)	TP (µg/l)	TFe (µg/l)
1 ft from spoils	9/14/92		2	<20	310	18	160
ponds silt screen	9/15/92	AM	2.5	<20	280	13	240
	9/15/92	PM	2.7	<20	250	26	370
	9/16/92	AM	3.3	<20	260	26	330
	9/22/92		2.9	<20	350	30	370
	9/29/92		4.5	59	330	50	360
	10/20/92		1.1				
	10/20/92		0.58				
	10/21/92		1				
	10/22/92		1.8				
	11/2/92		4.9				
	11/5/92		8	<20	310	29	800
50 ft from spoils	9/14/92		2.3	<20	300	16	170
ponds silt screen	9/15/92	AM	2.2	<20	260	<10	200
	9/15/92	PM	2.8	<20	270	23	380
	9/22/92		1.7	82	280	35	310
	9/29/92		1.7	<20	280	50	350
	10/20/92		2.3				
	10/20/92		0.55				
	10/21/92		2.2				
	10/22/92		1				
	11/2/92		4.7				
	11/5/92		7.3	<20	300	38	610
North end of	9/15/92	AM	0.26	<20	79	<10	<50
channel	9/15/92	PM	0.23	<20	120	<10	55
	9/16/92	AM	0.1	<20	95	18	<50
	9/22/92		0.66	<20	120	18	54
	9/29/92		2.8	<20	280	35	1100
	10/20/92		<.1				
	10/20/92		<.1				
	10/22/92		<.1				
	11/2/92		0.18				
	11/5/92		0.56				
10 ft from	8/24/92	Bkgrd		<20	140	24	<50
cutterhead	8/24/92			<20	140	<10	<50
	8/25/92		0.75	<20	160	<24	190
	8/26/92			<20	140	<10	<50
	8/27/92		2.1	<20	140	38	460
	8/28/92		0.3	<20	86	<10	140
	8/29/92		1.6	<20	400	31	430
	8/31/92		3.3	<20	120	19	620
	9/15/92	AM	15	<20	430	28	790
	9/15/92	PM	17	<20	500	<10	4600
	9/16/92	AM	44	<20	780	120	1500
	9/22/92		4.3	<20	390	28	920
	9/29/92		0.15	720	110	18	<50
	10/20/92		0.88				
	10/20/92		5				
	10/21/92		5.3				
	10/22/92		2.6				
	11/5/92		56	<20	910	70	5700
Dicharge from	9/16/92	AM	6.1				
spoils ponds	9/22/92		7.8				
	9/29/92		26				
	10/20/92		12				
	10/21/92		22				
	10/22/92		42				
	11/5/92		43				

Appendix A-7. Results of sampling in Tahoe Keys East Channel prior to dredging which tested the resuspension of turbidity and nutrients following boat passes at different speeds. This test provided information on the magnitude of resuspension from boat traffic over shallow sediments. Samples were collected at the surface immediately before the boat pass, near the bottom 10 seconds after the pass, and again at the surface 30 seconds after the pass. The TRG's research boat R/V Ted Frantz was run at 3mph, 6mph, and 10mph through different sections of the East Channel.

Site	Boat Speed (MPH)	Time before or after pass	Sampling Depth	Turbidity (NTU)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	DP (µg/l)	TP (µg/l)	DBAFe (µg/l)	TBAFe (µg/l)
Mid-Bulkhead East Access Ch.		Pre-test 0730	Surface	2.5	2	11	174	14	30	48	147
No. End Bulkhead	10	30 sec. before	Surface	4.5	2	5	223	14	51	54	383
East Access Ch.	10	10 sec. after	Near bottom	6.5	2	7	345	17	94	55	950
	10	30 sec. after	Surface	21	3	7	568	15	132	53	1762
Mid-Bulkhead	6	30 sec. before	Surface	3.8	2	4	208	15	42	49	243
East Access Ch.	6	10 sec. after	Near bottom	4.8	3	7	320	16	54	48	585
	6	30 sec. after	Surface	3.4	2	5	247	17	43	49	290
So. End Bulkhead	3	30 sec. before	Surface	2.8	3	5	274	18	30	60	162
East Access Ch.	3	10 sec. after	Near bottom	2.5	3	7	320	17	34	58	187
	3	30 sec. after	Surface	2.6	3	6	260	18	36	57	163
Outside Bulkhead	6	30 sec. before	Surface	3.2	2	3	131	16	38	39	161
East Access Ch.	6	10 sec. after	Near bottom	4	2	3	163	18	54	36	291
	6	30 sec. after	Surface	5.5	2	3	270	18	92	40	984
	6	13 min. after	Surface	3.7	2	2	138	14	42	37	119

Appendix A-6. Results of water column sampling around VMI 612 horizontal cutter suction dredge during testing 30 September 1993. Testing entailed operating dredge with different combinations of engine RPM (1300 and 1700 RPM) and cutter pressure (400 and 700 PSI). Samples were collected at 10 ft. distances ahead of the left and right ends of the cutter, and 10 ft. to the left side of the cutter. The test was conducted in a section of channel within the Tahoe Keys lagoons, in front of the Tahoe Keys Marina (refer to App. B. Map 4). The depth to the sediments varied, but was near 7-8 ft. in the channel middle along the dredge path.

Engine (RPM)	Auger Pressure (PSI)	Sampling Location	Distance Away (ft)	Depth (ft)	Turbidity (NTU)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	SRP (µg/l)	TRP (µg/l)	TP (µg/l)
1300	400	A (mid-front auger)	20	0	6.5	3	70	308	*	8	57
				3	6.2	3	65	332	*	8	44
				6	4.95	3	42	326	*	8	33
		B (right-front auger)	10	0	7.2	3	23	270	*	8	42
				3	6.55	3	34	292	*	8	42
				4	5.9	3	34	334	*	7	46
		C (left-front auger)	10	0	5.6	3	31	299	*	7	42
				3	5.35	3	23	298	*	6	34
				6	6.1	3	57	509	*	9	56
		D (left-side auger)	10	0	6.1	3	23	331	*	7	35
				3	5.6	3	28	323	*	7	34
				6	6.25	3	27	297	*	7	35
1700	400	B (right-front auger)	10	0	6.75	3	31	292	*	7	46
				3	5.7	3	27	263	*	6	36
				6	5.25	3	23	288	*	5	31
		C (left-front auger)	10	0	11	3	24	415	6	8	66
				3	6.1	3	32	282	4	7	38
				5	6.95	2	31	330	6	8	47
		D (left-side auger)	10	0	4.75	3	31	304	*	6	30
				3	4.5	3	34	308	*	7	30
				5	4.3	3	37	349	*	8	37
1300	700	B (right-front auger)	10	0	6.35	3	45	616	*	10	59
				3	22	3	45	1030	*	10	168
				5	24	3	48	939	*	14	203
		C (left-front auger)	10	0	12	3	35	448	6	10	92
				3	12	3	31	520	6	20	107
				5	12.5	2	32	493	8	10	101
		D (left-side auger)	10	0	10	3	32	397	*	7	88
				3	10.5	3	32	381	*	10	84
				5	10	3	34	457	*	10	90
1700	700	B (right-front auger)	10	0	5.3	3	40	396	*	7	46
				3	13	3	35	554	*	10	111
				5	18	3	38	613	*	12	183
		C (left-front auger)	10	0	16	3	37	683	9	11	127
				3	10	3	40	437	6	10	72
				5	13	3	41	568	11	11	103
		D (left-side auger)	10	0	12	3	44	445	*	10	105
				3	10	3	38	439	*	11	85
				4	72	3	200	2919	*	16	1027

* - Indicates not analyzed

Appendix A-5 Cont'd. Results of TRG monitoring during and following excavator dredging at Crystal Shores East, NV., 1993-94: (b) spoils dewatering sites (refer to App. B. Map 7).

(b)

Station Spoils Dewatering Area	Date	Time	Turbidity (NTU)	Chlorophyll a (µg/l)	Pheophytin (µg/l)	NO2NO3 (µg/l)	NH4-N (µg/l)	TKN (µg/l)	SRP (µg/l)	TRP (µg/l)	TP (µg/l)
11	10/8/93		0.35	*	*	3	3	75	1	2	19
11	10/13/93		0.21	0.24	0.05	4	1	82	1	3	16
12	10/8/93		0.31	*	*	3	5	43	1	2	18
Interstitial - 1	10/8/93		*	*	*	28	33	*	2	*	*
Interstitial - 2	10/8/93		*	*	*	3	1	*	2	*	*
Interstitial - 3	10/8/93		*	*	*	21	6	*	18	*	*
Interstitial - 4	10/8/93		*	*	*	35	1	*	2	*	*
Nearshore (1 in. deep) - A	10/8/93		*	*	*	8	18	*	1	*	*
Nearshore (1 in. deep) - B	10/8/93		*	*	*	1062	0	*	1	*	*
Nearshore (1 in. deep) - C	10/8/93		*	*	*	125	8	*	1	*	*
Nearshore (1 in. deep) - D	10/8/93		*	*	*	7	1	*	1	*	*
Nearshore (1 in. deep) - E	10/8/93		*	*	*	9	2	*	*	*	*

Appendix A-5. Results of TRG monitoring during and following excavator dredging at Crystal Shores East, NV.,1993-94: (a) harbor sites (refer to App. B. Map 7).

(a)

Station Harbor Sites	Date	Time	Turbidity (NTU)	Chlorophyll a (µg/l)	Pheophytin (µg/l)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	SRP (µg/l)	TRP (µg/l)	TP (µg/l)
1	9/29/93		0.43	0.14	0.08	3	2	70	1	2	17
1	10/6/93		17.5	*	*	*	*	*	*	*	*
1	10/8/93		165	*	*	154	60	1677	13	89	852
1	10/13/93		195	*	*	67	66	1326	4	78	1294
1	11/1/93		2.2	*	*	8	1	52	2	6	28
1	11/10/93	1230	0.4	0.39	0.11	6	1	60	1	*	9
1	11/10/93	1645	0.55	*	*	2	1	49	2	*	9
1	11/11/93		0.35	*	*	*	*	*	*	*	*
1a	11/10/93	1645	2.75	*	*	4	0	67	1	*	24
1a	11/11/93		0.32	*	*	*	*	*	*	*	*
2	9/29/93		0.31	0.17	0.05	3	3	72	1	2	16
2	10/6/93		0.58	*	*	*	*	*	*	*	*
2	10/8/93		3.2	*	*	3	1	70	1	5	24
2	10/13/93		1.05	0.25	0.12	2	1	48	1	3	24
2	11/1/93		0.44	0.3	0.05	4	0	24	1	3	19
2	11/10/93	1645	0.25	*	*	3	1	34	1	*	8
2	11/11/93		0.24	*	*	*	*	*	*	*	*
3	9/29/93		0.26	0.14	0.06	3	1	58	0	1	15
3	10/6/93		0.27	*	*	*	*	*	*	*	*
3	10/8/93		0.81	*	*	2	1	47	1	2	15
3	10/13/93		0.17	*	*	*	*	*	*	*	*
4	9/29/93		0.37	0.21	0.07	3	41	116	1	3	25
4	10/6/93		28	*	*	*	*	*	*	*	*
4	10/13/93		195	*	*	*	*	*	*	*	*
4	11/1/93		3.6	0.37	0.1	*	*	*	*	*	*
4	11/10/93	1230	17	0.5	0.25	17	2	117	3	*	93
4	11/10/93	1645	14.5	*	*	11	1	102	3	*	85
4	11/11/93	1230	0.65	*	*	2	1	43	1	*	9
4	7/15/94		*	0.32	0.32	1	0	116	2	*	21
4	9/6/94		*	1.62	0.43	*	*	*	*	*	*
4a	10/8/93		145	*	*	114	101	1314	20	55	846
5	9/29/93		0.32	0.17	0.05	3	2	40	1	2	19
5	10/6/93		0.77	*	*	*	*	*	*	*	*
5	10/8/93		0.24	*	*	2	1	54	1	3	18
5	10/13/93		0.23	0.21	0.09	2	1	51	1	2	29
5	11/1/93		0.31	0.27	0.09	*	*	*	*	*	*
5	11/10/93	1230	1.1	0.57	0.13	3	2	95	2	*	15
5	11/10/93	1645	0.89	*	*	3	1	42	1	*	12
5	11/11/93		0.24	*	*	*	*	*	*	*	*
6	9/29/93		0.33	0.18	0.06	3	3	27	1	2	16
6	10/6/93		0.57	*	*	*	*	*	*	*	*
6	10/8/93		0.23	*	*	3	2	57	1	2	16
6	10/13/93		0.23	0.26	0.04	*	*	*	*	*	*
7	9/29/93		1.75	0.38	0.28	3	1	76	1	2	24
7	10/8/93		0.54	*	*	3	2	90	1	2	17
7	11/10/93	1230	1.7	0.47	0.35	*	*	*	*	*	*
7	11/11/93		0.88	*	*	*	*	*	*	*	*
7	7/15/94		*	1.73	0.35	1	0	206	2	*	15
8	9/29/93		0.65	0.15	0.08	3	3	78	1	2	17
9	10/8/93		0.26	*	*	3	1	26	1	2	16
9	10/13/93		0.22	*	*	*	*	*	*	*	*
9	11/10/93	1645	0.4	*	*	2	1	50	1	*	11
10	10/8/93		0.6	*	*	2	0	31	1	2	19
10	10/13/93		0.18	*	*	*	*	*	*	*	*
10	11/10/93	1230	0.41	*	*	*	*	*	*	*	*
10	11/10/93	1645	0.24	*	*	2	0	42	1	*	8
13**	10/8/93		4.1	*	*	3	1	34	1	6	28
13**	10/13/93		6.15	0.3	0.09	2	1	50	1	8	45

* - Indicates not analyzed

** - Sampled near bottom

Appendix A-4 Cont'd. Results of TRG monitoring during and following dragline and clamshell dredging at Fleur Du Lac 1993-94 (refer to App. B. Maps 5 and 6).

Station	Date	Time	Turbidity (NTU)	Chlorophyll a (µg/l)	Pheophytin (µg/l)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	SRP (µg/l)	TRP (µg/l)	TP (µg/l)
7	9/17/93		41	*	*	26	2	249	2	27	161
7	9/20/93		58	*	*	35	1	340	2	46	193
7	9/22/93		26	*	*	19	*	259	1	37	125
7	9/27/93		4.5	0.2	0.08	2	2	59	3	*	14
7	10/7/93		0.8	*	*	2	2	81	1	*	9
7	10/12/93		0.26	0.18	0.07	*	*	*	*	*	*
7	11/8/93		0.2	*	*	2	1	43	1	*	8
8	9/17/93		1	0.11	0.09	6	2	51	1	3	17
8	9/20/93		0.23	*	*	4	1	47	1	2	12
8	9/22/93		0.23	*	*	6	3	49	3	2	11
8	9/27/93		0.21	0.07	0.05	3	2	62	1	*	7
8	10/7/93		0.14	*	*	2	1	44	1	*	6
8	10/12/93		0.28	0.13	0.04	*	*	*	*	*	*
9	10/7/93		0.4	*	*	2	0	47	1	*	9
Synoptic											
No. Transect -10ft.	9/2/93		0.21	0.07	0.05	0	0	*	*	3	8
No. Transect -50ft.	9/2/93		0.22	0.05	0.02	0	0	*	*	3	9
No. Transect -100ft.	9/2/93		*	0.07	0.04	0	0	*	*	3	9
Mid. Transect - 10ft.	9/2/93		0.24	0.11	0.05	0	1	*	*	3	8
Mid. Transect - 50ft.	9/2/93		0.23	0.06	0.06	0	1	*	*	3	9
Mid. Transect - 100ft.	9/2/93		0.16	0.06	0.04	0	1	*	*	2	8
So. Transect - 10ft.	9/2/93		0.14	0.06	0.05	1	0	*	*	2	8
So. Transect - 50ft.	9/2/93		0.14	0.05	0.05	0	0	*	*	2	8
So. Transect - 100ft.	9/2/93		0.13	0.06	0.03	0	0	*	*	2	8

* - Indicates not analyzed

Appendix A-4. Results of TRG monitoring during and following dragline and clamshell dredging at Fleur Du Lac 1993-94 (refer to App. B. Maps 5 and 6).

Station	Date	Time	Turbidity (NTU)	Chlorophyll a (μg/l)	Pheophytin (μg/l)	NO2NO3-N (μg/l)	NH4-N (μg/l)	TKN (μg/l)	SRP (μg/l)	TRP (μg/l)	TP (μg/l)
1	8/9/93		*	0.07	0.06	1	0	57	2	*	13
1a	8/19/93		*	*	*	2	2	42	5	*	12
1a	8/25/93		0.63	0.12	0.08	3	3	48	*	4	26
1a	8/30/93		8.6	*	*	7	2	64	*	19	68
1a	9/2/93		28	0.65	0.43	7	16	*	*	89	122
1a	9/9/93		42	10.15	0.37	65	5	359	7	25	172
2	8/9/93		*	0.1	0.06	1	0	69	2	*	11
2	8/16/93		*	*	*	2	3	66	2	*	9
2	8/17/93		*	*	*	2	3	64	2	*	8
2a	8/19/93		*	*	*	2	1	73	2	*	10
2a	8/25/93		0.29	0.07	0.04	2	4	30	*	2	23
2a	8/30/93		0.89	*	*	2	2	64	*	4	28
2a	9/2/93		0.63	0.09	0.05	2	1	*	*	4	11
2a	9/9/93		1.75	0.3	0.15	7	5	72	1	3	22
2a	9/17/93		0.32	0.1	0.06	4	1	52	1	2	14
2a	9/20/93		0.33	*	*	3	1	44	5	3	11
2a	9/27/93		0.21	0.07	0.04	2	0	35	2	*	5
2a	10/7/93		0.26	*	*	2	0	50	1	*	7
2a	10/12/93		0.36	0.15	0.02	*	*	*	*	*	*
3	8/9/93		*	0.14	0.06	1	0	49	2	*	10
3	8/19/93		*	*	*	1	1	51	2	*	5
3	8/25/93		0.2	0.16	*	3	2	63	*	3	25
3	8/30/93		0.91	*	*	2	1	55	*	4	26
3	9/2/93		0.24	0.11	0.05	0	1	*	*	3	8
3	9/9/93		0.23	0.1	0.06	5	3	43	1	3	15
3	9/17/93		0.5	0.13	0.06	4	2	51	1	3	14
3	9/20/93		*	*	*	3	2	60	2	2	14
3	9/27/93		0.32	0.1	0.05	2	1	36	1	*	7
3a	8/16/93		*	*	*	2	2	76	2	*	9
3a	8/17/93		*	*	*	2	2	84	2	*	8
4	8/9/93		*	0.14	0.1	4	0	59	2	*	15
4	8/19/93		*	*	*	5	1	52	4	*	10
4	8/25/93		0.55	0.48	0.38	5	4	76	*	3	26
4	8/30/93		0.44	*	*	6	0	82	*	3	26
4	9/2/93		0.63	0.25	0.16	7	4	*	*	4	14
4	9/9/93		0.37	0.11	0.1	9	20	156	1	3	16
4	9/17/93		0.7	0.12	0.07	3	0	94	1	3	17
4	9/20/93		0.21	*	*	6	3	58	5	3	15
4	9/27/93		0.21	0.13	0.1	4	2	44	2	*	9
4a	8/16/93		*	*	*	2	1	47	2	*	8
4a	8/17/93		*	*	*	1	0	51	2	*	8
5	8/9/93		*	0.1	0.1	18	1	151	7	*	31
5	8/16/93		*	*	*	4	35	361	62	*	132
5	8/17/93		*	*	*	38	16	308	53	*	107
5	8/19/93		*	*	*	30	8	336	53	*	84
5	8/25/93		24	*	*	9	6	85	*	24	167
5	8/26/93		13	*	*	10	5	439	*	17	95
5	8/30/93		11	*	*	9	23	270	*	18	110
5	9/2/93		6.7	0.68	0.2	4	11	*	*	12	27
5	9/9/93		32	8.83	1.74	76	10	325	15	20	142
5	9/16/93		4.2	*	*	*	*	*	*	16	38
5	9/17/93	1030	3.8	*	*	*	*	*	*	*	*
5	9/17/93	1400	2.6	*	*	*	*	*	*	*	*
5	9/22/93		2.6	0.28	0.22	3	6	93	2	*	19
5	9/27/93		1.35	0.6	0.18	2	2	70	3	*	14
5	10/7/93		1.35	*	*	2	0	139	1	*	11
5	10/12/93		0.33	0.18	0.07	*	*	*	*	*	*
5	11/8/93		0.25	*	*	3	2	73	1	*	8
5	6/15/94		*	0.27	0.29	1	2	29	4	5	13
5	7/18/94		*	0.12	0.06	1	1	*	2	*	*
5	9/2/94		*	1.14	1.25	*	*	*	*	*	*
5a	9/20/93		2	*	*	6	2	106	1	9	27
5b	9/17/93	1400	2.3	1.15	0.39	3	17	125	4	7	26
6	8/9/93		*	0.37	0.18	1	1	81	2	*	20

Appendix A-3 Cont'd. Results of TRG monitoring at: (b) spoils impoundment basin sites during1993 hydraulic dredging at Tahoe Keys (refer to App. B Map 4).

(b)

Station Spoils Treatment System	Date	Turbidity (NTU)	Chlorophyll a (µg/l)	Pheophytin (µg/l)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	SRP (µg/l)	TRP (µg/l)	TP (µg/l)
Sand Class. 1st Tank	8/30/93	720	*	*	37	57	11199	*	114	3231
Sand Class. 1st Tank	8/30/93	965	*	*	*	*	*	*	*	*
Sand Class. Effluent	8/30/93	825	*	*	9	52	11332	*	157	4175
Sand Class. Effluent	8/30/93	760	*	*	*	*	*	*	*	*
Pond 1 - site 2	8/25/93	21	*	*	26	35	276	*	20	74
Pond 1 - site 2	8/26/93	15	*	*	26	32	321	*	11	62
Pond 1 - site 2	8/30/93	17	*	*	13	45	168	*	5	74
Pond 1 - site 2	9/3/93	22	1.47	0.54	5	55	240	*	4	84
Pond 1 - site 2	9/22/93	7.35	*	*	4	7	198	1	4	29
Pond 1 - site 2	9/30/93	25	*	*	7	44	354	*	2	103
Pond 1 - site 3	8/30/93	18	*	*	*	*	*	*	*	*
Pond 2 - site 4	8/30/93	5.3	*	*	14	22	170	*	6	21
Pond 2 - site 4	9/3/93	25	1.31	0.71	6	16	263	*	4	101
Pond 2 - site 4	9/22/93	6.65	*	*	3	7	164	1	3	27
Pond 2 - site 4	9/30/93	14.5	*	*	6	28	278	*	2	64
Pond 2 - site 5	8/30/93	4.6	*	*	*	*	*	*	*	*
Pond 3 - site 6	8/25/93	29	*	*	3	3	480	*	24	114
Pond 3 - site 6	8/26/93	*	*	*	3	3	330	*	20	71
Pond 3 - site 6	8/30/93	4.7	*	*	*	*	*	*	*	*
Pond 3 - site 7	8/25/93	27.5	*	*	3	4	541	*	31	110
Pond 3 - site 7	8/26/93	10	*	*	3	4	282	*	14	44
Pond 3 - site 7	8/30/93	4.7	*	*	17	21	202	*	7	26
Pond 3 - site 7	9/3/93	16	1.48	0.6	9	24	213	*	4	69
Pond 3 - site 7	9/22/93	7.9	*	*	4	10	198	1	4	34
Pond 3 - site 7	9/30/93	*	*	*	6	22	290	*	4	91
Inside Silt Curtain	8/25/93	1.4	*	*	5	6	226	*	8	26
Inside Silt Curtain	8/30/93	2.5	*	*	4	16	240	*	7	31
Inside Silt Curtain	9/3/93	2.7	1.34	0.25	4	3	168	*	5	21
Inside Silt Curtain	9/22/93	4.1	*	*	3	1	185	1	7	24
Inside Silt Curtain	9/30/93	17	*	*	3	54	166	*	8	72
Ouside Silt Curtain	8/25/93	1.6	*	*	2	6	273	*	5	27
Ouside Silt Curtain	8/30/93	1.7	*	*	2	9	264	*	5	26
Ouside Silt Curtain	9/3/93	1.6	0.5	0.73	2	7	229	*	6	21
Ouside Silt Curtain	9/22/93	2.25	*	*	3	10	228	4	5	18
Ouside Silt Curtain	9/30/93	3.85	*	*	3	23	254	*	5	22

*- Indicates data not analyzed

Appendix A-3. Results of TRG monitoring at: (a) Tahoe Keys Marina and lagoon sites during 1993 hydraulic dredging (refer to App. B Map 4).

(a)

Station Marina and lagoon sites	Date	Turbidity (NTU)	Chlorophyll a (µg/l)	Pheophytin (µg/l)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	SRP (µg/l)	TRP (µg/l)	TP (µg/l)
1	8/25/93	1.2	*	*	2	3	96	*	4	31
1	9/3/93	0.8	0.48	0.38	2	0	100	*	4	24
1	9/16/93	2.2	*	*	3	5	135	*	5	29
1	9/22/93	0.7	0.29	0.13	3	1	80	1	2	18
1	9/30/93	1.35	0.75	0.22	2	12	149	*	2	18
2	9/22/93	3.15	1.26	0.33	3	11	301	1	4	24
2	9/30/93	2.4	1.43	0.26	3	24	233	*	5	20
3	8/25/93	3.25	*	*	3	8	309	*	7	32
3	8/30/93	5.25	*	*	3	22	274	*	10	48
3	9/3/93	27	1.66	0.68	6	13	296	*	17	122
3	9/16/93	15	4.62	0	6	56	334	*	11	60
3	9/22/93	5.9	2.83	0.55	3	16	308	1	7	34
3	9/30/93	3.55	1.89	0.52	3	33	250	*	5	25
3	9/6/94	*	2.99	0.4	*	*	*	*	*	*
3a	9/22/93	4.3	1.44	0.32	2	1	249	1	6	30
3a	9/30/93	3.4	1.2	0.34	*	*	*	*	*	*
4	9/22/93	5.9	1.31	0.3	3	10	235	1	8	37
4	9/30/93	2.1	1.17	0.16	3	18	240	*	4	19
5	9/22/93	4	1.41	0.35	3	17	252	1	5	28
5	9/30/93	2.1	1.31	0.27	3	25	198	*	5	22
6	9/22/93	2.3	1.61	0.35	3	11	267	1	5	23
6	9/30/93	8	1.42	0.42	3	26	194	*	7	51
7	9/22/93	2.5	0.71	0.29	3	2	238	2	5	19
7	9/30/93	2.8	1.18	0.34	2	20	145	*	4	22
8	9/22/93	1.95	0.49	0.18	7	4	246	3	5	20
8	9/30/93	2.4	0.87	0.24	2	18	206	*	4	22
9	9/22/93	1.95	0.61	0.2	3	5	233	1	3	21
9	9/30/93	1.7	0.78	0.23	3	18	219	*	3	16
10	8/25/93	3.45	*	*	2	5	261	*	3	52
10	8/30/93	24.5	*	*	3	20	517	*	37	143
10	9/3/93	33	2.04	0.91	6	33	340	*	21	158
10	9/16/93	12	1.96	0.56	3	25	289	*	6	45
10	6/23/94	*	1.1	0.39	*	*	*	*	*	*
10	7/18/94	*	2.01	0.77	1	1	*	3	*	*
10	8/4/94	*	2.11	0.74	*	*	*	*	*	*
10	9/6/94	*	2.64	0.4	*	*	*	*	*	*
11	8/25/93	3.9	*	*	3	5	231	*	8	37
11	8/30/93	7	*	*	4	21	264	*	15	61
11	9/3/93	11	1.95	1.5	5	26	256	*	18	68
12	8/25/93	3.3	*	*	2	5	249	*	7	32
13	8/25/93	1.8	*	*	3	9	246	*	8	28

Appendix A-2. Results of TRG monitoring of spoils impoundment basins, during 1992 hydraulic dredging at Tahoe Keys (refer to App. B Map 3).

Date	Station	Turbidity (NTU)	SRP (μg/l)	DP (μg/l)	TRP (μg/l)	TP (μg/l)	NO2NO3-N (μg/l)	NH4-N (μg/l)	TKN (μg/l)	DBAFe (μg/l)	BAFe (μg/l)
**9/4/92	1	28	9	36	32	69	22	71	346	224	1424
	2	28	12	45	40	92	23	77	367	343	1379
	3	29	10	49	66	74	23	71	203	340	1350
	4	32	13	57	33	38	12	8	421	335	1376
	5	31	12	40	33	56	9	6	236	299	1160
	6	51	33	64	74	126	20	8	417	456	1959
	7	52	27	55	100	141	18	7	401	455	1980
**9/10/92	3	9	5	38	39	38	17	3	271	111	364
	5	9	5	33	18	60	*	3	252	117	1470
	7	41	18	56	48	137	15	7	458	701	3064
9/11/92	1	70	6	35	4	132	7	246	559	512	5269
	2	19	3	38	65	63	3	63	291	63	1023
	3	30	5	36	10	66	5	49	289	78	*
	4	33	3	39	40	100	4	2	320	74	2554
	5	31	3	30	26	112	8	2	421	58	2650
	6	21	6	37	33	84	4	1	365	74	1420
	7	33	5	38	44	116	4	1	459	701	2315
9/12/92	1	41	3	28	18	72	4	252	556	196	2854
	2	20	3	36	13	48	4	56	221	108	1223
	3	20	3	27	60	47	4	50	228	129	1256
	4	18	3	33	24	43	4	26	269	151	1562
	5	16	4	28	13	57	4	11	280	108	939
	6	19	3	31	15	77	3	1	201	87	1085
	7	20	3	32	18	82	3	1	278	69	1148
	Outflow	20	4	30	21	90	3	2	296	80	1199
9/13/92	1	22	3	28	28	52	4	121	352	183	1181
	3	15	3	32	45	43	4	41	243	152	882
	5	12	3	31	12	41	3	5	200	115	568
	7	13	4	33	11	62	3	3	354	115	561
9/15/92	1	34	3	26	18	116	4	153	659	206	3256
	5	11	4	32	10	39	3	4	116	126	486
	7	16	3	33	13	63	3	2	236	107	579
9/17/92	1	60	4	32	24	175	14	315	781	121	4007
	2	43	4	32	24	117	7	339	614	88	2439
	3	45	3	28	16	133	9	364	596	74	2853
	4	35	3	31	25	111	6	283	501	79	2128
	5	31	4	34	26	92	7	208	410	73	1810
	6	36	3	22	34	119	4	250	568	190	2095
	7	26	3	26	16	80	5	58	582	79	1382
9/22/92	Inflow 1355	707	3	13	72	6760	4	382	26620	64	175791
	Inflow 1400	1153	6	17	66	12666	6	583	39484	435	340687
	1	58	5	15	25	207	4	414	962	315	5790
	2	47	3	12	14	148	6	357	620	90	3563
	3	35	2	10	7	94	6	331	498	70	2777
	4	26	2	10	9	99	6	277	320	47	1836
	5	22	2	10	8	88	6	244	298	38	1534
	6	15	1	9	5	78	6	173	433	20	1025
	7	11	2	10	6	70	6	86	308	19	664
	Outflow	13	2	10	15	64	6	99	317	22	820
9/24/92	Inflow	385	5	18	19	1390	6	201	13074	250	98400
	1	50	3	13	12	190	4	161	1147	156	4773
	3	38	3	12	16	132	5	413	567	183	3075
	5	34	2	13	15	116	5	320	502	132	2502
	7	52	3	12	16	143	9	210	731	99	3004
	Outflow	50	3	13	18	64	8	248	621	91	3022
9/29/92	Inflow	2000	2	5	46	14204	7	304	34926	*	515568
	1	510	3	7	28	2227	8	245	8207	46	102000
	2	110	3	7	42	246	10	263	698	52	7373
	3	105	2	8	25	253	11	287	667	42	*
	4	84	3	6	35	211	10	323	556	36	5029
	5	74	3	6	20	153	10	314	602	41	4722
	6	56	2	6	28	146	10	316	549	70	2904
	7	55	2	7	35	134	12	325	576	41	2633
	Outflow	53	1	6	32	131	13	327	701	40	2838

* - Asterisk indicates not analyzed

**- Indicates samples analyzed for soluble constituents were pre-filtered through precombusted GF/C filters these dates; on all other dates samples analyzed for soluble nutrients were filtered through deionized water-rinsed 0.45μ HA Millipore filters

Appendix A-1 Cont'd.. Results of TRG monitoring around VMI 612 horizontal cutter suction dredge during 1992 dredging of the Tahoe Keys East Channel (refer to App. B Map 2).

Transect(s) / Conditions	Dist. from dredge (ft)	Front or Back of dredge	Dist. from Top/Bottom	Turbidity (NTU)	SRP (µg/l)	DP (µg/l)	TRP (µg/l)	TP (µg/l)	NO2NO3-N (µg/l)	NH4-N (µg/l)	TKN (µg/l)	DBAFe (µg/l)	BAFe (µg/l)
11/12/92 Transects/	200	Front	Top - 1 ft	1.5	N/A	N/A	N/A	12	N/A	0	N/A	N/A	N/A
transect depth approx. 3-5 ft.	100	Front	Top - 1 ft	6.7	N/A	N/A	N/A	23	N/A	3	N/A	N/A	N/A
downwind depth approx. 1-2 ft.	100	Front	Bottom - 1 ft	13	N/A	N/A	N/A	51	N/A	3	N/A	N/A	N/A
slight N/E wind	50	Front	Top - 1 ft	5.3	N/A	N/A	N/A	22	N/A	2	N/A	N/A	N/A
	50	Front	Bottom - 1 ft	11	N/A	N/A	N/A	51	N/A	2	N/A	N/A	N/A
	20	Front	Top - 1 ft	7.3	N/A	N/A	N/A	39	N/A	4	N/A	N/A	N/A
	20	Front	Bottom - 1 ft	10.5	N/A	N/A	N/A	32	N/A	10	N/A	N/A	N/A
	10	Front	Top - 1 ft	20	2	N/A	N/A	39	2	18	N/A	N/A	N/A
	10	Front	Bottom - 1 ft	32	2	N/A	N/A	58	2	24	N/A	N/A	N/A
	0	mid-dredge	Top - 1 ft	20	N/A	N/A	N/A	93	N/A	7	N/A	N/A	N/A
	20	Back	Top - 1 ft	2.8	N/A	N/A	N/A	20	N/A	1	N/A	N/A	N/A
	20	Back	Bottom - 1 ft	18	3	N/A	N/A	51	2	5	N/A	N/A	N/A
	50	Back	Top - 1 ft	6	N/A	N/A	N/A	25	N/A	4	N/A	N/A	N/A
	50	Back	Bottom - 1 ft	11	2	N/A	N/A	35	2	15	N/A	N/A	N/A
	100	Back	Top - 1 ft	7.1	N/A	N/A	N/A	25	N/A	4	N/A	N/A	N/A
	100	Back	Bottom - 1 ft	23	N/A	N/A	N/A	46	N/A	38	N/A	N/A	N/A
	200	Back	Top - 1 ft	7.6	N/A	N/A	N/A	26	N/A	3	N/A	N/A	N/A
	10	Downwind	Top - 1 ft	22.5	N/A	N/A	N/A	70	N/A	12	N/A	N/A	N/A
	20	Downwind	Top - 1 ft	14	N/A	N/A	N/A	41	N/A	8	N/A	N/A	N/A
	50	Downwind	Top - 1 ft	5.7	N/A	N/A	N/A	23	N/A	1	N/A	N/A	N/A
	100	Downwind	Top - 1 ft	3.7	N/A	N/A	N/A	20	N/A	3	N/A	N/A	N/A
	200	Downwind	Top - 1 ft	2	N/A	N/A	N/A	14	N/A	2	N/A	N/A	N/A