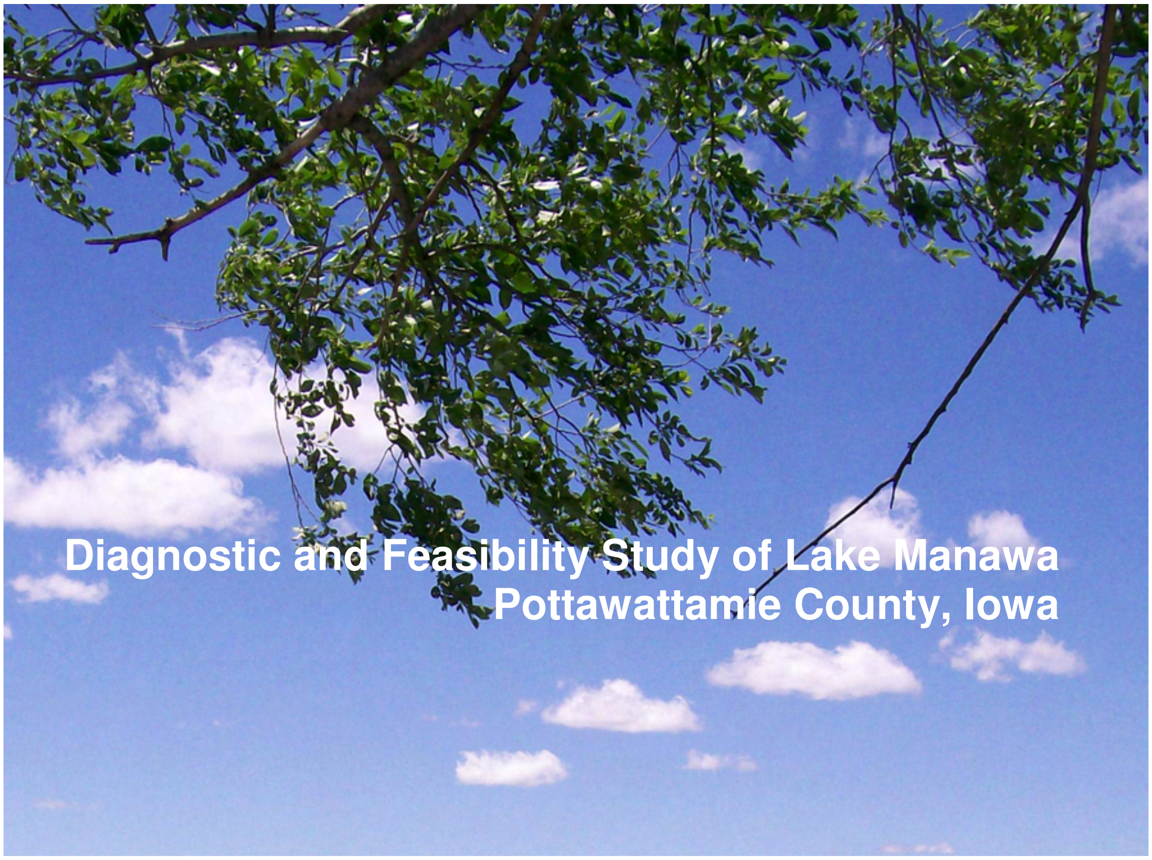
TETRA TECH



Diagnostic and Feasibility Study of Lake Manawa
Pottawattamie County, Iowa

Iowa Department of Natural Resources

March 2009

complex world CLEAR SOLUTIONS™

Executive Summary

The Iowa Department of Natural Resources (IDNR) contracted with Tetra Tech, Inc., to further investigate water quality improvement methods, including the feasibility of a large-scale dredging project at Lake Manawa. The dredging project is a vital component of an overall water quality improvement project, as it would create additional depth and volume in Lake Manawa; without these two physical changes, achieving long-term water quality goals would be difficult.

Past analysis indicated significant concerns about the potential effect of dredging on the overall seepage from the lake periphery. Tetra Tech's review of available information, additional investigations, and technical analysis all indicate that a dredging project is technically, environmentally, and financially feasible. Tetra Tech believes that several methods are available to dredge the lake. At this time, however, with the volatile energy and financing markets, it is difficult to precisely specify the dredging method that will produce the best project for IDNR. Additionally, the dredging method identified that is likely to produce the best result is currently unproven in the United States.

Along with a plan for dredging Lake Manawa, additional options to reduce the pollutant load to the lake were analyzed. In conjunction with Iowa's Lake Restoration Program, IDNR has established water quality goals that would be difficult to achieve with a dredging project alone. As a result, methods to reduce seepage and the volume of water diverted from Mosquito Creek were investigated, along with options that target the immediate watershed and the internal load. A combination of the most effective methods was developed for Lake Manawa through analysis of pollutant load reductions and cost estimates of the alternatives. Water quality models representing the anticipated lake response to the methods show water quality that would exceed the goals set by IDNR.

Recommendations to further investigate some of the mitigation measures deemed necessary to conduct the dredging operations are presented in this study and are proposed as part of an intermediate next phase. This proposed "Pilot Dredging Project" phase would provide data that would reduce the risk involved both in providing the materials to the specifications required and in the ability to control additional seepage from areas along the lake bottom, where underlying sands would become exposed. If all assumptions in this study can be proven true, the project remains a viable opportunity for both IDNR and the Iowa Department of Transportation (IDOT).

LICENSED PROFESSIONAL ENGINEER
MICHAEL K.
SOTAK
16681
IOWA

2.16.09

Table of Contents

List of Tables

List of Appendices

1.0 INTRODUCTION

1.1 Purpose

This project involves a diagnostic and feasibility study of available methods to improve the quality of water in Lake Manawa, Iowa. The primary goals of lake restoration is to increase the mean depth from 6.1 feet to 10 feet and to increase the water clarity to a secchi depth of 4.5 feet at least 50 percent of the time, as measured from April through September. A secondary goal is to obtain deeper sand that could be used for nearby planned Iowa Department of Transportation (IDOT) road projects. Tetra Tech, Inc., in Omaha, Nebraska, was contracted by the Iowa Department of Natural Resources (IDNR) to conduct this diagnostic and feasibility study.

1.2 Background

Lake Manawa is located within the City of Council Bluffs, Iowa, in a state park managed by IDNR (see Figure 1 in Appendix A). A unique opportunity presented itself when IDOT expressed potential interest in obtaining large volumes of borrow material to use as roadway fill for the upcoming improvements to Interstates I-29 and I-80. A dredge operation on Lake Manawa would not only help improve water quality, but it could be a source of borrow material for IDOT. Therefore, one component of this project will be to assess the effects of dredging on the lake and the feasibility of obtaining material that meets IDOT's construction specifications and project schedule.

1.2.1 Site Description

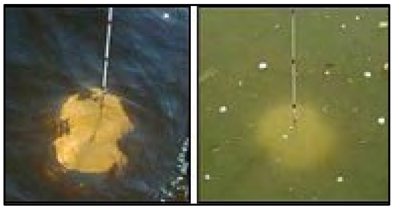
Lake Manawa is a 747-acre lake primarily used for recreation. The lake lies within the historical Missouri River floodplain, which consists of flat terrain. The size of the drainage area that contributes directly to Lake Manawa has been reported to be up to 3,200 acres, but with the gentle topography it is unlikely the lake receives runoff from an area as large. The area that drains to the lake also may vary from one storm event to another. During light rains, water will pond in low-lying areas near the lake and infiltrate into the ground instead of running off in ditches or storm sewers. Larger rain events create greater volumes at rates much higher than can infiltrate into the ground, increasing the amount of water that will drain to the lake. Through visual inspection of flow patterns, the average drainage area was set at approximately 700 acres (see Figure 2 in Appendix A).

The lake is located within the boundary of the 1,529-acre Lake Manawa State Park. As shown in Figure 2, residential developments are located along the eastern shoreline and in coves south and west of the lake. Mosquito and Indian Creeks run southerly and adjacent to the lake on the east and west, emptying into the Missouri River, located south of the lake. Water from Mosquito Creek is diverted into Lake Manawa to help maintain the desired water surface elevation of around 967 feet above mean sea level (feet amsl).

1.2.2 Water Quality

The existing water quality conditions in Lake Manawa have deteriorated to the point that the lake has been included on the Iowa Impaired Waters list under Section 303(d) of the

Clean Water Act for turbidity and nutrients. This designation means that the lake does not meet state water quality standards and that the state must develop a total maximum daily load (TMDL) to establish allowable pollutant loads to the lake.



Sampling data for Lake Manawa were obtained from the Iowa State University (ISU) Limnology Laboratory for the years 2000 through 2007. The lake's water clarity was measured at an average secchi depth of 1.3 feet. Secchi depth is a representation of the turbidity (or cloudiness) caused by suspended particles and dissolved solids in the lake. It is measured by lowering a disk into the water and recording the depth where the disk is no longer visible. An average phosphorous concentration of 117 micrograms per liter (µg/L) also was reported. Nutrients, such as phosphorus, are the food source for algae, and high concentrations often lead to frequent algal blooms during the summer. Overall, Lake Manawa is ranked in the bottom 27th percentile for overall water quality within the State of Iowa's lake system. Shallow depths are also another issue that must be considered for water quality. With a current mean depth of 6.1 feet, the majority of the lake bottom sediments are highly susceptible to resuspension, which reintroduces sediments and pollutants that have settled out of the water column back into the lake. The large quantity and the quality of flow from Mosquito Creek are also problematic, as they contribute a large portion of the pollutant load to the lake.

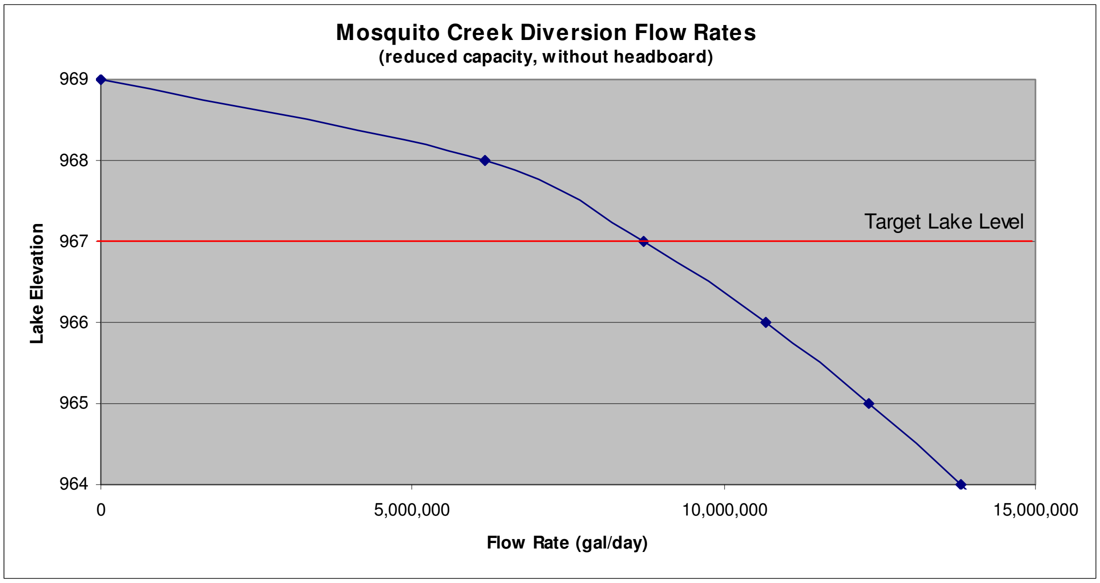
1.2.3 Hydrologic System

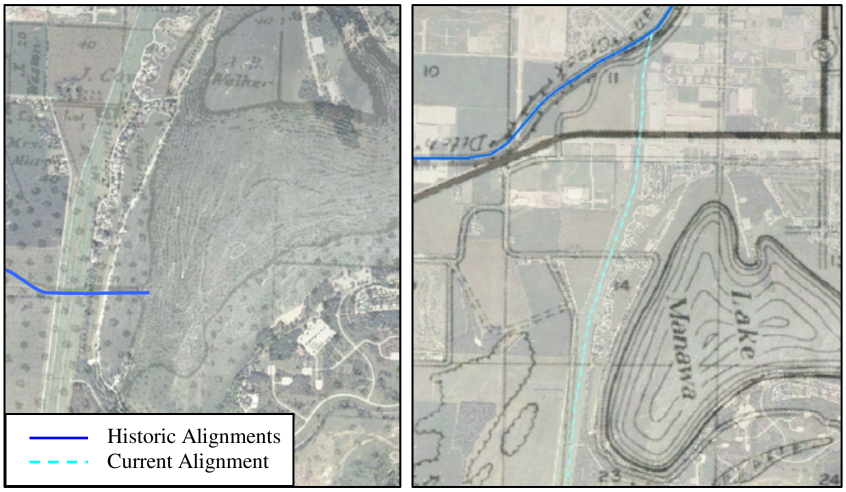
The hydrologic system of Lake Manawa is complex and is affected by several water features. These features include the lake itself, Mosquito Creek, Indian Creek, the Missouri River, and the groundwater table.

This historic map of the Missouri River channel overlain on a recent aerial of Lake Manawa shows how the lake once fit into the River channel.

Lake Manawa was a historical meander of the Missouri River that was cut off during a large flood event in 1881, leaving today's oxbow lake. Over time, Lake Manawa has struggled with low water levels. Historically, water was diverted from the Missouri River into the lake to keep it at the desired elevation of 967 feet amsl. In 1955, a diversion structure was constructed on Mosquito Creek to divert water by gravity flow into Lake Manawa. This diversion allows the lake to sit "perched" above the local groundwater table. The lacustrine deposits that accumulated over time also have contributed to creating a "seal" on the bottom of the lake, enabling a groundwater mound to form above the local aquifer. Water losses from the lake to the groundwater occur at high rates, causing difficulty in maintaining the desired water surface level.

Mosquito Creek is east of Lake Manawa, varying in distance from 2,000 feet to 7,000 feet. Its watershed is more than 200 square miles and predominantly drains agricultural land in the Loess Hills, as well as an urbanized portion of the City of Council Bluffs. As described above, the lake's level is maintained at approximately 967 feet amsl by opening and closing the gate on the diversion structure. When clarity levels in Mosquito Creek drop below a planned level, the gate is closed until conditions improve, unless water levels are too low. When the gate is fully open, the rate the water is diverted from the creek varies with the lake level, as depicted below.





Indian Creek is located approximately 400 feet west of Lake Manawa. Historically, Indian Creek flowed into Lake Manawa until it was redirected to flow into the Missouri River northwest of the lake in the late 1800s. In light of continued flooding, the creek was rerouted again in 1950 to run south directly adjacent to the lake to the Missouri River. At that time, the creek was approximately 900 feet west of the lake, but the excavation of the coves on the lake's west shoreline reduced the distance to 400 feet on average. The creek's current water surface elevations adjacent to Lake Manawa range from 958 to 960 feet amsl, approximately 7 to 9 feet lower than the average water surface elevation in the lake.

The Missouri River lies 3 miles west of Lake Manawa, then takes an easterly bend to run approximately 2,300 feet south of the lake. The water surface elevation in the Missouri River varies greatly depending on the time of year, as the U.S. Army Corps of Engineers (USACE) manipulates the water levels for barge traffic. To extend the data range for U.S. Geological Survey (USGS) Gage 06610505 at Council Bluffs, the average difference between USGS Gage 06610000 at Omaha and 06610505 at Council Bluffs was found and applied to the Council Bluffs Gage. An average difference of 5.99 feet was found between the two gages with a 99 percent confidence interval of 0.02 feet, indicating statistically consistent differences in elevations as indicated by the normal downstream slope through the channel. The Council Bluffs data set was expanded by this operation to include 1984 through 2008. However, data prior to 2001 were not used in further analysis because of an apparent operational change of reservoir management by USACE, as was evident by a 2.5-feet average height decrease after the 2000 water year. After the 2000 water year, a higher level of consistency was found in average Missouri River levels during the winter. According to the USGS gages from 2001 to 2008, the Missouri River water surface level south of the lake ranged from 953 feet amsl on average in the winter (December to February) to an average of 959 feet amsl during shipping season (March to November).

The local groundwater flows south to southwest toward the Missouri River. Groundwater table elevations are also largely influenced by the fluctuating water surface levels in the Missouri River. The water mound formed below Lake Manawa is connected to the local groundwater table, and the rate the water flows from the lake to the groundwater is a major component of the hydrologic system.

1.2.4 Soils and Geology

Soils boring were drilled in Lake Manawa in 2004 and 2007 by Geotechnical Services, Inc (GSI). The boring logs reported thicknesses of lacustrine deposits (mixtures of organics, clays and silts) ranging from 0 to 14 feet. The soil characteristics of this layer create a hydraulic seal on the bottom of the lake, which prevents water from seeping out of the lake at high rates (where this layer is present). The lacustrine layer is underlain by a silt and sand mixture (ML and SM) followed by fine to medium grained sand (SP) in the majority of the lake. There is an exception in the north-central portion of the lake, where the lacustrine layer is immediately underlain with fine to medium grained sand (SP).

As a component of this study, Tetra Tech conducted a geophysical exploration around the perimeter of the lake, collecting subsurface soil data to depths up to 300 and more feet. The geophysical exploration indicated that bedrock ranges from 90 to 135 feet bgs at the site. This interpretation is confirmed by similar findings in drilling logs for observation wells reported in HDR's *Hydrogeologic Evaluation Report* for IDOT, September 2007.

The bedrock is of the Kansas City and Bronson Groups consists primarily of fossiliferous limestone and gray shales.

1.3 Project Approach

The three major components of this project include analyzing seepage, water quality treatment options, and alternative dredge methods. Tetra Tech used the following steps in support of these three major components:

- Model water quality
- Establish a water budget and determine seepage rates
- Identify methods of reducing the pollutant load
- Analyze the feasibility of dredge
- Develop alternative dredging methods
- Model future water quality conditions
- Develop recommendations
- Create an implementation plan

2.0 PRELIMINARY ANALYSIS

2.1 Water Quality Analysis

Currently, Lake Manawa suffers from low clarity (turbidity) and high phosphorus concentrations. These conditions are largely a result of the high sediment and phosphorus pollutant loads to the lake. Therefore, one of the most effective methods to improve the lake's water quality is to reduce this pollutant load. Additionally, changes to the lake's physical characteristics (such as depth, volume, and geometry) will also have great impacts on water quality. There are three known main sources of pollutant loading to Lake Manawa: the Mosquito Creek inflow, the Lake Manawa Watershed, and internal loading. There is also the potential for atmospheric deposition; however, the associated pollutant load was not estimated during this analysis. Mid-American Energy is located southeast of the lake; however, phosphorus emissions related to coal plants are generally not of concern. Coal combustion potentially leads to atmospheric deposition of mercury, nitrogen oxides (NOx), and sulfur dioxide (SO2), which could be of greater concern.

A large load is associated with the primary source of water, the Mosquito Creek diversion. The loess hills, which consist of highly erodible soils, drain to the creek and transport high sediment loads. In addition, agricultural practices in the watershed increase the sediment and phosphorus delivery rates. Runoff is also collected from the eastern portion of Council Bluffs and carries common urban pollutant loads, such as fertilizers and roadway oil and grease.

The 700-acre watershed directly around Lake Manawa is another source of pollutants to the lake. Approximately half of the drainage area is urban, including residential, commercial, industrial, and a golf course. The remaining land is primarily undeveloped park ground and a small piece of agricultural land. The amount of impervious area is much greater in the urban setting, created by features such as roads, parking lots, and buildings. Impervious areas inhibit precipitation from infiltrating into the ground, increasing the amount of runoff and pollutants transported to the lake. These impervious areas also restrict the opportunity for treatment of runoff through natural processes, such as filtration or vegetative nutrient uptake.

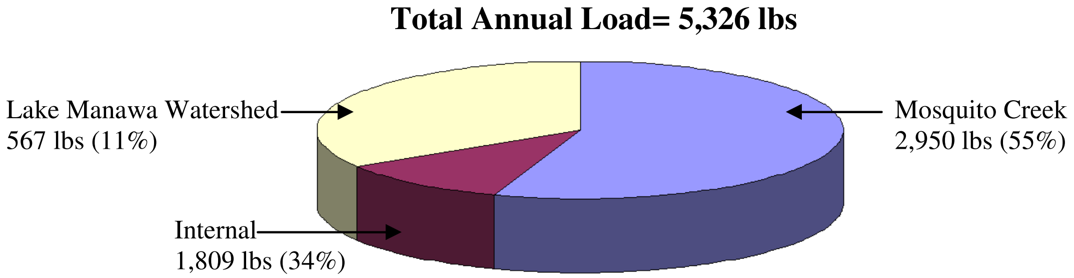
The third source is an internal pollutant load, which includes all pollutants that come from within the lake. The most common internal loads are attributed shoreline erosion and resuspension of lake bottom material. Natural causes of resuspension include wind and aquatic biota, and man-made causes include motorized watercrafts and swimming and wading. Eroding shorelines contribute a sediment load to the lake. Resuspension of lake bottom material reintroduces pollutants that have settled back into the water column, creating turbidity and making phosphorus available for algae consumption. The internal load is highly dependent on the physical characteristics of the lake, primarily lake depths. Depths that are affected by speedboating are a function of the size of motor, the speed of the boat, and the lake bottom material. On average, depths of 8 to 10 feet must be achieved to eliminate lake bottom resuspension. With an average lake depth of 6.1 feet, the majority of Lake Manawa is susceptible to internal loading caused by speedboats and other watercraft.

2.1.1 Modeling

Improving water quality is the primary purpose of this project; therefore, the first step was to analyze existing conditions in Lake Manawa and model the current pollutant loads. Using the water quality data from ISU, the Canfield-Bachman equation was applied to Lake Manawa to calculate the existing pollutant load. The Spreadsheet Tool for Estimating Pollutant Loads (STEPL) was used to model the external pollutant load from the Lake Manawa watershed, whereas sampling data and diversion records from IDNR were applied to develop pollutant estimates for Mosquito Creek. Once the model was created, alternatives to improve quality were developed and implemented into the model to estimate future loading conditions. This useful tool provides insight to the measures that are needed to achieve water quality goals.

Tetra Tech opted to focus its modeling efforts on total phosphorus for numerous reasons. First, several phosphorus modeling techniques have been developed and are commonly used. Second, there is a direct relationship between the sediment and phosphorus delivery, as phosphorus adsorbs to soil particles. Therefore, the phosphorus model is considered an accurate representation of the two main pollutants of concern for Lake Manawa.

Given the sampling data and the physical characteristics of the lake, the current annual phosphorus load (in pounds per year) was estimated. Furthermore, the load was broken down by source. This information is helpful in determining where to focus the load reduction efforts and is illustrated in the following graph.



2.1.2 Goals

As stated in the purpose of this project, IDNR's primary goal is to increase the water clarity to a secchi depth of 4.5 feet at least 50 percent of the time as measured from April through September. This goal is equivalent to a phosphorus concentration of approximately 34 μg/L, a drastic reduction from the existing concentration of 117 μg/L. The water quality is Lake Manawa is summarized in Table 1.

Table 1. Lake Manawa Water Quality Summary

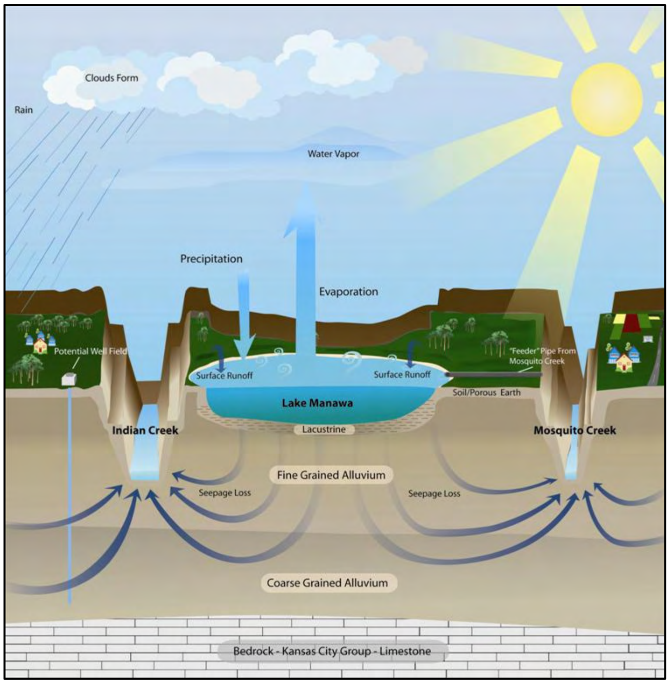
	Existing Conditions	Goal
P Concentration (μg/L)	117.0	34.0
Secchi Depth (feet)	1.3	4.5
Average Depth (feet)	6.1	10.0

Several alternatives were investigated that either reduce the pollutant load to the lake or that alter physical characteristics of the lake. The goals will likely be reached through a combination of the alternatives. Throughout this project, the impact of each alternative on the water quality of the lake was analyzed. A summary of the total impact of the recommended alternatives and the estimated future water quality conditions for the lake is located in Section 3.7.

2.2 Water Budget and Seepage Analysis

Developing a water budget for Lake Manawa was an integral part of this study. This budget represents the process of balancing the lake's inflow and outflow to create a numerical representation of the hydrologic system. From the budget, the understanding of the overall seepage and factors that affect the seepage rates can be refined.

2.2.1 Water Budget



A water budget consists of a mass balance of the hydrologic system; for Lake Manawa that includes precipitation, watershed runoff, evaporation, diversion inflow, and seepage. Historical data records were collected for precipitation, evaporation, Mosquito Creek diversion volumes, Missouri River levels, and Lake Manawa levels. Usable overlapping data currently exist only for years 2007 through 2008, which were used as the best available information to calibrate the water budget model. Other years were investigated; however, data were inconsistent or questionable and did not provide a stable analysis of seepage. The calculation interval for the water budget was daily instead of monthly, primarily because of the high hydraulic conductivity and fluctuations in lake and river levels.

Precipitation data were taken from a rainfall gage at the Council Bluffs Airport, which provided daily data for the analysis. Several significant rainfall events were captured during the summer months; based on the distance from Lake Manawa, however, the data recorded during these events are questionable. During the analysis, several of the rainfall events were found to be outliers because they could not be fit within the modeled equations and were removed.

Watershed runoff was considered unknown because of the unknown amount of infiltration, the high potential for ponding, and the flat slopes. A constant ratio was assumed for runoff to rainfall for all storm events despite expected differences in infiltration caused by storm variability.

Evaporation rates were taken from the experimental gage station at Cantana, Iowa, through the Iowa State Agronomy Department. The evaporation rates were calculated by using available meteorologic information, and not by the typical pan evaporation method; however, these data compare well with pan evaporation data from other area stations.

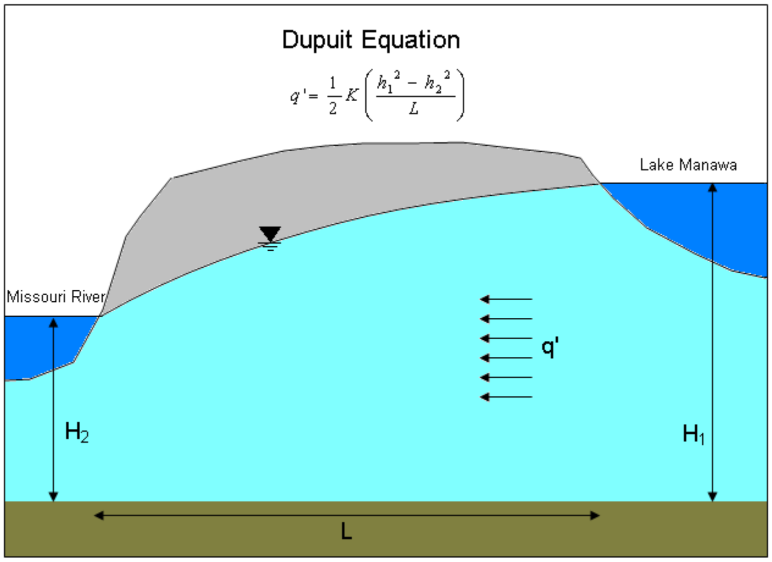
Diversion information was supplied by IDNR; this information was in the form of recorded dates of gate openings and closures. IDNR has used an equation to estimate the volume of diversion flow based on the water surface elevation of Lake Manawa. Tetra Tech developed an equation based on the as-built plans to verify this equation; this equation compared well with the DNR's equation.

Seepage was considered an unknown and was the primary variable to be solved.

During the initial analyses, all tested groundwater equations failed to represent Lake Manawa seepage values. A Monte Carlo analysis allowed testing ranges of hydraulic conductivities, rainfall to runoff ratios, and other groundwater equation variables to assess the viability of each equation and the sensitivity of each variable. The Monte Carlo analysis used thousands of random simulations of possible values for each variable to assess the best possible solution of the model's seepage with the known seepage based on the mass balance. This method showed that the Mosquito Creek diversion data were suspect, as no other variable could account for the pattern of errors. Further modeling showed that the diversion capacity provided the "best fit" at 58 percent of the current estimated capacity. This result is consistent with the findings from an inspection by Mr. Rooter Plumbing in October 2008 during an attempt to videotape portions of the diversion system. Because of the depth and clarity of the water, quality video was not attained from all areas; however, sedimentation and debris were notated during this inspection in several areas. Sediment deposits were expected because of the design and operation of the diversion system: during periods of no diversion flow, a portion of the diversion pipe is full of water (zero velocity), allowing deposition to occur near the outlet. Furthermore, flow through the diversion pipe does not appear to have sufficient velocity to remove deposits, as a proper culvert design would allow. Applying this reduction to the diversion volumes allows for the overall seepage to be estimated from Lake Manawa with respect to Missouri River levels.

2.2.2 Seepage Analysis

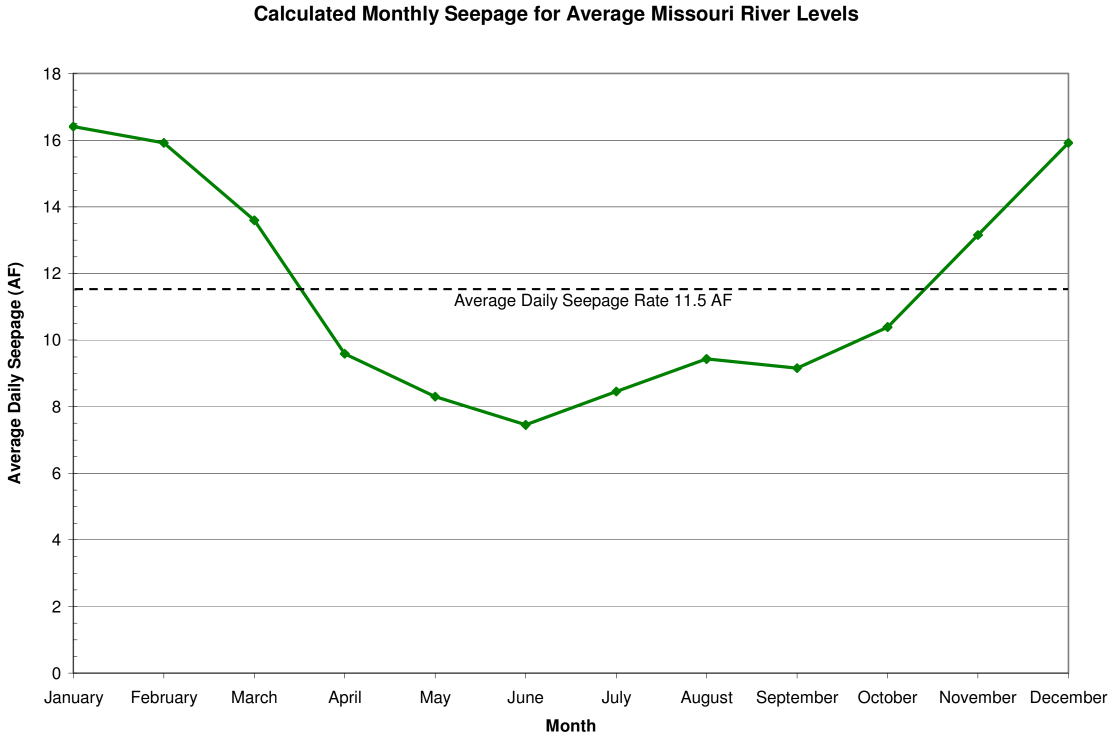
Seepage from Lake Manawa was analyzed using several methods to find an equation best representing the current understanding. Because several sets of data were questionable, Monte Carlo analyses were used to evaluate each equation against the questionable data sets. Various groundwater seepage equations were used along with a stochastical approach to assess the most appropriate equation for modeling seepage. The most accurate representation of the seepage out of Lake Manawa was reflected by the Dupuit Equation; this equation is typically used to quantify flow through an embankment with known boundary conditions, as shown in the following image.



$$Q = \frac{k * (H_1^2 - H_2^2)}{2 * L}$$

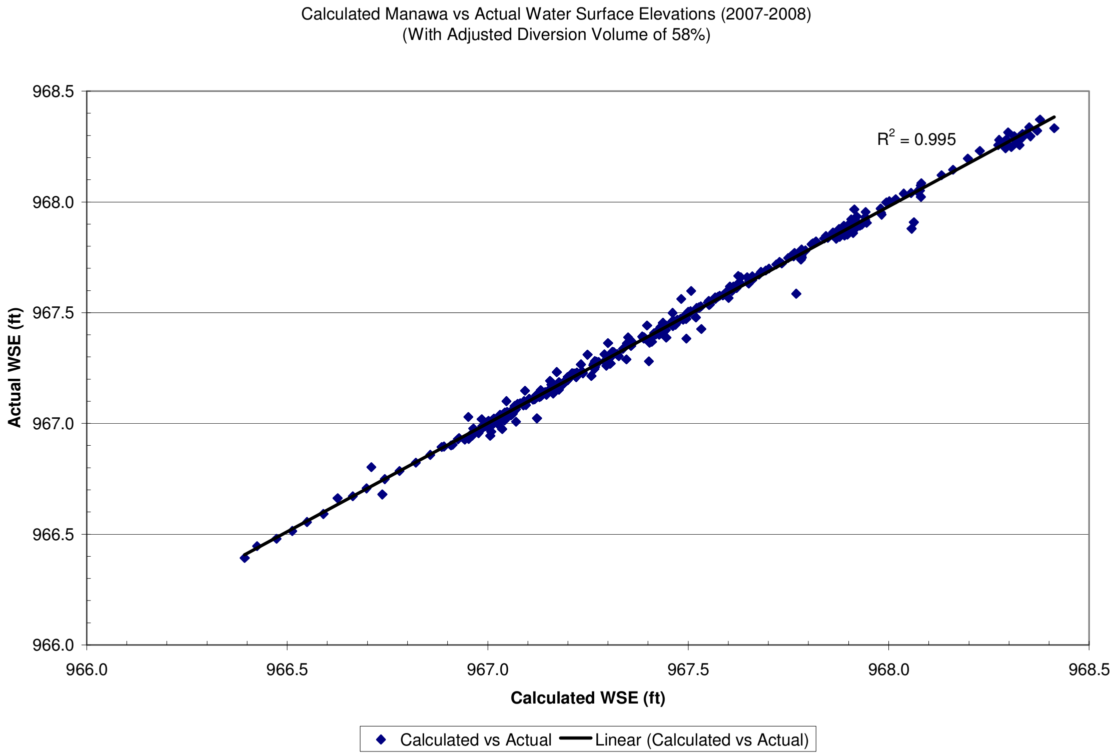
q’	Flow per Unit Width of Embankment
K	Hydraulic Conductivity
H1	Head at Origin
H2	Head at Distance L
L	Flow Length

As discussed previously, it was concluded that the overall rate of seepage is highly correlated with elevation of the groundwater, and therefore, the Missouri River. The groundwater table elevation generally follows the same pattern as the Missouri River; while they are not at the same elevation, one can be used as a reference to the other (with the exception of Missouri River high water induced by upstream rain events, and short-term groundwater peaks caused by infiltration). The seepage rate is directly influenced by the groundwater elevation compared with Lake Manawa. When the groundwater table is high (generally along with the Missouri River), the results of this analysis show that the lake experiences seepage losses at a rate of approximately 9 acre-feet per day, or 2.9 million gallons per day. When the Missouri River is lowered approximately 6 feet during the winter, this lowered level is mimicked by the groundwater and 6 feet of hydraulic head is gained. This increase in hydraulic head causes the seepage rate to increase to approximately 14 acre-feet per day, or 4.6 million gallons per day. A plot of the estimated seepage from Lake Manawa compared with the average Missouri River level for each month is shown below; seepage ranges from approximately 16 acre-feet per day to nearly 7 acre-feet per day, with an average of 11.5 acre-feet per day for the year.

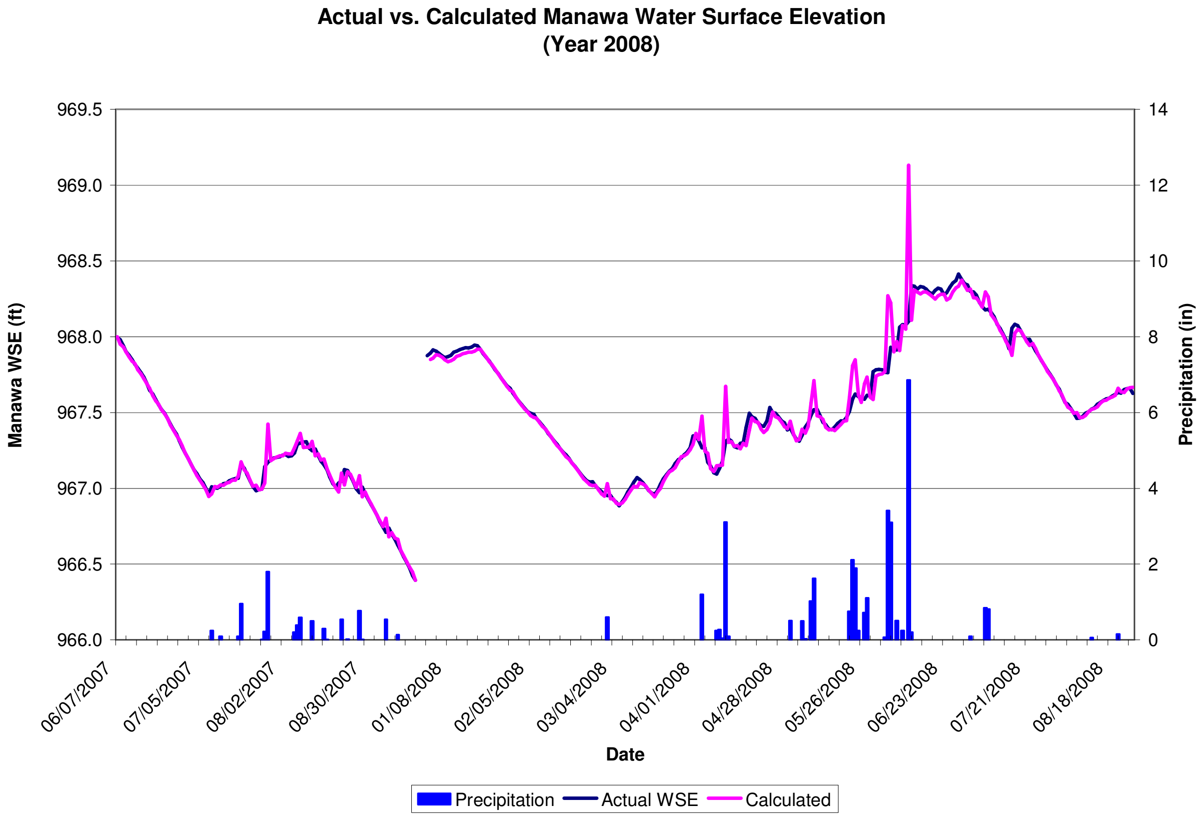


A current unknown is the overall effect of the planned wellfield development by Council Bluffs Water Works on Lake Manawa. A hydrogeology report for the wellfield delivered shortly before this study was completed listed three potential pumping scenarios and concluded that the seepage rate increase from Lake Manawa would range from approximately 200,000 to 509,000 gallons/day (0.6-1.5 acre-feet/day). This rate is a 5 to 10 percent increase from the average daily seepage rate reported above. The quantities and net effect on Lake Manawa have not been verified, however. It can be expected, however, that an increased gradient caused when groundwater levels are lowered by the wellfield will cause additional seepage because of the significant seepage toward Indian Creek and the Missouri River in the southwest part of the lake.

By applying Tetra Tech's understanding of the behavior of Lake Manawa with respect to the local groundwater conditions, Tetra Tech can accurately model the 2007 to 2008 data set with a high level of accuracy; as shown in the graph below. Based on the location of the gage used to record precipitation, some data problems can be seen during significant rainfall events; however, these problems are limited and do not impair the findings. By removing the 16 outliers (significant rainfall events) from the 341 total days modeled, Tetra Tech found the daily predictions matched the actual Manawa water surface elevations quite well; the deviation from actual ranges from +0.09 feet to -0.18 feet, and the correlation was found to be 99.5 percent. The outliers point to an overestimated drainage area size or runoff coefficient for the watershed area.



Below is a graph showing the actual Lake Manawa elevations compared with Tetra Tech's calculated elevations. This graph was generated using a 42 percent reduction in the diversion rates, and all other data mentioned in Section 2.2.1; no outliers were removed for this graph. Unfortunately, data gaps prohibited use of a continuous simulation — mainly a simulation where each successive day's results are based on the previous results. The approach shown is a daily correction: each day's results are calculated from the previous day's correct data value. Although this approach does not allow investigation of systematic deviations (results that increasingly deviate from the correct value), the results are promising and form a good basis for future modeling with extended data sets.



2.2.3 Seepage Modeling

The seepage analyses were conducted on four idealized two-dimensional cross-sections between Lake Manawa and the adjacent hydrologic features using the Seep/W 7.14 component of GeoStudio 2007 by Geo-Slope International, Ltd (1991). Seep/W was used to conduct steady-state finite element seepage analysis to evaluate the seepage rates at the selected cross section. The default size of the finite element mesh in the seepage model was set at 5 feet. A head elevation boundary condition equal to the elevation of the lake and the river or creek was applied on the bottom of the lake and river or creek. Further analysis evaluated the impacts of dredging the lake; the results will be discussed in Section 4.1.2. Seepage from the lake was evaluated at sections A through E shown on Figure 3. The existing seepage rates were analyzed using different scenarios to represent the seasonal changes of the Missouri River water surface elevation. The model was calibrated so that the range of seepage rates fell within the range provided in the seepage analysis above.

Modeling of existing conditions indicates seepage occurs between the lake and Indian Creek (section A), between the lake and the Missouri River (sections B and E), and between the lake and Mosquito Creek (section D). The model does not indicate seepage along section C based on the lack of topographic low points in that area and the general hydraulic gradient to the south. Therefore, seepage on the north side of the lake is relatively insignificant. Overall, the data indicate most seepage is toward the Missouri River and Indian Creek, with less seepage toward Mosquito Creek. To calculate total seepage to a hydrologic feature, the flow through each cross section was multiplied by the length of the hydrologic feature. These rough estimates indicate seepage from the lake varies with the stage of surrounding water bodies, but mainly with the stage of the Missouri River, since its elevation varies more than the others. The results are shown in the table below.

Table 2. Seep/W 7.14 Seepage Results

Section	Approximate Seepage Rate (ac-ft/d)	
	Missouri High	Missouri Low
A – Seepage to Indian Creek	5.90	5.90
B – Seepage to the Missouri River	3.69	6.07
D – Seepage to Mosquito Creek	0.21	0.21
E – Seepage to the Missouri River	1.80	3.75
Total	11.60	15.93

	Missouri High	Missouri Low
Seepage to Indian Creek	51%	37%
Seepage to the Missouri River	47%	62%
Seepage to Mosquito Creek	2%	1%

2.3 Geophysical Exploration

A geophysical site characterization was completed by Tetra Tech from May 12 through May 20, 2008. The geophysical survey was completed in the southwestern portions of the Lake Manawa State Park and the vicinity of Lake Manawa. For more details on the methodology and field investigation, please see Appendix B.

2.3.1 Objective

The objective of this geophysical investigation was to identify subsurface resistive and conductive features in relation to the local hydrogeologic framework and lithology, specifically, for the area adjacent to Indian Creek and the southwestern area between Lake Manawa and the Missouri River. This geophysical survey was conducted to assist in identifying areas of potential water loss from Lake Manawa into Indian Creek, the Missouri River, and the regional aquifer, in advance of a proposed dredging project for the IDOT. The geophysics also provided for some "truthing" of the in-lake soil data found in the sub-surface investigations and also identified some alluvial formations (including channels and soil deposition patterns) consistent with the historical locations of the Missouri River and Indian Creek.

2.3.2 Summary of Findings

The geophysical exploration provided a large quantity of data representing the subsurface soils around the west and southwest perimeters of the lake. These areas were targeted because the local groundwater flows south to southwesterly and the subsurface soils in that direction would have the most impact on seepage. It is also known that historical flow paths of both the Indian Creek and the Missouri River are located to the west and southwest. The results identified several prominent features that could be areas of concentrated flow to groundwater.

Along the south and east shorelines of Lake Manawa's southwest lobe (see Profiles 3 and 4 in Appendix B), a coarse grained sand and gravel layer was identified in the upper 30 feet of soil on the east and south ends of the profiles. This layer overlies an extensive silt-clay layer (30 to -60 feet below ground surface [bgs]) approximately 30 feet thick that likely acts as at least part of an aquitard. These features are interpreted to be laterally extensive, as they are present in locations surveyed farther south, toward the Missouri River. It is probable that they are deposits from historical Missouri River flow paths and could extend from Lake Manawa to the Missouri River. Sand and gravel have high hydraulic conductivities, which allow water to flow at faster rates than in clays and silts. The sand and gravel layer identified in the southwest lobe may act as preferential flow zones for groundwater. With these features in such close proximity to the lake, there is great potential that surface water is accessing these paths and increasing the overall seepage rate from the lake.

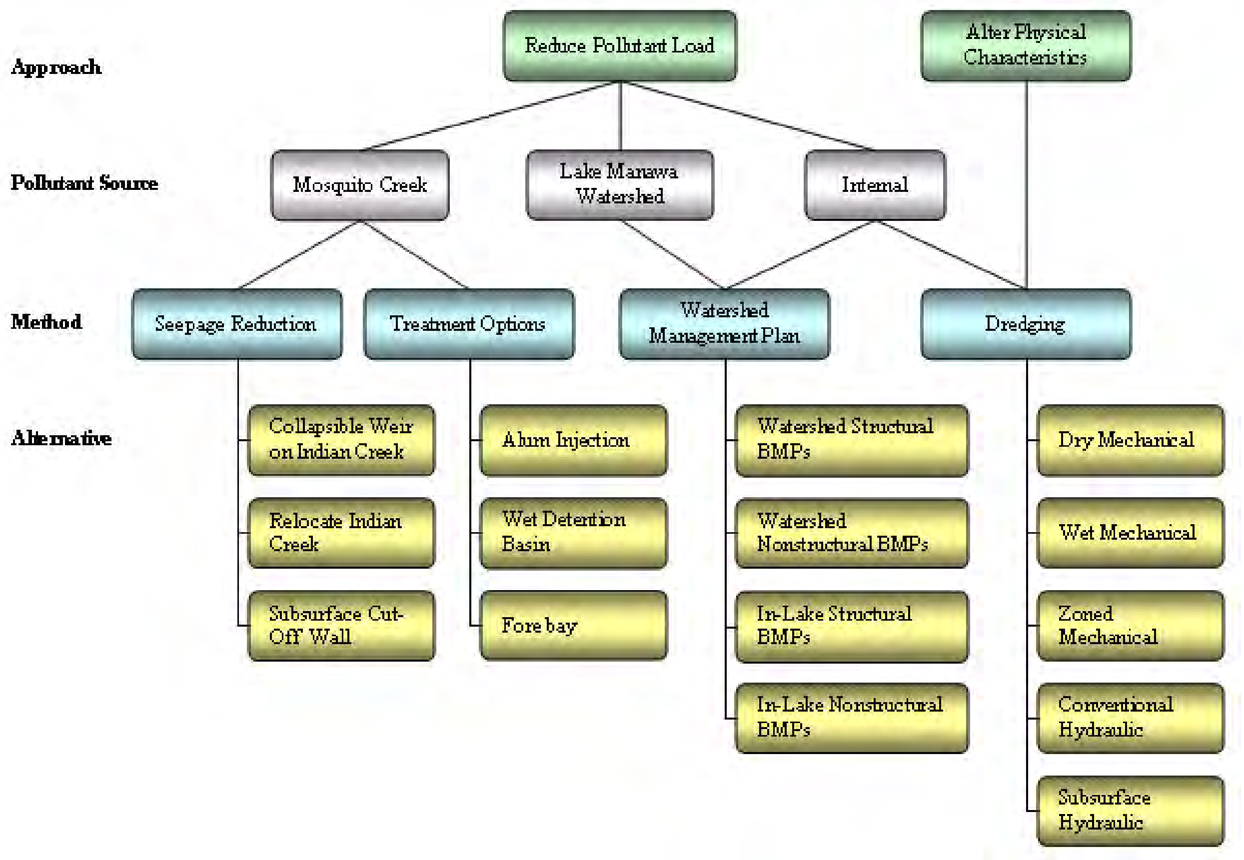
Similar deposits of sand and gravel were identified between Lake Manawa and Indian Creek (See Profiles 1, 2 and 6 in Appendix B). The locations are sporadic along the profiles and generally at depths from 30 to 60 feet below ground. However, a consistent silty-clay layer is not present below the sand and gravel, as seen on Lake Manawa's southwest lobe. In this location, the sands and gravel are primarily underlain with silty-sands with pockets of silty-clay.

3.0 WATER QUALITY IMPROVEMENTS

Two different approaches to improving poor water quality were explored:

- Reduce the pollutant load
- Alter physical characteristics of the lake that affect the lake's response to pollutant loading

Each of the main sources identified in Section 2.1 will be targeted to reduce the pollutant load, as depicted in the diagram below. The Mosquito Creek pollutant load will be addressed by analyzing methods to reduce seepage (subsequently reducing the required diversion volume and the associated pollutant load) and to treat the diverted water. A watershed management plan will be developed to address methods that reduce both direct watershed runoff and internal pollutant loads. Dredging the lake was also investigated for improvements to water quality because it would alter the physical characteristics of the lake as well as have an affect on the pollutant load produced from within the lake. Each alternative will be investigated in terms of the feasibility, water quality benefit, cost, and operation and maintenance requirements.



An important consideration for water quality is the long-term sustainability of the improvements. Long-term sustainability emphasizes the importance of selecting methods that continuously prevent pollutant loads from entering Lake Manawa. No single alternative is capable of addressing all the pollutant sources as well as altering the lake's response. Although dredging alone may have significant immediate results, it does not address any of the external pollutant sources. A combination of the methods will be required to achieve a sustainable project that meets the aggressive water quality goals set for Lake Manawa.

The following analyzes the alternatives developed for each method of improving water quality as described above.

3.1 Seepage Reduction Alternatives

Reducing seepage from Lake Manawa would be beneficial not only for maintaining the desired water surface elevation, but for water quality as well. The flow diverted from Mosquito Creek is the main source of inflow; however, it also transports a large pollutant load to the lake. If the amount of seepage could be reduced, the volume of water needed to maintain the desired lake level and the pollutant load associated with the source would decrease. Several options were analyzed in an attempt to identify cost effective or otherwise beneficial methods of reducing seepage.

3.1.1 Construct a Collapsible Weir on Indian Creek

As discussed above in the seepage analysis, one of the driving factors of seepage is the difference in hydraulic head between Lake Manawa and receiving water features. The two water features that are receiving the most flow as modeled are the Missouri River and Indian Creek. The elevation of the Missouri River fluctuates, but is controlled by USACE, and altering the Corps' river management plan is not likely. Altering the elevation of Indian Creek is potentially more plausible.

Increasing the water surface elevation in the creek would decrease the difference in hydraulic head, consequently reducing the seepage rate. The hydraulic head can be decreased by constructing a weir that would impound baseflow in the creek to a designated elevation (see Figure 4). Reducing the design capacity of the channel is not an option because Indian Creek serves as a storm drainageway for a large portion of Council Bluffs. To address this issue, the weir could be designed to collapse during runoff events so that the existing channel capacity could be maintained. During runoff events, the creek would experience higher flows that would cause the weir to collapse, thereby restoring the existing channel capacity.

In analyzing this option, there are issues that must be addressed concerning the Indian Creek Levees, local residences, the City of Council Bluffs stormwater system, and the Missouri River.

The Indian Creek levees were constructed by USACE and are locally sponsored and maintained by the City of Council Bluffs. Coordination with these two entities on the feasibility of this alternative would be imperative. In conversations with the USACE, it was stated that the recommended alternatives should not reduce the capacity of the levees. As such, it was assumed that any alternative proposed for Indian Creek should not increase maximum water surface elevations during design storm events. If a collapsible weir is deemed the preferred alternative, a hydraulic analysis must be performed to prove the capacity of the levees is not compromised.

Another consideration that must be addressed is the stability of the levees. The system was not originally designed to permanently impound water above the stream bed. Therefore, the effects of impounding the water must be addressed, as well as the effects of quickly lowering the water surface elevation. These slope stability conditions would be analyzed during a subsequent design phase.

Potential impacts to the local groundwater table and to local residences must be addressed as well. The majority of homes located on the west coves of the lake have basements. Raising the elevation of the creek will in return raise the elevation of the local groundwater table, potentially to elevations greater than the nearby basements. The exact increase will vary with distance from the structure and the location between Indian Creek and Lake Manawa. The elevation of each basement has not currently been identified and should be investigated further if this alternative is taken to final design.

The City of Council Bluffs stormwater system taps into Indian Creek to drain stormwater to the Missouri River. Any alternative implemented on Indian Creek cannot reduce the capacity of the creek to receive and convey design stormwater flows. The locations of stormwater outfalls to Indian Creek were obtained through the City of Council Bluffs Public Works Department (CBPWD). The outlets closest to Lake Manawa are located at the Highway 92 and 275 bridge. To ensure that the collapsible weir system would not impair stormwater flow to the creek, the backwater from the structure must not reduce design flows or add to long-term maintenance concerns. As-built construction documents of the culverts were obtained through CBPWD and report the culvert invert elevation on the east levee at slightly above 962 feet amsl. Therefore, water will not be permanently inundated by the collapsible weir above this elevation. Table 3 below shows the ranking for the collapsible weir.

Table 3. Collapsible Weir Ranking

	Rank	Discussion
Feasibility	Medium (2)	This alternative would involve significant coordination with USACE and the City of Council Bluffs to prove the capacity of the levees is not compromised.
Seepage Impact /Water Quality Benefits	Medium (2)	Site constraints limit the maximum water surface in Indian Creek and prevent large impacts on seepage. There would be a noticeable pollutant reduction associated with the seepage reduction experienced with this alternative.
Cost	Low (3)	The main expense is associated with the collapsible weir. Others include earthwork and bank stabilization.
Operation and Maintenance	Low (3)	There would be very little requirements, only to monitor and ensure the weir is functioning correctly

3.1.2 Relocate Indian Creek

Increasing the distance between Lake Manawa and Indian Creek would decrease the hydraulic gradient between the two hydrologic features. This distance could be increased by relocating Indian Creek farther west. Several factors must be considered in selecting a new route for Indian Creek. In light of construction costs, it is likely that the channel must remain in its current location at the Highway 92 and 275 bridge. The best new route for the channel would be selected based on the impacts to the existing land (see Figure 5). The current land use directly to the west is primarily agricultural with a few residences, industrial buildings, and roads. All buildings and homes are to be avoided during relocation. The cost to obtain land rights and to replace roadways will be included in the cost estimate for this alternative.

It would be necessary to coordinate with USACE and the City of Council Bluffs for the feasibility of this alterative. Such drastic changes to the levees would require involvement and approval from the USACE regional headquarters. The design of the new channel and levees must ensure that the capacity of the levee system is not reduced. With this alternative, the option to design the new system with increased carrying capacity in the stretch adjacent to Lake Manawa is available.

Rerouting the channel would create significant impacts to Indian Creek, as the existing channel would be filled. A permit from USACE must be acquired to work on any channel considered jurisdictional waters of the United States (which includes Indian Creek). Obtaining a permit for projects with small impacts (less than 300 feet) is relatively simple; however, thousands of feet would be altered by this alternative. The channel would be mitigated with at least a 1:1 ratio with reconstruction to the west, but obtaining a permit for this work may still prove challenging.

Two scenarios with slightly differing preliminary designs were investigated with this alternative, described below and summarized in Tables 4 and 5:

Scenario 1

- Indian Creek relocated 200 feet west of the existing alignment. The current west levee would be used by the new alignment as the proposed east levee, requiring only one new levee to be constructed
- The existing east levee would be removed and the material would be used to fill the existing channel.

Scenario 2

- Relocate Indian Creek 1,600 feet west of the existing alignment. Remove the existing levees and fill the existing channel. An entirely new channel and levee system would be constructed along the new alignment.

Table 4. Relocate Indian Creek Ranking- Scenario 1

	Rank	**Discussion**
Feasibility	Medium (2)	This alternative would involve significant coordination with USACE and the City of Council Bluffs. Relocating the channel would have to be approved by the USACE regional headquarters. Obtaining land rights and easements and permitting the channel impacts will also be an obstacle.
Seepage Impact /Water Quality Benefits	Medium (2)	The impact on seepage depends on the new distance from the channel to the lake; these results were based on increasing it to 200 feet.
Cost	High (1)	The main expenses are associated with earthwork grading of new levees and removing the existing system, purchasing land rights and easements, and road reconstruction.
Operation and Maintenance	Low (3)	None

Table 5. Relocate Indian Creek Ranking- Scenario 2

	Rank	Discussion
Feasibility	Medium (2)	This alternative would involve significant coordination with USACE and the City of Council Bluffs. Relocating the channel would have to be approved by the USACE regional headquarters. Obtaining land rights and easements and permitting the channel impacts will also be an obstacle.
Seepage Impact /Water Quality Benefits	High (3)	The impact on seepage depends on the new distance from the channel to the lake; these results were based on increasing it to 1,600 feet.
Cost	High (1)	The main expenses are associated with earthwork grading of new levees and removing the existing system, purchasing land rights and easements, and road reconstruction.
Operation and Maintenance	Low (3)	None

3.1.3 Subsurface Cut-Off Wall

A subsurface cut-off wall is an underground barrier that is constructed to stop or re-route the flow of groundwater or other established phreatic surface. This alternative incorporates material with very low hydraulic conductivity into the system, which forces moving water to find a longer route or decreases the rate water can pass through the pores and reduces the seepage rate. Cut-off walls can be designed in several different forms, most commonly as slurry walls or jet grouting. A slurry wall is constructed by excavating a trench and mixing the excavated material with bentonite. The trench is then backfilled with the soil and bentonite mixture. Jet grouting uses high-pressure streams of grout to erode, mix, and cement soils. This method applies drilling and pumping techniques, so no excavation is required. The cost of jet grouting is higher than slurry walls and there are potential depth limitations.

The geophysical exploration provided detailed information on the soil content between Lake Manawa and Indian Creek (see Appendix B). The resulting profiles identified a thick clay layer from the surface to approximately 30 feet of depth, which is attributed to the levee constructed in the area. Soils between the clay and limestone (roughly at 110 feet deep) are highly irregular, primarily silty sand with seams of clay and sand and gravel deposits throughout. In this situation, the effect of a subsurface cut-off wall on seepage depends on the depth. Ideally, the cut-off wall would tie into limestone, creating a continuous impermeable barrier between the lake and the creek. The constructability and economic feasibility of implementing cut-off walls to such great depths must be taken into consideration.

The geophysical exploration also identified features that indicate potential zones of preferential groundwater flow in the southwest portion of the lake. Since Lake Manawa is an oxbow of the Missouri River, it is probable that the features identified are deposits from the historical river channel. It is anticipated that treatment targeted to these areas will produce the greatest impacts on localized seepage. As shown in the geophysical profiles, a coarse grain sand and gravel is located near the ground surface that is underlain by a clay layer. The depth to clay ranges from 30 feet to 70 feet, and limestone is at approximately 110 feet below ground. The clay layer appears to be continuous, unlike the area adjacent to Indian Creek, where it was highly sporadic. This stratigraphy creates the option of a cut-off wall that ties into the clay layer, as opposed to extending to limestone, by creating a barrier with very low permeability.

It is important to select the most appropriate method of constructing subsurface cut-off walls for the locations adjacent to Lake Manawa. The preferred method generally relies on the site location, desired depths, construction access, and cost. Trenching and excavating slurry walls require access to staging and mixing areas, whereas jet grouting is better suited for projects with space constraints. The amount of open space between the Indian Creek levee and the residential neighborhood west of the lake is variable. Slurry walls would be the desired alternative, as they are the economically favorable, but the feasibility of construction in the limited available space would need to be investigated in further detail. If deemed infeasible, jet grouting would be appropriate. There are a few space limitations in the park area southwest of the lake: the topography and roads are the main obstacles. The most suitable form of subsurface cut-off wall between the lake and the Missouri River would likely be a slurry wall based on these site conditions.

Two scenarios with slightly differently preliminary designs were investigated with this alternative (see Figure 6):

Scenario 1

- Slurry wall that extends to bedrock (approximately 110 feet) adjacent to Indian Creek spanning the entire length of the lake (approximately 8,000 feet)
- Slurry wall that extends to clay layer (approximately 70 feet) southwest of the lake

Scenario 2

- Slurry wall that extends to bedrock (approximately 110 feet) adjacent to Indian Creek that target potential preferential flow zones (sand and gravel seams) identified in the geophysical exploration (approximately 3,000 feet)
- Slurry wall that extends to clay layer (approximately 70 feet) southwest of the lake

The effects of extending the cut-off wall adjacent to Indian Creek to depths less than 110 feet were modeled. The results showed minimal affects on seepage because they do not tie into the low-permeable layer. The continuous clay layer located south of the lake provides a layer of low permeability to tie to a slurry wall, so that it appears unnecessary to extend the slurry wall to bedrock at the location southwest of the lake. The rankings for the slurry walls appear in Tables 6 and 7.

Table 6. Subsurface Cut-Off Wall Ranking- Scenario 1

	Rank	Discussion
Feasibility	Medium (2)	Limited involvement with USACE and the City of Council Bluffs. Depth to limestone is not constant, which would require further investigation. Space limitations may change the type of cut-off wall.
Seepage Impact /Water Quality Benefits	High (3)	Seepage to Indian Creek is greatly reduced when the slurry walls tie into bedrock. The impact to overall seepage rates and the reduced volume required from Mosquito Creek would likely be significant.
Cost	VERY HIGH (0)	The expense is the construction of slurry walls, as described above (spanning the entire length of Indian Creek)
Operation and Maintenance	Low (3)	None

Table 7. Subsurface Cut-Off Wall Ranking- Scenario 2

	Rank	Discussion
Feasibility	Medium (2)	Limited involvement with USACE and the City of Council Bluffs. Depth to limestone is not constant, which would require further investigation. Space limitations may change the type of cut-off wall.
Seepage Impact /Water Quality Benefits	Medium (2)	Seepage to Indian Creek is impacted by slurry walls that target the sand/gravel seams. The impact to overall seepage rates and the reduced volume required from Mosquito Creek would not be as great as Scenario 1.
Cost	HIGH (1)	The expense is the construction of slurry walls, as described above. The cost if reduced because the walls would only be constructed in targeted areas identified in the geophysical investigation.
Operation and Maintenance	Low (3)	None

3.1.4 Whole Lake Treatment

Alternatives that address the entire lake include lake bottom liners and slurry walls around the entire lake. With such a large surface area and perimeter length, these options are not economically favorable. The premise behind the seepage analysis was to identify areas of concentrated seepage as the focus for the reduction efforts. If it is deemed impossible to meet the water quality goals through a combination the alternatives identified in this study, whole lake treatment could be revisited as a last resort. A more detailed investigation of the lake bottom and perimeter may prove helpful in identifying areas of exposed sand on the lake bottom or preferential flow paths to groundwater. Lake bottom treatment is a consideration for all dredging options, as this study analyze how best to manage material that has to be moved to access targeted dredge material, as well as the final condition of all disturbed areas.

3.2 Mosquito Creek Treatment Options

Pollutant concentrations in Mosquito Creek are high because of the land use in the large watershed. During this study, samples were collected at the diversion structure to test the quality of the water diverted to Lake Manawa; see Appendix C for the results. Currently, Mosquito Creek contributes 55 percent of the pollutant load to the lake. Since this load is the only that is concentrated and localized in a pipe, it is a prime location to focus treatment efforts that could have large impacts on water quality.

3.2.1 Alum Injection (In-pipe Treatment)

The options to treat diverted Mosquito Creek flow within the pipe are limited. Alternatives to reduce sediment transport are not viable options, as they are a function of trapping and settling the particles. This alternative would cause the pipe to silt in and reduce the carrying capacity, limiting the volume of water that flows to the lake when the gate is open. Aluminum sulfate (alum) injection targets the phosphorus particles in the stormwater. When added to water, alum forms a non-toxic precipitate that binds with phosphorus, creating a floc. The floc is then transported within the flow to the lake, where it settles to the bottom. Floc management can become an issue in shallower lakes and therefore can be controlled either in a detention basin or by deepening a localized area where it can settle on the bottom of the lake.

The Mosquito Creek diversion pipe would be a prime location for alum injection. It carries large volumes of water that are easily targeted for treatment. The injection of alum is generally paired with whole-lake treatment, which is explained in further detail in Section 3.4. The injection system will require maintenance and operation tasks, such as stocking the alum storage tanks.

Chemical applications such as alum applications do not treat the incoming sediment load, only the phosphorus. Treatments that target both loads are more favorable in this situation, since turbidity and nutrients are both of great concern. Therefore, alum would not be recommended as the sole treatment measure of the Mosquito Creek diversion, but instead should be paired with an alternative that incorporates sediment capture. By incorporating an injection system downstream of a primary treatment method, the effluent phosphorus concentration for alum to treat will be reduced. This method would also reduce the alum dose concentration and the frequency of restocking the storage tank required. The ranking for alum injection is shown in Table 8.

Table 8. Alum Injection Ranking

	Rank	Discussion
Feasibility	High (3)	Treating Mosquito Creek would be a highly feasible location, and the piping already exists. Easy location to target concentrated load.
Water Quality Benefits	Medium (2)	Treatment would result in very high phosphorus removal; however, the alternative incorporates no sediment reduction.
Cost	Low (3)	With the piping already in place the main cost is associated with the injection system and storage tank.
Operation and Maintenance	Medium (2)	Maintenance associated with the alum restocking needs.

3.2.2 Wet Detention Basin (Upland Treatment)

The use of a wet detention basin to treat water from Mosquito Creek was investigated. Wet detention basins hold water for extended periods, allowing sediment and the absorbed phosphorus particles to settle. Wetlands vegetation is also a component in the basin that treats water through nutrient uptake. An approximate 60 to 80 percent pollutant reduction is associated with this alternative, depending on the retention time. Since this alternative encourages sedimentation, maintenance will be required to sustain the necessary treatment volume.

The most appropriate location for a wet detention basin would be in an open area along the existing pipeline. The diversion pipe would be tapped into and emptied into an excavated basin. The basin would allow for sufficient retention time to settle and treat the pollutant load. An outlet would tap back into the pipeline to convey treated water to the lake. Additional exit and entrance losses would be experienced with this alternative, but the pressure head created by the diversion structure would still be great enough to deliver the treated water to the lake by gravity.

The current flow estimates for the Mosquito Creek diversions were used for the preliminary design concepts (see Figure 7). The seepage rate and diversion volumes could change because of upcoming lake improvements. If taken into final design, these potential changes should be investigated in further detail. Preliminary design determined the basin would require 12 surface acres (approximately 5 feet deep), providing a retention time of 48 hours. It would likely completely silt in within 30 years without maintenance. Sediment removal would be required to increase the lifetime and maintain the capacity of the basin. Vegetation harvesting and re-planting is another long-term maintenance consideration.

The potential of obtaining the necessary land rights or easements on the property must be considered and pursued if taken to the final design. The Omaha Airport Authority was contacted on the potential creation of additional waterfowl habitat in the area. It was confirmed that the location and size of the anticipated detention basin would not increase the problems the airport currently experiences with waterfowl. Geese prevention measures would also be incorporated into the design to discourage the use of this area by migrating waterfowl. The ranking for this alternative is shown in Table 9.

Table 9. Wet Detention Basin Ranking

	Rank	Discussion
Feasibility	High (3)	Few concerns with this alternative. Minor concerns include acquiring land rights and easements and maintenance.
Water Quality Benefits	High (3)	Treating the Mosquito Creek water and trapping approximately 60 percent of the pollutant load associated with the diversion would have significant impacts to water quality.
Cost	Low (3)	The main expenses are associated with earthwork grading of basin, the inlet and outlet works and the land rights and easement cost.
Operation and Maintenance	Medium (2)	Sediment removal and vegetation harvesting and replanting

3.2.3 Forebay (End of Pipe/In-Lake Treatment)

Treatment similar to a wet detention basin could be implemented in the lake by placing a forebay within the lake at the Mosquito Creek diversion pipe outlet. A forebay would trap and settle the sediment particles, preventing the pollutant load from entering the main body of Lake Manawa. This forebay would be dug out to great depths to prevent annual maintenance for sediment deposition. Wetland vegetation would also be incorporated along the fringe to allow nutrient uptake to further treat the water. The trapping efficiency for forebays is normally around 40 to 60 percent after construction. Because of the size limitations described below, the trapping efficiency of the forebay alternative at Lake Manawa would be reduced to 20 percent and would require periodic maintenance.

The forebay would be armored (likely with rock riprap) to create a stable basin that is not susceptible to erosion and that operates as efficiently as possible. The excavation of a forebay could be incorporated into the potential dredging grading plan. On-site investigations showed that a large, armored structure would compromise access to the lake to nearby homeowners and several boat docks for local condominium residents. Therefore, the size of the forebay would likely be limited to an area that does not inhibit shoreline access, reducing the available capacity of the forebay. Also for safety purposes, the forebay should be contained within the no-wake zone 300 feet from the shoreline. Applying the sampling data from the Mosquito Creek diversion, it is estimated that sediment storage requirements range from 0.6 to 2 acre-feet per year. The proposed forebay (see Figure 8) would incorporate approximately 0.2 acre into the forebay with depths down to 20 feet. This design only creates 4 acre-feet of storage and would have a short lifetime before sediment must be removed to maintain capacity. The size of the structure should be maximized if taken into the final design to reduce the frequency of required maintenance. The ranking for this alternative appears below in Table 10.

Table 10. Forebay Ranking

	Rank	Discussion
Feasibility	Medium (2)	Concerns regarding lake access for local residence that limit size and capacity of structure. Frequent maintenance of an in-lake structure could be difficult and expensive.
Water Quality Benefits	Medium (2)	Medium load reduction is anticipated, assuming This assumes the wet detention pond is not implemented and the forebay would be considered primary treatment for the diverted flow.
Cost	Low (3)	The main expenses are excavation within the lake and the cost to hard armor the structure.
Operation and Maintenance	High (1)	Frequent sediment removal required because of the size restrictions

3.3 Water Quality Management Plan

The water quality management plan (WMP) is created to addresses both watershed alternatives for the uplands directly adjacent to Lake Manawa and in-lake options to reduce internal loading. Ensuring sustainability of the water quality is as important, if not more, than the immediate effects of the alternatives on the lake. The WMP is a culmination of recommended best management practices (BMPs), which are effective, practical, structural or non-structural methods that prevent or reduce the transport of sediment, nutrients, pesticides, and other pollutants to a water body. These practices aim to reduce the pollutant load to the lake to reduce the natural eutrophication process.

Two advisory committees were organized to assist Tetra Tech in identifying the recommended alternatives for the WMP. The watershed council (WC) was composed of community members and stake-holders of the lake. This council helped gauge the feasibility and the level of anticipated public acceptance for each alternative. A technical team (TT) made up of employees of local agencies was organized to help develop alternatives and analyze the feasibility using their technical knowledge.

3.3.1 Watershed Alternatives

As determined in modeling existing conditions, the annual phosphorus load associated with the Lake Manawa watershed is 537 pounds. It is a small percentage of the overall load, but addressing this opportunity for loading reduction can be achieved relatively easily and provides an excellent opportunity to involve users in the overall education process about lake management. At such close proximity to the lake, watershed pollutant loading is quickly transported to the lake, with immediate impacts on the water quality. This source can also be targeted and reduced with relatively simple measures.

The structural BMPs that were investigated for Lake Manawa's watershed apply natural treatment process to overland runoff. Man-made BMPs, such as sand filters, stormwater treatment systems, and infiltration trenches, were not investigated in full detail. These alternatives are more expensive, require frequent maintenance, and are usually applied when space in limited. Limited space is not a major constraint within the watershed, and natural treatment processes were favored for this reason.

The City of Council Bluffs is currently developing stormwater improvements to the residential neighborhood located directly east of the lake. The proposed design implements pervious pavement along the residential streets that are designed to infiltrate and filter stormwater runoff. Based on the proposed stormwater improvements, the east neighborhood was not included in the investigation for further recommendations. Pervious pavement was included in the current model for future conditions; the model can be adjusted after the extents of the stormwater improvements are known.

Aerial photography, topography, and on-site investigations were used to identify feasible locations for the structural alternatives described above. The majority of locations selected were on park or city property; privately owned land was not targeted. However, the alternatives and management practices feasible for private lots are highly recommended and would be further investigated during th8e final design and during a continued watershed management education process. Lake access along the shoreline is common. Access must be taken into consideration during the final placement of the BMPs, ensuring frequent access points to the lake. The locations selected are tentative, as the feasibility of site-specific conditions must be investigated further during the final design.

The recommended alternatives (see Figure 9) are listed and briefly described below:

Structural

- Bioretention: a structural BMP used to treat stormwater, often in urban settings, using native vegetation to filter, increase infiltration, and uptake nutrients. The subsurface soils are engineered, sandy and silt mixtures that encourage infiltration to the surrounding soils. Native vegetation can tolerate extreme climate conditions and has deep-rooted systems to uptake water and increase infiltration. Underdrain pipes can be installed if site conditions are not conducive to deep infiltration. Bioretention cells are implemented in low-lying areas of concentrated flow, often adjacent to impervious area. Locations were selected based on available space within the park and City of Council Bluffs property. Low-lying areas adjacent to parking lots and roads were targeted. Eleven locations were identified that total 1 acre in area, and another 1 acre is recommended within residential lots. Overall, a total of 2 acres (87,120 square feet [ft^2]) of bioretention are recommended for the Lake Manawa watershed.
- Bioswale: a structural BMP that uses native vegetation to filter and increase infiltration as stormwater is conveyed. The design concepts are the same as bioretention, with the added conveyance feature. These BMPs can be implemented in locations such as degrading ditches or concrete-lined channels. Locations were selected based on available space within the park and City of Council Bluffs property. Existing flow paths that currently provide minimal water treatment were targeted. Bioswales are also recommended in areas adjacent of parking lots and roadways within the watershed. A total of 5,500 linear feet (approximately 2 acres by applying a 15-feet average width) are recommended.

- Wet Detention: wet detention structures treat stormwater by retaining water for extended periods to allow pollutants to settle out of the water column. Wetland vegetation will also be incorporated that uptake nutrients with their biotic processes. Only one location within the watershed was identified for implementation of this alternative. With such flat terrain, few areas of concentrated flow exist that would warrant the wet basin, instead of a bioretention cell. The location that drains 17 acres of residential area northwest of the lake was selected for 0.2 acre of wet detention.
- Vegetated Buffer Strip: a simple structural BMP that uses filtration from native vegetation. This BMP is a strip ranging in 10 to 100 feet wide of native vegetation planted around the perimeter of water bodies, filtering unconcentrated runoff. Approximately 8,950 feet of vegetated buffer strip are recommended around the perimeter of Lake Manawa. Locations were selected around the entire lake that are not already adequate vegetated. Areas adjacent to roads were targeted; however, breaks in the buffer were created to ensure access points to the shoreline. The width of the buffer strip is limited by the close proximity of the road, averaging around 15 feet.
- Water Quality Drain Inserts: a structural BMP inserted into stormwater sewer inlets to trap and filter pollutant latent (usually grease and oil from roads) runoff before it is discharged into the lake. This method is effective in removing common roadway pollutants, such as sediment, oil, and grease; however, the trapping efficiency for phosphorus is low. All the storm inlets within the residential neighborhoods that lead to Lake Manawa were selected for this alternative, totaling 16 water quality drain inserts.

Non-Structural

- Fertilizer Management: an ordinance within the watershed that requires monitoring the fertilizer spread on residential and commercial lawns in the watershed. No-phosphorus fertilizer is recommended, unless a need for phosphorous fertilizer is indicated by soil sampling. Otherwise, low-phosphorus fertilizer is an acceptable alternative. Dosing rates, frequency, and application methods are also management practices that should be performed correctly. This ordinance is recommended for the entire watershed. Soil should be sampled in each residential lot to assess phosphorus fertilizer needs.
- Pet Waste Management: an ordinance that requires owners to pick up pet waste and dispose of it properly. This ordinance would include all areas in the watershed, including residential lots. This ordinance is recommended for the entire watershed. Approximately 10 receptacles are recommended around the lake and within the high-use park area.
- Street Sweeping: a regular street sweeping route implemented on the streets within the Lake Manawa watershed would collect sediments, oils, and greases and prevent their transport to the lake.
- Water Fowl: as with all lake management studies, opportunities to control waterfowl should be employed. Waterfowl, and particularly geese, add to the bacteria and phosphorous loading to the lake with the relatively large amount of waste a goose produces every day. It is difficult to discourage geese from large

areas of open water, but all opportunities to control use of the lake by waterfowl should be employed. These opportunities usually come in the way of designating lake use areas, planned shoreline vegetation, and park management practices.

An information and education committee is essential for public awareness and implementation of the non-structural alternatives. Public acceptance of the alternatives is imperative for them to be successfully implemented. Methods of enforcement must also be identified if the non-structural alternatives are selected. To help provide a scientific background to a management practice, soil should be sampled on lots where fertilizers are applied. Sampling would include residential, commercial, park, and golf course areas. The results will indicate whether the phosphorus levels in the soils are adequate to maintain healthy lawns and do not need additional phosphorus. The watershed alternatives are ranked in Table 11.

Table 11. Watershed Alternatives Ranking

	Rank	Discussion
Feasibility	High (3)	Minimal concerns with this alternative. Coordination with land owners to implement alternative will be necessary.
Water Quality Benefits	Low (1)	The alternative significantly reduced the load produced by the watershed; however the impact to the total pollutant load was low.
Cost	Low (3)	The main expenses are earthwork grading and materials for the structural alternatives.
Operation and Maintenance	Medium (2)	Vegetation management of several watershed BMPs

3.3.2 In-Lake Alternatives

The existing conditions model indicated that 1,810 pounds of the annual phosphorus load can be attributed to internal loading. This amount is a large portion (34 percent) of the total load that will be addressed by implementing recommended in-lake alternatives. Dredging is one in-lake alternative that will be investigated in greater detail in Section 4. The in-lake alternatives investigated for Lake Manawa include the structural and non-structural options listed and described below.

Structural

- Wetlands: in-lake wetlands develop in the shallow areas of the lake. Wetland vegetation treats the water though uptake of nutrients. Not only do they treat the water, but they act in competition with algae for their food source (phosphorus). Wetlands also help prevent resuspension of bottom sediment. They create natural no-wake zones where speed is limited by the shallow depths and vegetation, and the root systems anchor the lake bottom sediments and the vegetation dampens out wakes produced by wind or boating. Using aerial imagery and lake bathymetry maps, 100 acres were identified as suitable locations for wetland creation within the lake. Armoring wetland areas with riprap or protecting them with other applications such as geotubes near common boating areas would protect them from wave action (and can also help to create suitable spawning areas to promote the fishery).

- Shoreline Stabilization: the protection or enhancement of eroding shorelines. Stabilization methods include hard-armored structures, such as jetties and breakwaters, or lining the shoreline with rock riprap. In areas with low susceptibility to erosion, “softer” or natural approaches can be applied. These other approaches include geotubes, shoreline regarding, and wetlands. Shoreline stabilization reduces the amount of erosion and the associated sediment load to the lake. Locations of eroding shoreline were targeted for stabilizations, totaling approximately 1,500 feet recommended for treatment.
- Sediment Forebays: sediment traps located at outfalls into the lake. The few outlets that empty into the lake have small drainage areas and the pollutant load was low enough that it did not warrant the high material construction costs of the structures.

Non-Structural

- Watercraft Management: an ordinance for the lake that would restrict speeds in specified areas in addition the 300-feet no-wake zone around the perimeter (approximately 240 acres). By implementing no-wake zones, the area within the lake that is susceptible to resuspension of lake bottom material decreases and the internal load is reduced. The locations would depend on the dredging plan. The area that would remain shallow (8 or less feet deep) would be targeted. This BMP will be investigated in greater detail during the final design, but it is anticipated that no-wake zones would not greatly affect the common boating paths on Lake Manawa. It is also possible that restricting motor sizes may have a positive effect on reducing lake bottom resuspension.

Several factors were considered when the locations for the alternatives within the lake were identified. Obstruction to boating paths should be avoided as much as possible in to gain public acceptance. Therefore, existing and potential no-wake zones would be ideal wetland locations. Growth and enhancement of existing wetlands in areas along the shoreline are recommended. However, shoreline access to the lake is also a consideration for wetland placement. Wetlands provide aquatic habitat, but open water is also desired for angler access. The majority of Lake Manawa’s shoreline is currently hard armored with rock riprap in areas that experience frequent wave impacts. An on-site inspection was conducted to identify eroding shoreline that needs to be addressed. Hard-armored structures should be implemented in locations within the vicinity of high-traffic boating or in areas with long fetch lengths. The softer approaches should be selected when they apply to create a more natural effect. The WC was also consulted to assist in selecting ideal alternative locations to ensure public acceptance. The rankings for this alternative are shown in Table 12.

Table 12. In-Lake Alternatives Ranking

	Rank	Discussion
Feasibility	High (3)	Minimal concerns with these alternatives. The placement of these alternatives will favor locations that avoid the common boating paths.
Water Quality Benefits	Low (1)	The combined reduction of the alternatives is somewhat low compared with the total load in the lake.
Cost	High (1)	The main expenses are associated with hard armoring that protects the shoreline or wetlands. The worst-case scenario was assumed (solid rock riprap hard armoring), but it is likely cheaper options could be applied.
Operation and Maintenance	Low (3)	Limited maintenance, mostly to monitor the stability of structures.

3.4 Whole Lake Alum Application

The application of alum to the entire water surface of the lake will bind with the phosphorus in the lake's water column, forming a floc and settling to the bottom. This binding of phosphorus prevents it from being an available source of food for algae. The settled floc also addresses internal loading by preventing the release of phosphorus from the soils along bottom of the lake. Whole lake treatment is a one-time application that remains effective for approximately 10 years, as summarized in Table 13.

Table 13. Whole Lake Alum Application Ranking

	Rank	Discussion
Feasibility	High (3)	Highly feasible. A minor concern is that alum application would require limited activity on the lake for a short period of time (2 to 3 weeks).
Water Quality Benefits	Medium (2)	Treatment would result in high phosphorus removal; however, the alternative incorporates no sediment reduction.
Cost	Medium (2)	The cost is associated with the cost of the chemical applied to the large surface area of the lake.
Operation and Maintenance	Medium (2)	Maintenance associated with the need for alum to be reapplied once the treatment is no longer effective.

3.5 Dredging

Dredging is the excavation of material from beneath a water body. Dredging would alter the water quality of Lake Manawa in two ways: it would reduce the internal pollutant load, and it would improve the lake's response to pollutant loading. Increases to both mean lake depth and total storage volume are experienced with dredging. Increasing the depth would reduce the total lake bottom area susceptible to resuspension by water craft, and therefore reduce the internal pollutant load. The increase in water volume will help dilute the pollutant load in the lake and increase the residence time. Incorporating some deeper areas into the lake will also allow for some stratification in the lake, and therefore promote the seasonal turnover that promotes lake health.

In terms of water quality, the benefits of dredging Lake Manawa will be great. Under normal circumstances, a dredge operation of such large magnitude would likely not be considered because of the economic feasibility. Since IDOT is interested in purchasing the material from IDNR after it has been excavated, however, this option is now economically feasible. From the standpoint of water quality and cost, this alternative is highly favored. A detailed analysis of the feasibility and dredging methods for Lake Manawa is located in Section 4.

Table 14. Dredging Ranking

	Rank	**Discussion**
Feasibility	High (3)	See Section 4.
Water Quality Benefits	High (3)	A reduction to the annul load is anticipated from reducing the amount of area susceptible to resuspension. Additional improvements are attributed to dredging for the lake's response to a given pollutant load (reduced pollutant concentrations).
Cost	High (1)	Reimbursement from IDOT reduces the extremely high cost associated with dredging; however, large volumes will still create substantial costs.
Operation and Maintenance	Low (3)	None.

3.6 Other

Miscellaneous options to improve the water quality of Lake Manawa include a water quality monitor on the Mosquito Creek diversion structure and potential options for alternative sources of water.

3.6.1 Water Quality Monitor

A water quality monitor was previously implemented on the Mosquito Creek diversion structure. The monitor would take turbidity readings and the gate allowing flow to Lake Manawa would be triggered to close when levels become too high. Although this monitor works in concept, in actuality, lake levels, and not water quality, govern when the gate opened and closed. If the monitor triggers the gate to close because of poor clarity but the lake levels are low, the gate will be manually reopened. The main advantage of the monitor is to prevent pollutant-laden flushes that occur during rain events from being diverted into the lake. This monitor was washed away during a flood, and replacing it is an alternative to help reduce the pollutant load to the lake. If implemented, measures should be taken to secure the monitor to prevent another washout. This option is summarized in Table 15.

Table 15. Water Quality Ranking

	Rank	Discussion
Feasibility	High (3)	No concerns with this alternative.
Water Quality Benefits	Low (1)	The load reduction is attributed to preventing the pollutant-laden first flush from entering the lake.
Cost	Low (3)	The main expense is the monitor and reinforcements to prevent it from washing away.
Operation and Maintenance	Low (3)	Monitor periodically to ensure performance.

3.6.2 Alternative Water Source

With numerous hydrologic features in the area, it is possible that Mosquito Creek may not be the best source of water to help maintain the water surface elevation in Lake Manawa. Major factors to consider would be the quality of water, available volume of water, and the cost to convey the water to the lake. Although the quality of water currently received from the Mosquito Creek diversion is poor, the quantity is never in short supply, and there is little cost since it is conveyed to Lake Manawa via a gravity flow system. The other potential options are Indian Creek, Lateral 5 Drainage Ditch, and groundwater.

The water quality of Indian Creek is unknown, as there are no sampling data. By analyzing the drainage area, pollutants associated with an urban runoff are anticipated. The sediment load would likely be less than in Mosquito Creek, but the nutrient load would likely be similar. The quality and quantity would not rule out Indian Creek as a source of water to Lake Manawa; however, the method of transport and associated cost prevent this option from becoming favorable. A structure to impound water and create head between the two features would be necessary to divert the water using gravity flow. The same elevation restrictions apply that were discussed for the collapsible weir structure. The maximum water surface of Indian Creek to is 962 feet amsl to avoid submerging or reducing the capacity of a storm sewer that outlets into Indian Creek. Therefore, a pumping system with annual power costs would be necessary to transport water to the lake.

Lateral 5 Drainage Ditch drains a portion of the City of Council Bluffs and would be expected to carry the same urban pollutant load as Indian Creek. With such a small drainage area, baseflow conditions of the ditch would likely not carry sufficient volumes to provide the required quantity of water during dry periods.

Groundwater is generally of higher quality than surface water since it experiences natural filtration as it flows through soil. Quantity would not be an issue, but the method to transport water to the lake would require an additional energy source. Another consideration would be the drawdown effects of pumping in the vicinity of the lake on water surface elevation of Lake Manawa. If this option were selected as a favorable alternative, drawdown would need to be investigated in further detail.

After the alternative water sources for Lake Manawa were considered, it is apparent that each source has its own drawbacks. It is preferred to keep a source of water that does not require annual pumping costs to transport water to the lake. Therefore, Mosquito Creek will remain the main source of water to the lake, as long as the quality and quantity are addressed through the methods described above. If it is determined that the goals cannot be met after the methods have been applied, then this alternative should be revisited. No further investigation was performed for preliminary design of this alternative.

3.7 Alternatives Comparison

As the alternatives presented above are assessed, the primary benefit of concern is the ultimate effect on water quality in the lake, although there are multiple benefits of each. Because this study has focused on the reduction of the phosphorous loading to the lake as the catalyst to improve water quality, the "effectiveness" of each alternative is ultimately graded by its net effect on the lake's water quality. Throughout the project, additional considerations, such as the feasibility, cost, and operation and maintenance requirements, were also analyzed and described in the sections above. The tables below present a summary of all the alternatives and how they compare with one another.

Table 16. Mosquito Creek Treatment Alternatives Ranking

	Wet Detention	Forebay	Alum Injection
Feasibility	3	2	3
Water Quality Benefit	3	2	2
Cost	3	3	3
Maintenance Requirements	2	1	2
Total	**11**	**8**	**10**

Table 17. Seepage Reduction Alternatives Ranking

	Collapsible Weir	Relocate Indian 1	Relocate Indian 2	Subsurface Wall 1	Subsurface Wall 2
Feasibility	2	2	2	2	2
Water Quality Benefit	2	2	3	3	2
Cost	3	1	1	0	1
Maintenance Requirements	3	3	3	3	3
Total	**10**	**8**	**9**	**8**	**8**

Table 18. Watershed Treatment Ranking

	Lake Manawa Watershed BMPs
Feasibility	3
Water Quality Benefit	1
Cost	3
Maintenance Requirements	2
Total	**9**

Table 19. Internal Load Reduction Alternatives Ranking

	Dredging	Lake Manawa In-Lake BMPs	Whole Lake Alum
Feasibility	3	3	3
Water Quality Benefit	3	1	2
Cost	1	1	2
Maintenance Requirements	3	3	2
Total	**10**	**8**	**9**

The estimated cost and phosphorus reductions were developed for each alternative (see table below). This estimate includes dredging as a phosphorus load reduction alternative, but it does not represent the positive effect of dredging on water quality by altering the lake's response to pollutant loading. The load reduction that is included is associated with reducing the amount of lake bottom surface area that is susceptible to resuspension (area shallower than approximately 8 feet) that contributes to the internal load. Three of the alternatives shown — the collapsible weir in Indian Creek, the relocation of Indian Creek, and the slurry cut-off walls — do not reduce phosphorus loading at all. Rather, they reduce the total seepage from the lake and therefore reduce the amount of water required from Mosquito Creek to keep the lake full. The total phosphorus loading reduction is therefore the total phosphorus in the water no longer needed from Mosquito Creek for this level of seepage reduction. Land rights and construction costs (with a 20 percent contingency) were used to develop the cost estimates, shown in Table 20.

Table 20. Alternatives Cost and Reduction

Mosquito Creek Treatment	Reduction (lbs/yr)	Cost	Cost/lb
Wet Detention Basin	1,770	$598,560	$338
Forebay	590	$305,712	$518
Alum injection	2,360	$84,000	$36

Indian Creek- Seepage Reduction	Reduction (lbs/yr)	Cost	Cost/lb
Collapsible Weir	672	$460,000	$685
Relocate Indian 1	336	$3,615,480	$10,764
Relocate Indian 2	1,114	$5,998,800	$5,387
Subsurface Cut-Off Wall-1	1,900	$11,975,009	$6,303
Subsurface Cut-Off Wall-2	836	$5,789,223	$6,929

Lake Manawa Watershed	Reduction (lbs/yr)	Cost	Cost/lb
Lake Manawa Watershed BMPs	364	$203,757	$560

Internal

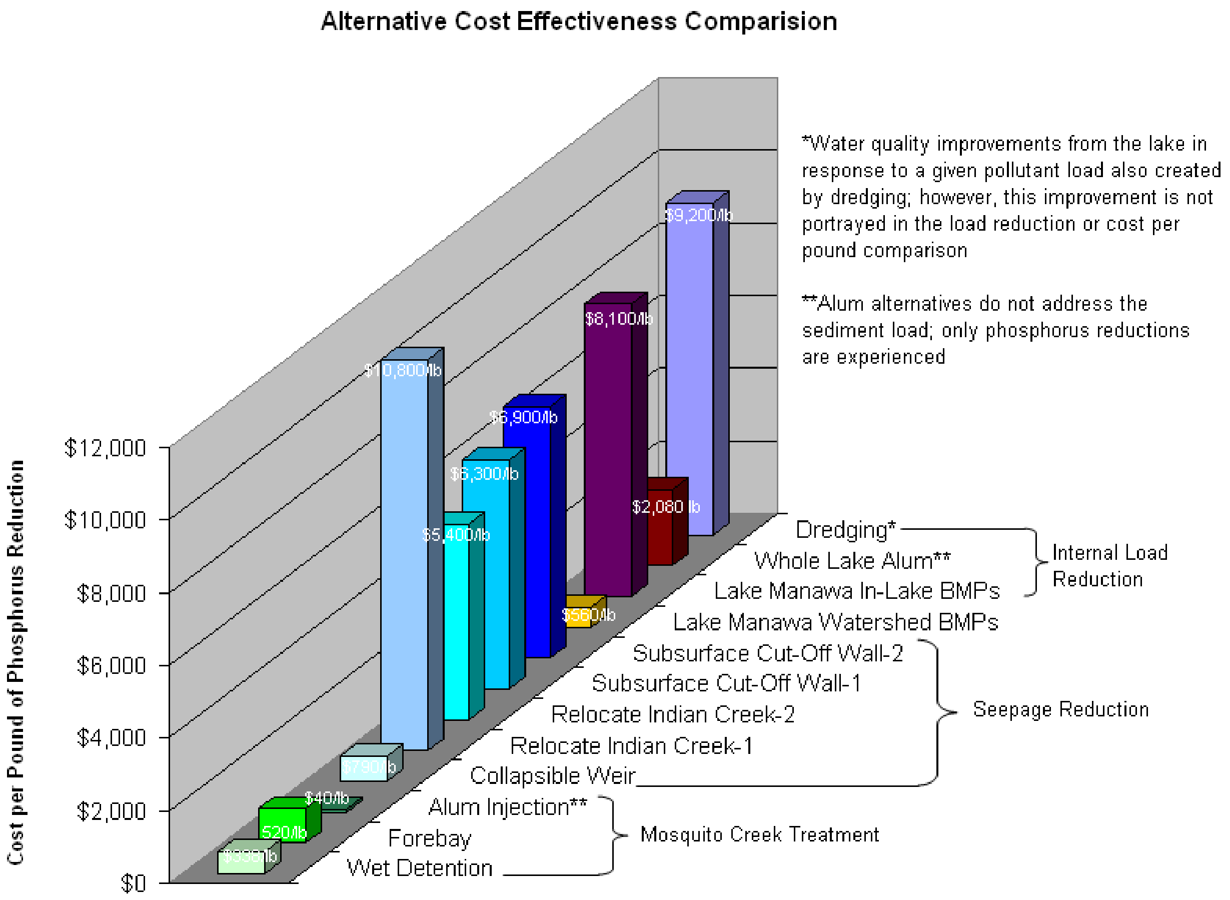
	Reduction (lbs/yr)	Cost	Cost/lb
Lake Manawa In-Lake BMPs	181	$1,457,475	$8,057
Dredging*	661	$6,050,000	$9,158
Whole lake alum	814	$1,691,429	$2,077

Other

	Reduction (lbs/yr)	Cost	Cost/lb
Water Quality Monitor	10	$4,000	$400

*Water quality improvements from the lake in response to a given pollutant load also created by dredging; however, this improvement is not portrayed in the load reduction or cost per pound comparison

A graphical representation of the values in Table 20 was created to show the cost effectiveness of each alternative studied to prevent phosphorous from entering the lake.



*Water quality improvements from the lake in response to a given pollutant load also created by dredging; however, this improvement is not portrayed in the load reduction or cost per pound comparison

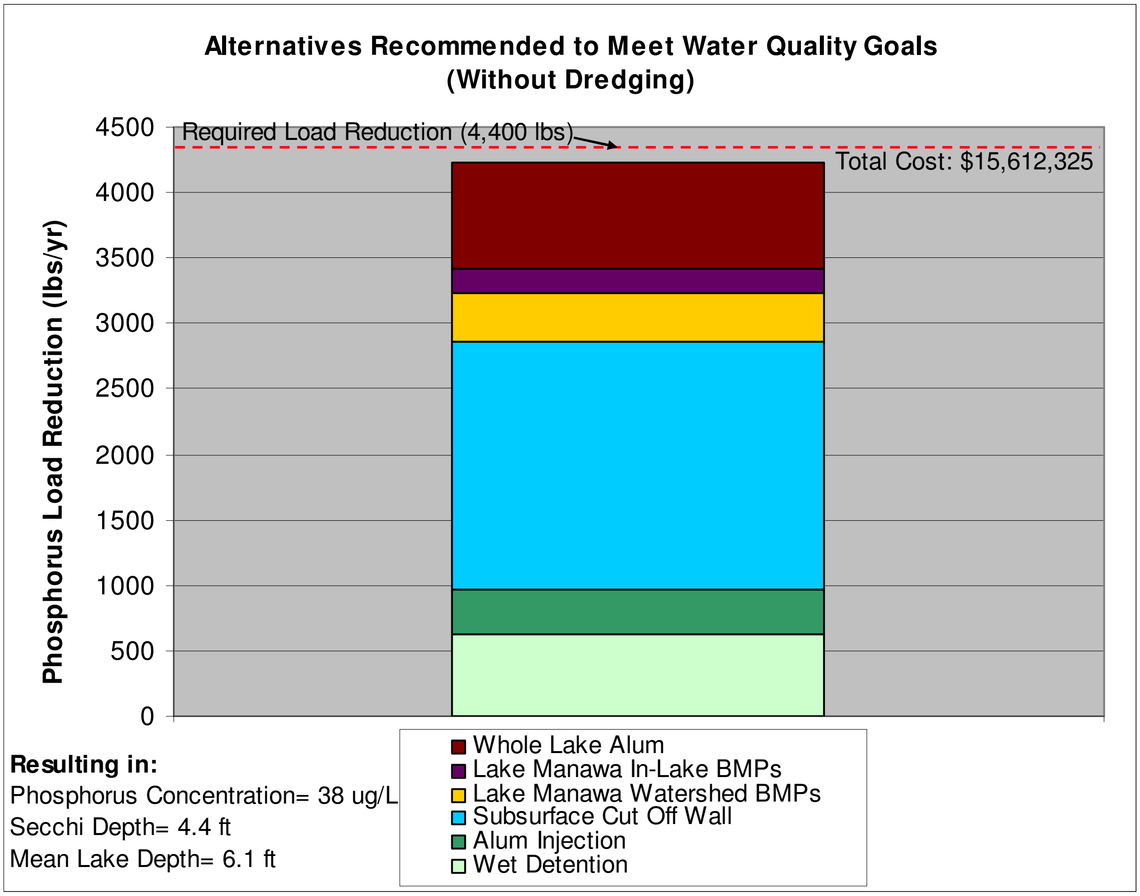
**Alum alternatives do not address the sediment load; only phosphorus reductions are experienced

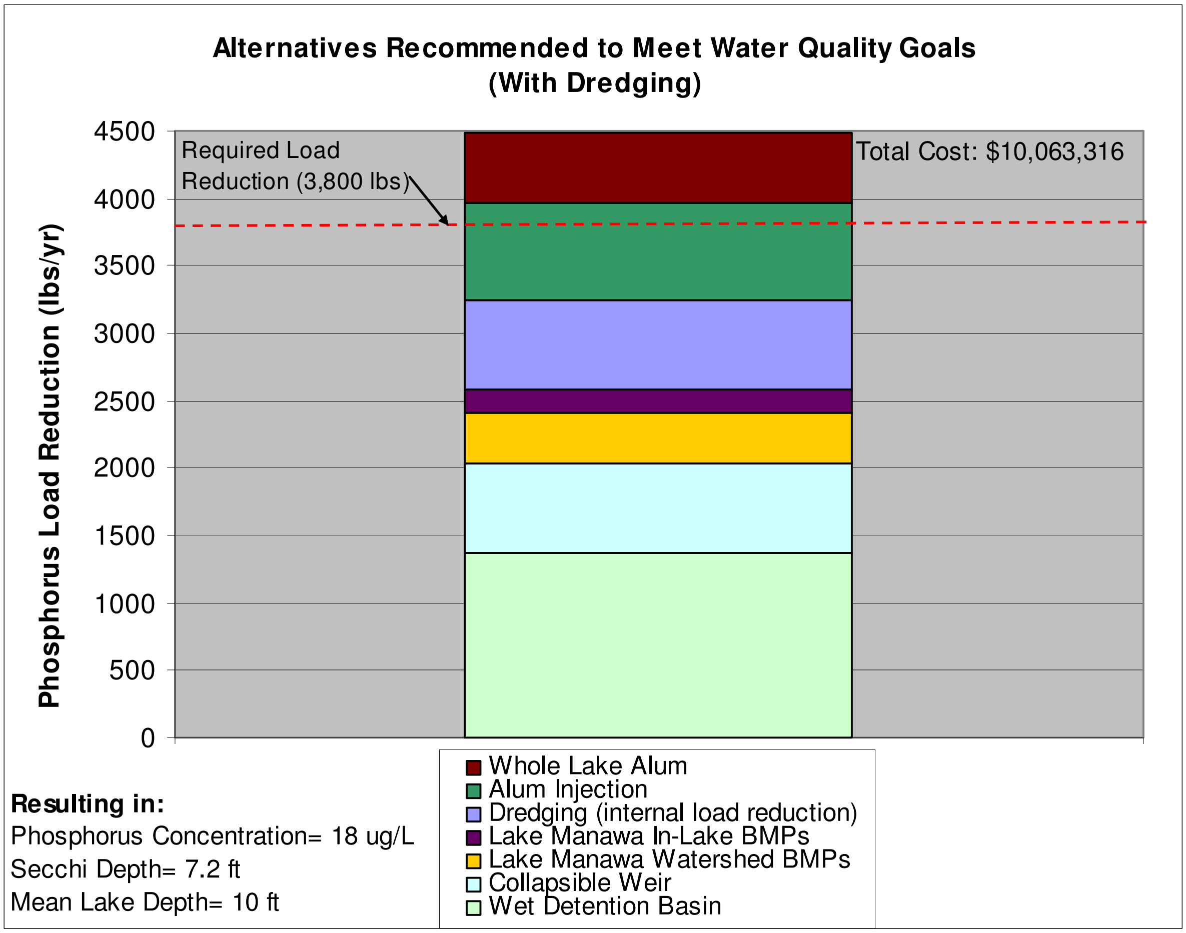
3.8 Achieving Water Quality Goals and Recommended Alternatives

The approaches to improving water quality are either to reduce the pollutant load, alter the physical characteristics of the lake, or implement a combination of the two. The water quality summary figure depicts the depths or pollutant load reductions necessary to meet the water quality goals (see Figure 10). Simple economics dictates that the lowest unit cost methods of achieving the reduction goals should be maximized. Some of the goals, however, involve hard limits based on the total reduction amount available through that method, or may be subject to limits that are a function of the law of diminishing returns. An additional qualification is that all of the information is based on the effects dictated by information known to date. It is possible that additional information that may be obtained in future phases of the project may have a significant effect on the effectiveness (either performance or cost to achieve it) of the alternatives. As with most projects, it is assumed that the plan forward is a work in progress and will be adjusted as additional information is obtained.

Two project scenarios are shown below depicting the alternatives necessary to achieve (or nearly achieve) the project's water quality goals. As can be seen, two scenarios have been created, one that does not assume dredging and one that does. With the dredging project scenario, the required loading reduction is much lower, given the additional volume of water in the lake for dilution that affects the lake's response to pollutant loading. This comparison assumed that dredging the lake would result in depths that meet IDNR's goal of an average of 10 feet. Approximately 5 million cubic yards (CY) would need to be dredged to achieve these depths.

The load estimates included below will vary from the numbers reported in the table above for some alternatives, depending on the combination of alternatives implemented. (For example, the wet detention basin treatment and alum injection values are reduced when seepage reduction alternatives are implemented that decrease the volume of water delivered to the basin.)





The scenario without dredging incorporates the most aggressive phosphorus reduction methods to come close to meeting the water quality goals. The dredging scenario by far exceeds the water quality goals for this project (as shown on Figure 10), and contains the recommended set of alternatives for implementation. Although the Lake Manawa In-Lake BMPs did not rank highly in the comparison methods above (primarily because of the high cost of hard armored shoreline stabilization structures), they are still recommended. Shoreline stabilization not only contributes to improving water quality, but increases the aesthetic appeal and accessibility to the lake. The remaining alternatives recommended are based on the results of the comparison methods above and create the most cost-effective plan to reach the water quality goals. Whole lake alum would be optional in this scenario, as the load reduction is met without this alternative. However, a one-time treatment after dredging takes place would be strongly recommended as a remedial measure to address the additional phosphorus load created by disturbing and removing the lake bottom sediments. Table 21 provides a summary of the phosphorus reductions and cost estimates for the recommended alternatives.

Table 21. Recommended Alternatives Summary

	Reduction (lbs/yr)	Cost
Wet Detention Basin with Collapsible Weir	1367	$478,560
Alum injection (secondary) with Collapsible Weir	729	$84,000
Collapsible Weir	672	$460,000
Lake Manawa Watershed BMPs	364	$203,757
Lake Manawa In-Lake BMPs	181	$1,457,475
Dredging	661	$6,050,000
Whole Lake Alum with Dredging	517	$1,691,429
Water Quality Monitor	10	$4,000
Total	**4,500**	**$10,063,316**

4.0 DREDGING ANALYSIS

As discussed above, dredging significant quantities of material from Lake Manawa will add to localized and mean lake depths and increase the total lake volume, two significant physical factors in determining the lake's response to its pollutant loading. Unlike most lake dredging projects, the unit cost of the material is not the driving factor since it was concluded that the unit cost of acquiring the targeted material may be similar to alternative sources available to IDOT.

4.1 Feasibility

As discussed above, the feasibility of the dredging project switched its focus from unit cost to other secondary considerations such as project schedules, environmental impacts, and improvements to the aquatic ecology. This is not to say that minimizing costs is not important; instead, costs are not as critical to the feasibility of the project given the opportunity to work cooperatively with IDOT.

4.1.1 Geotechnical Considerations

The geotechnical feasibility of the dredging project focused on the targeted materials and their ultimate, potential use as fill in an interstate highway project. Some details on the extraction, handling, storage, and delivery of the materials would have to be worked out during final design, but no immediate concerns were noted. The feasibility of the dredging alternatives focused instead on the end use of the materials. Figures 11 and 12 show a general summary of the location and properties of the materials considered for this analysis.

Based on this review of the materials and test data presented in the GSI report, the majority of the materials identified in the borings from Lake Manawa are suitable for use as highway embankment fill. Regardless of the method ultimately chosen to remove sediments from the lake bottom, the materials will need to be spread and allowed to dry after excavation and before use as fill. If it is possible to segregate the sand and the silt and sand mixture from the lacustrine layer, drying will be enhanced for the sand and the sand and silt. Large, low stockpiles, frequent processing, and warm weather conditions will also reduce drying time.

The sand and sand and silt materials can be combined during excavation or processing to form a suitable embankment fill material. After suitable drying, portions of the lacustrine material could be mixed with the sand and sand and silt material to improve its engineering properties. The quantities of each material that are available will depend on the dredging methods used. If only sand and silt and sand materials are mixed, a fill that has less than 25 percent silt and clay materials can be achieved. As lacustrine materials are added, the percent passing the No. 200 sieve and the organic content of the fill would increase rapidly. The strength and suitability of the materials could be improved significantly by stabilization using available fly ash. Headwaters Resources has Class C fly ash available in the area and that it has been successfully used with soils similar to those found below Lake Manawa to improve the engineering properties of the soils. Experience with fly ash stabilization for road subgrade indicates that the site soils could be blended with the available fly ash to form a suitable embankment fill with engineering properties superior to those of the untreated soils. The optimum percentages of fly ash, sand and silt, and lacustrine soils will need to be established in a laboratory using suitable samples of each material.

The sand and sand and silt materials could also be used to construct temporary access berms or roads to facilitate the dredging operations. A woven geotextile fabric will be needed to help stabilize these berms or roads for the construction traffic.

4.1.2 Effects on Seepage

Even the earliest discussions about this project identified the potential effects of dredging on the seepage exiting Lake Manawa and the local groundwater table. Through calibrating the water budget model and establishing several groundwater models, guidelines for estimating the net effects of the dredging component of the project have been devised. At this time, several project specifics are missing, including the total volume of material to be dredged, the mix of materials necessary to maximize the quality of the potential road fill, and the in situ material depth layers in several areas of the lake. All of this information would be determined during final design. Some assumptions were made and are described here to further investigate the effect of the dredging project.

The net effects on the water budget can also be computed because the current seepage rates have been established. For long-range planning, the effects on seepage have two effects on the water budget: first any reductions in the overall seepage have the same overall effect on the water budget in that they reduce the outflow and therefore also reduce the required inflow from Mosquito Creek. Second, any reductions in the required inflow from Mosquito Creek come with the added benefit that the pollutant load associated with the inflow from Mosquito Creek is also avoided. Therefore, attempts at reducing seepage have significant benefits.

In the model used, the controlling factor in the seepage estimate is the thickness of the lacustrine layer, as it serves as the controlling factor in the overall transmissivity rate. The thickness of the lacustrine layer was modeled at the sections analyzed, based on the available geotechnical information and on the geophysics information obtained during this study. The net effects on the seepage were modeled at each location by removing the lacustrine layer and then both replacing the layer (by incorporating a thin compacted clay layer) and leaving the underlying sand exposed. When the dredging and the replacement of the seal were modeled, seepage rates are actually reduced by the low permeability of the compacted clay layer. These rates are not reported in the table below, as the realistic ability to compact a clay seal is still in question and would vary with each dredging method. The results of dredging and leaving sand exposed are located in the table below. Ultimately, whether the lacustrine layer is replaced will be a function of the final dredging plan (location and depth of excavation planned) and water quality improvements made. The example project with costs for this study assumed that the lacustrine layer was replaced at all locations at a depth to match the pre-project seepage rates, as shown in Table 22.

Table 22. Post-Dredging Seepage Rates (No Lacustrine Layer Replacement)

Missouri River High

Section	Approximate Increase Seepage Rates with Dredging Alternatives (ac-ft/d)		
	Existing	5 Foot Depth	10 Foot Depth
A – Seepage to Indian Creek*	5.90	5.95	6.66
B – Seepage to the Missouri River**	3.69	3.87	3.89
D – Seepage to Mosquito Creek**	0.21	0.25	0.30
E – Seepage to Missouri**	1.80	2.22	4.03
Total	11.60	12.29	14.88
% Increase	---	6%	28%

Missouri River Low

Section	Approximate Increase Seepage Rates with Dredging Alternatives (ac-ft/d)		
	Existing	5 Foot Depth	10 Foot Depth
A – Seepage to Indian Creek*	5.90	5.95	6.66
B – Seepage to the Missouri River**	6.07	6.38	6.42
D – Seepage to Mosquito Creek**	0.21	0.25	0.30
E – Seepage to Missouri**	3.75	4.58	5.41
Total	15.93	17.16	18.79
% Increase	---	8%	18%

* Assumed 10-foot lacustrine thickness, sand exposed when dredged to 10 feet
**Assumed 5-foot lacustrine thickness, sand exposed when dredged to 5 and 10 feet

The 5-foot dredge depth model represents the effects of dredging and exposing sand in the majority of the lake, except for area adjacent to Indian Creek. The lacustrine layer is thicker at this location, and with this model 5 feet of the lacustrine material would remain in place. The 10-foot dredge depth model represents exposing sand in the entire lake.

4.2 Dredging Method Alternatives

Several known dredging methods are detailed below. As stated in Section 4.1.1 above, the exact quantity of both the overall materials and specific materials are not known at this time. Therefore, to compare the dredging alternatives, it was generally assumed that the project would target acquiring as much as possible of the desired sand materials (thereby reducing out-of-lake use of the overburden) as a percentage of the total material dredged. This approach would minimize any uncertainty in the drying time and mixing of lacustrine materials with sand or fly ash. During final design, and after some of the unknowns stated above are answered, the trade-offs of moving lacustrine materials once and perhaps twice to acquire the desired sand materials as compared with using the lacustrine materials in an engineered soil mixture will be analyzed.

A dredging prioritization map was prepared that is pertinent to all of the dredging alternatives discussed below, except for the sub-surface dredging option, to facilitate access to the desired sand material and reduce potential effects to the lake seepage. That map is shown as Figure 13 and represents only of the two criteria discussed above. It is understood that some post-dredging "sculpting" of the lake bottom may need to take place to achieve some of the depth diversity desired in the lake. Therefore, the effort required for the "sculpting" was considered equal to analyze the dredging alternatives. Each dredging alternative was investigated and analyzed based on the following parameters: cost, risk of success, construction timeline, environmental and aquatic habitat impact, impact to fishery, temporary water quality impact, and odor and intangibles. Note that when these parameters are ranked below, it is not an analysis of the effects of removing large volumes of sediment from the lake bottom, but of the advantages and disadvantages of each different method in doing so. The cost and risk of success parameters were considered two of the driving factors in the selection of a dredging method; therefore, they were weighted more heavily than others during the analysis. Additionally, it was assumed that the dredging project was to access the sand material below the overburden and that the entire overburden would be considered unusable.

4.2.1 Dry Mechanical Dredging

Dry mechanical dredging is the name given to the process of removing dredged material mechanically (versus hydraulically) with machinery from a drained lake. Many types of construction equipment can be used to remove the dredged material, depending on how well the lake bed dries out and how stable the lake bed is to support machinery traffic. Because the effort to remove the unusable portions of the overburden is part of this process, targeting areas that minimize the unusable overburden removal quantities is a priority. The mechanical dredging alternative does not require removing the majority of the unusable overburden from the lake area, but rather can move it aside temporarily.

As the dredging is conducted, unusable overburden must be removed or moved aside so that access to the desired material can be gained. It is possible that this material may provide some benefit to the construction process as coffer dams or to help direct surface drainage. However, in general, minimizing the need to move any unusable material will reduce construction costs. Once materials are removed, the unusable overburden can be used to fill in areas where desired materials were removed and possibly to restore a seal above the sandy, more hydraulically conductive areas

Mechanical dredging can become burdensome if the lake bed cannot be dried to a workable state. Therefore, significant dewatering may be required to keep the lake bed dry enough to support heavy construction equipment. It may take considerable time before localized groundwater can be drained down enough not to cause seepage problems within the drained lake because Lake Manawa acts as a perched aquifer. Existing groundwater contours indicate that groundwater enters the lake from the north at an elevation higher than the lake bed, and therefore may provide a lasting source of seepage into the lake.

Furthermore, no system is in place to drain the lake. Pumping the lake down would be costly. To effectively drain the lake, an open ditch would likely have to be cut from the south side of the lake to the Missouri River to supplement water that would drain from normal seepage. Even if the lake were drained, the inflow of groundwater would likely create unfavorable work conditions, and water management plans (including sump pumps) would most certainly be necessary. The cost to continuously supply energy to dewater the lake will be included in the analysis of this alterative.

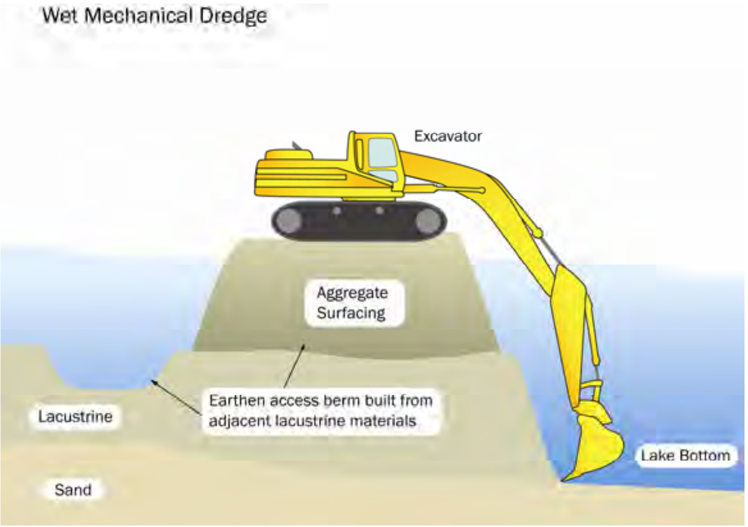
Table 23. Dry Mechanical Dredge Ranking

Weight	Criterion	Rank	Weighted Rank	Description
2	**Cost**	Medium (2)	4	Pros: Inexpensive unit cost, overburden easier to manage
				Cons: Must remove overburden, significant dewatering is needed, impact to at least one recreation season
2	**Risk of Success/ Feasibility**	Medium (2)	4	Pros: Reliable equipment and process to reach desired material, easy to segregate materials during construction, easy to replace seal if necessary
				Cons: Very difficult to manage seepage (into lake) during construction
1	**Construction Timeline**	Medium (2)	2	Pros: Being able to see material reduces unknowns; once lakebed is dry, excavation is reasonably fast
				Cons: Ideal to construct in drier, warmer conditions but groundwater will be lower in the winter
1	**Environmental/ Aquatic Habitat Impact**	Low (1)	1	Pros: Very easy to create depth diversity, easy to re-vegetate
				Cons: Entire lake must be drained, most existing habitat destroyed
1	**Impact to Fishery**	Medium (2)	2	Pros: New fishery to have well sculpted habitat

Weight	Criterion	Rank	Weighted Rank	Description
				Cons: Fishery lost during construction
1	**Temporary Water Quality Impact**	Medium (2)	2	Pros: None
				Cons: Turbidity when re-filling lake
1	**Odor/Intangibles**	Low (1)	1	Pros: None
				Cons: High chance of odor problems when lake is dry

4.2.2 Wet Mechanical Dredging

A wet mechanical dredge is the name given to the process of removing dredged material mechanically (versus hydraulically) with machinery without draining the lake. More than likely, an excavator will be used to remove both the overburden and target material. Targeting areas that minimize any unusable overburden removal quantities is a priority because the effort to remove the unusable portions of the overburden is part of this process.



This method is likely to be conducted either by a barge-mounted excavator or by reaching the material from a land-based vantage point above the lake. The land-based dredging method will be limited by the reach of the excavator (the "stick length") in terms of what can be reached from the shoreline. To provide access to the entire target area, it is possible that access berms will be constructed within the lake area. The number, length, and location of the access berms are a function of the depth that can be reached with the excavator. (The deeper it can reach, the smaller the area that needs to be covered to obtain the desired dredge volume.) The materials needed to construct the access berms must be stable enough for the heavy equipment to do its work. On-site materials will likely have to be mixed with coarse aggregates to form a base that will support heavy machinery.

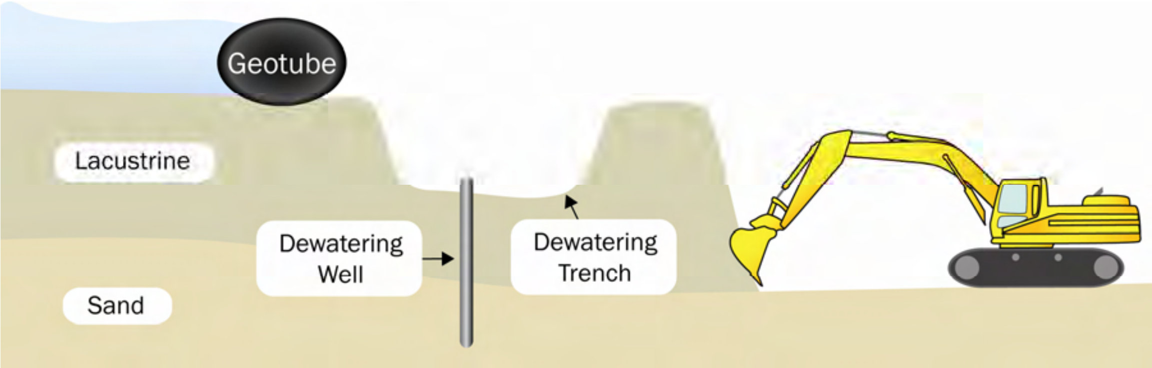
Once the dredging is completed, the access berms could be left in place, but many will cause considerable disruptions to boating. Therefore, the access berm materials can either be removed completely, pushed into the excavated areas, or relocated to the next access berm area. Table 24 shows the ranking for this option.

Table 24. Wet Mechanical Dredge Ranking

Weight	Criterion	Rank	Weighted Rank	Description
2	**Cost**	Medium (2)	4	Pros: Inexpensive unit cost once desired material is reached, little effect on recreation
				Cons: Must remove all the over burden, must manage overburden in wet condition (in lake) or in staging area (out of lake); significant access planning needed
2	**Risk of Success/ Feasibility**	Medium (2)	4	Pros: Reliable equipment and process to reach desired material
				Cons: Unknown difficulty in managing unusable overburden in wet conditions; difficult to replace lacustrine seal if needed; difficulty segregating materials during construction
1	**Construction Timeline**	Medium (2)	2	Pros: Begin any time
				Cons: Process likely slow because of the inability to see work
1	**Environmental/ Aquatic Habitat Impact**	Medium (2)	2	Pros: No need to drain lake; moderately easy to create depth diversity
				Cons: Significant increase in turbidity around work, minimal ability to re-vegetate work areas
1	**Impact to Fishery**	Medium (2)	2	Pros: No loss of lake area during construction
				Cons: Limited ability to sculpt habitat
1	**Temporary Water Quality Impact**	Low (1)	1	Pros: None
				Cons: Temporary turbidity around work area
1	**Odor/Intangibles**	High (3)	1	Pros: Very little odor created by process
				Cons: None

4.2.3 Zoned Mechanical Dredging

Zoned mechanical dredging is the name given to the process of removing dredged material mechanically (versus hydraulically) with machinery from a drained portion of a lake. All of the discussion points are the same as discussed above in Section 4.2.1 Dry Mechanical Dredge, with the exception of the use of coffer dams to avoid having to drain the entire lake.



Dewatering the construction areas becomes increasingly difficult in a zoned dredged area. The same groundwater seepage problems exist as if the entire lake had been drained, plus seepage concerns increase around the perimeter of the zoned area. Dewatering may involve a more active system such as sump pumps and wells to keep up with seepage under, around, and through the coffer barriers.

Many different types of coffer barriers can be built or exist including using in situ materials, "tilt up" coffer dams, inflatables, and geo-tubes. Temporary coffer dams are easily removed. Parts of coffer dams, such as earthen berms and geo-tubes, may have to be moved, removed, or relocated once the dredging is completed to allow for full lake access or to better take advantage of creating depth diversity in the lake bottom for fish habitat. The ranking for this alternative is shown in the table below.

Table 25. Zoned Mechanical Dredge Ranking

Weight	Criterion	Rank	Weighted Rank	Description
2	**Cost**	Medium (2)	4	Pros: Moderately inexpensive unit cost, overburden easier to manage
				Cons: Must remove overburden; significant dewatering is needed; impact to recreation
2	**Risk of Success/ Feasibility**	Medium (2)	4	Pros: Reliable equipment and process to reach desired material; easy to segregate materials during construction
				Cons: Extremely difficult to manage seepage (into the lake) during construction
1	**Construction Timeline**	Medium (2)	2	Pros: Being able to see material reduces unknowns, once zoned portion is dry, excavation is reasonably fast
				Cons: Ideal to construct in drier, warmer conditions but groundwater will be lower in the winter
1	**Environmental/ Aquatic Habitat Impact**	Medium (2)	2	Pros: Only a portion of the lake must be drained; easy to create depth diversity; easy to re-vegetate
				Cons: Most existing habitat destroyed when drained
1	**Impact to Fishery**	High (3)	3	Pros: New fishery to have well-sculpted habitat; fishery saved during construction

Weight	Criterion	Rank	Weighted Rank	Description
				Cons: None
1	**Temporary Water Quality Impact**	High (3)	3	Pros: Minimal impacts during construction
				Cons: Minor turbidity when re-filling zoned areas
1	**Odor/Intangibles**	Low (1)	1	Pros: None
				Cons: High chance of odor problems when zoned areas are dry

4.2.4 Conventional Hydraulic Dredging

Hydraulic dredging is the name given to the process of removing dredged material hydraulically by conveying part liquid and part solid slurry from the lake bottom to a staging and drying area without draining the lake. The entire process design depends on the material properties of the dredged materials, including the unit weight, in situ densities, and time to dry the material once it is out of the lake. Another significant factor is the distance to the staging and drying area. Because the effort to remove the unusable portions of the overburden is part of this process, targeting areas that minimize any unusable overburden removal quantities is a priority.

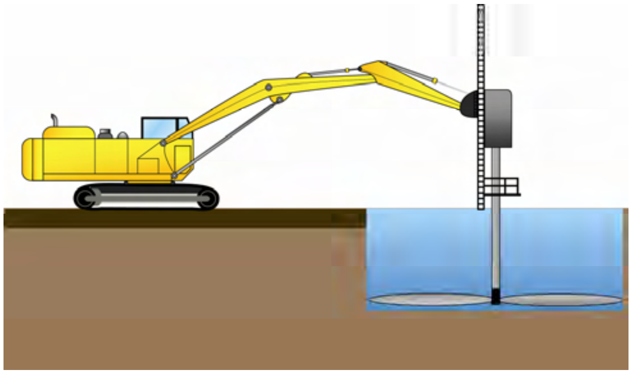
This method is normally conducted by a barge-mounted pump. The pump forces the slurry into a pipeline that delivers the slurry to a staging area for drying and preparation. The staging area design factors in the size basins that are needed to dewater the slurry and dry the material and possibly is the first step in separating and preparing the material for use. The ranking for this alternative is shown in Table 26.

Table 26. Conventional Hydraulic Dredge Ranking

Weight	Criterion	Rank	Weighted Rank	Description
2	**Cost**	Low (1)	4	Pros: Little impact on recreation
				Cons: Potentially expensive unit, cost depending on material properties (sand is heavy, creating high energy costs); must remove all the over burden; must manage overburden in wet condition (in lake) or in staging area (out of lake)
2	**Risk of Success/ Feasibility**	Medium (2)	4	Pros: Barge can reach any portion of lake easily
				Cons: Unknown difficulty in managing unusable overburden in wet conditions; difficult to replace lacustrine seal if needed; difficulty segregating materials during construction
1	**Construction Timeline**	Medium (2)	2	Pros: Begin any time
				Cons: Process likely slow because of inability to see work; long drying time with additional water needs to perform dredge
1	**Environmental/ Aquatic Habitat Impact**	Medium (2)	2	Pros: No need to drain lake; moderately easy to create depth diversity
				Cons: Significant increase in turbidity around work; minimal ability to re-vegetate work areas
1	**Impact to Fishery**	Medium (2)	2	Pros: No loss of lake area during construction
				Cons: Limited ability to sculpt habitat
1	**Temporary Water Quality Impact**	Low (1)	1	Pros: None
				Cons: Temporary turbidity around work area
1	**Odor/Intangibles**	Low (1)	1	Pros: None
				Cons: Significant potential for odor because of process in staging area

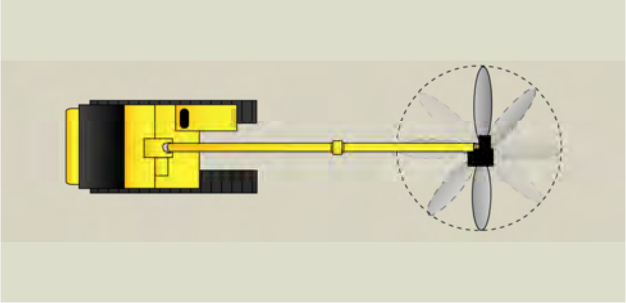
4.2.5 Subsurface Hydraulic Dredging

Subsurface dredging is the name given to a new process of removing dredged material hydraulically from a geologic formation (layer) below the lake bottom. As with the "normal" hydraulic dredging process described above, this method is advantageous in that there is no need to drain any portion of the lake.



The desired material is accessed via a "lance" that penetrates the overburden above the desired material by normal drilling operations. Hydraulic jets around the head of the lance force lake water into the material surrounding the head to loosen it. Pressure in the confined system and additional directional jets in the lance force the slurry of desired material and lake water up in to the lance, where it is conveyed to a staging area on a barge or on the shore. A distinct benefit of this process is the ability to access the desired material without having to move the overburden material.

The aftereffects of the process are a function of the soil properties, the depth of the overburden, and the shape of the "cavern" left in the material removed. It is likely that significant amounts of material would be removed from access areas because moving or relocating the lance adds additional mobilization costs, and because the formation depths of the desired materials are considerable. It is anticipated that the overburden would eventually "collapse" into the area below where material was removed. All attempts will be made to avoid shear cracks in the settled overburden that may open higher-capacity seepage paths because the rate and shape of the "collapsed" overburden can be somewhat controlled.



Locating the areas for dredging will be a function of the desire to reduce any potential increases in seepage because the overburden is not deep enough anywhere in the lake to figure as a major factor. For now, the analysis will assume that the Dredging Prioritization Map (Seepage) will be used to locate the operations. The ranking for the alternative appears in Table 27.

Table 27. Subsurface Hydraulic Dredge Ranking

Weight	Criterion	Rank	Weighted Rank	Description
2	**Cost**	High (3)	6	Pros: Low to medium unit cost;, no need to remove overburden, which significantly reduces quantity and overall cost; little impact on recreation
				Cons:
2	**Risk of Success/ Feasibility**	Medium (2)	4	Pros: Limited impact to lacustrine seal; easy to segregate materials during construction
				Cons: Unproven method in the U.S.; unit cost in question
1	**Construction Timeline**	Medium (2)	2	Pros: Sand dries faster than silty/clay materials; method not affected by season (can begin any time once equipment if available)
				Cons: Unknown schedule to manufacture equipment
1	**Environmental/ Aquatic Habitat Impact**	Medium (2)	2	Pros: Lake does not need to be drained; easy to spread increased depth areas around (not restricted by lacustrine thickness)
				Cons: Minimal ability to re-vegetate work areas
1	**Impact to Fishery**	Medium (2)	2	Pros: No impact to fishery during construction; resulting lake bottom highly irregular, creating significant depth diversity
				Cons: Difficult to shape or enhance shallow areas
1	**Temporary Water Quality Impact**	High (3)	3	Pros: Very little increase in turbidity during construction
				Cons: None
1	**Odor/ Intangibles**	High (3)	3	Pros: Little to no odor
				Cons: None

4.2.6 Drag line dredging

Large drag lines are set up to remove large quantities of materials from water bodies for large dredging operations in ports, harbors and in mining applications. Generally, the setup for the lines is time-consuming and costly, but material can be removed at a relatively inexpensive unit cost once the system is in place. After discussions with several contractors that specialize in this type of dredging, none of them thought that an inland lake project would make sense because of the requirements to mobilize the equipment. Whether at ports and harbors or in mining applications, these types of dredge lines are usually intended to stay in place for long periods of time.

4.3 Alternatives Comparison

Throughout the investigation, the dredged methods were analyzed based on the following parameters: cost, risk of success, construction timeline, environmental and aquatic habitat impact, impacts to fishery, temporary water quality impact, and odor/intangibles. The parameters were also weighted according to the level of importance. Below is a summary the weighted rankings and how they compare with one another.

Table 28. Dredge Alternatives Ranking Summary

Criterion	Weighted Rank				
	Dry Mechanical	Wet Mechanical	Zoned Mechanical	Conventional Hydraulic	Subsurface Hydraulic
Cost	4	4	4	4	6
Risk of Success/ Feasibility	4	4	4	4	4
Construction Timeline	2	2	2	2	2
Environmental/ Aquatic Habitat Impact	1	2	2	2	2
Impact to Fishery	2	2	3	2	2
Temporary Water Quality Impact	2	1	3	1	3
Odor/Intangibles	1	1	1	1	3
Total:	**16**	**16**	**19**	**16**	**22**

4.4 Recommended Dredge Alternative

As shown above and perhaps as was evident in the descriptions of the various dredging methods described above, the subsurface dredging method is likely best suited for this project, given the specific conditions at Lake Manawa. However, it is not currently known whether the equipment can be made available at the project site when it is needed.

Because four other dredging methods have been identified and appear to be at least possible, some additional work in proving that these methods work will relieve any contractor's fears about being able to produce the desired material. The bidding climate when this study was drafted would likely produce a competitive bid, perhaps even more competitive than a bid using the locally unproven subsurface dredging method.

5.0 FINAL RECCOMENDATIONS SUMMARY

At the start of this study, it was anticipated that the plan eventually implemented would incorporate some level of three plan components: seepage reduction, nutrient loading reduction, and dredging. Throughout the report, methods to reduce seepage as part of various dredging alternatives and some that stand-alone (without associated dredging) were identified. These alternatives were coupled with nutrient loading measures to quantify how the project might collectively achieve enough of each of the three plan components to meet the overall water quality goals.

Even now that a scenario has been identified as a preferred alternative, it is likely to be “tweaked”as a minimum as additional information is gathered and the project is implemented. What is important is to consider that there is a way to achieve the water quality goals and that, although the implemented project may change, there is enough “wiggle room” in the ability to achieve the goals to allow trade-offs among the project components while still achieving the water quality goals. The overall water quality model and general engineering and scientific practices will allow IDNR to analyze the tradeoffs and ensure the successful achievement of the water quality goals.

5.1.1 Additional Considerations

All of the alternatives presented in this study require additional study, which is anticipated during the final design phase. Local geologic conditions, material properties, and proximity to other on-site resources will affect the potential performance, cost, and constructability of each alternative. All assumptions to date are a function of what is known at the time of this study.

5.1.2 Constructability Issues

All known constructability issues have been addressed in this report. Similar to the discussion in the section above, additional issues may present themselves during final design. Additionally, a “pilot dredging program” has been proposed in Section 7, below, to learn more about the various dredging alternatives proposed, including any constructability issues that may arise.

5.1.3 Permitting

At this time, it is assumed that the permits needed for the project will include, as a minimum, a floodplain development permit from the City of Council Bluffs, a National Pollutant Discharge Elimination System (NPDES) permit from IDNR, and a General Permit 98-05 (Lake Maintenance) from the U.S. Army Corps of Engineers; a Clean Water Act Section 404 permit may be needed because temporary dredged material will be placed in the lake. A more detailed permit review will be determined when the final plan is established and any further investigations will be identified.

6.0 OPTIONS TO REDUCE RISK

When recommended alternatives are carried forward into the final design, additional studies and data collection may benefit the project to confirm feasibility and reduce risk. A final decision on the appropriateness of the measures discussed below will be made when a final alternative is selected.

6.1 In-lake Geophysics and Soil Borings

Once a final design concept is known, additional soils investigations can help in reducing any unknowns about each project area. Geophysics can help to measure geologic formation depths at specific locations to assist in preparing proper grading plans and in calculating material volumes that will be dredged. Depending on the proximity to soil borings that have already been completed to date, additional holes may be needed to sample materials and investigate any differences.

Additionally, depending on the construction method chosen, some strength testing of in situ materials will be needed to test the compatibility with the proposed construction equipment.

6.2 Finite Cell Model

A finite cell model would allow a study of the entire lake area at once for the effects of a dredging project on seepage. Models to date have assumed seepage along a two-dimensional seepage path and then converted the values to total lake seepage by multiplying the modeled seepage by the lengths over which the seepage occurs.

A significant amount of additional information would have to be collected to properly construct a finite cell model. In-lake and additional shoreline geophysics and additional borings would need to be collected to map the existing soil surfaces within the model. Then, they would be altered in accordance with a dredging plan to assess the net effects on total seepage from the lake. Although developing a finite cell model is a significant effort, it is widely accepted that it produces the most reliable results.

6.3 Groundwater Study (Piezometers)

This study adapted all groundwater information from previous studies and investigations and was assumed to be accurate. Interpolations were taken from a relatively small number of piezometers, given the project area. Additional assurances could be gained by monitoring groundwater in some specific locales, such as the residential areas that could be affected by raised water levels in Indian Creek.

6.4 Pilot Dredging Project

As described in Section 7.1 below, a pilot dredging project would be useful in both testing some of the assumptions about a dredging project and in demonstrating to IDOT that a dredging project can produce material with the desired properties for their roadway projects.

7.0 NEXT STEPS AND IMPLEMENTATION

At the conclusion of this study, IDNR has been notified that a dredging project at Lake Manawa is possible, given the concerns to the lake's water budget. Through development of this diagnostic and feasibility study, IDOT and other affected agencies have also been made aware of the progress and are aware that the feasibility of a large dredging project at Lake Manawa is still planned. At the time this study was published, information about the total amount of fill material needed by IDOT was still unknown, as IDOT is completing the preliminary design phase and some significant changes could still take place.

7.1 Pilot Dredging Project

In moving forward, Tetra Tech agrees with IDNR that some "truthing" of the information contained in this study about the feasibility of the dredging project has merit to reduce risk and provide additional information that will be useful during the final design. Therefore, the next phase proposed for the project is to develop a pilot program that will test some of the dredging methods proposed to see if the construction methods anticipated are realistic and to prove that the material properties of the dredged materials can be obtained. The dredging pilot project proposed will be ready for the spring and summer of 2009.

7.2 Effects of Potential Federal Economic Stimulus

While the dredging pilot project is being conducted, Tetra Tech will work with IDNR to monitor the status of the IDOT project and the potential effects of the anticipated federal economic stimulus project. A list of items needed before final design can be completed will be assembled so that if the project schedule for IDOT is accelerated, rapid progress toward a final design at Lake Manawa can be made.

7.3 Final Design Phase

Assuming that the pilot dredging project confirms this study's findings and the project feasibility is further confirmed, the next phase would be a final design phase. This phase would be to develop construction documents for a dredging plan for a known quantity of material and address the seepage, material properties, and net effect on water quality for the plan. Additional geotechnical and geophysical information will need to be obtained as well for some site-specific locations that are significant parts of the overall dredging plan. Additionally, design will need to be completed for many of the planned water quality improvements outside of the dredging project.

7.3.1 Sample Design Plan

A sample design plan is described to provide an example final design package and associated cost. In general, it is assumed for this exercise that the plan would follow the alternatives to meet water quality goals with dredging that is described in Section 3.7 above. There are several components of the overall plan to meet water quality goals outside of the dredging project, including implementation of the wet detention basin to treat the inflow from Mosquito Creek, the collapsible weir on Indian Creek, Lake Manawa Watershed BMPs, Lake Manawa In-Lake BMPs, and Alum Injection. The total costs for this plan, along with the associated dredging costs, are shown below.

Table 29. Sample Project Costs

	Land Rights	Construction Costs	20% Contingency	T/E/P*	Subtotal
Wet Detention Basin	$200,000	$298,800	$99,760	$79,712	$678,272
Alum Injection System	$0	$70,000	$14,000	$16,800	$100,800
Collapsible Weir	$0	$300,000	$60,000	$172,000	$532,000
Watershed BMPs	$0	$169,798	$33,960	$40,751	$244,509
In-Lake BMPs	$0	$1,214,563	$242,913	$291,495	$1,748,970
Whole Lake Alum	$0	$1,691,429	$338,286	$405,943	$2,435,657
Dredge (see below)	$0	$8,525,000	$1,705,000	$2,046,000	$12,276,000
				Total:	$18,016,208

* Testing, Engineering, and Permitting

Table 30. Sample Dredge Project Construction Costs**

	Volume (CY)	Unit Cost (per CY)	Cost
Overburden Removal	850,000	$6.50	$5,525,000
Overburden Removal and Replacement	500,000	$11.00	$5,500,000
Sand Removal	5,150,000	$6.00	$30,900,000
Aquatic Habitat Improvements	200,000	$3.00	$600,000
Project Miscellaneous***	---	---	$2,000,000
		Total:	$44,525,000
Reimbursement From IDOT	6,000,000	$6.00	$36,000,000
		Dredge Cost:	$8,525,000

** The dredging project assumes that 6 million CY will be needed for the IDOT project. To reach sand, 1.35 million CY of overburden would be removed, of which 850,000 CY are usable overburden and 500,000 CY is overburden that has to be moved and replaced. Dredging in the areas and to the depths shown on Figure 14 will produce 5.15 million CY of sand. This in addition to the 850,000 CY to be treated with flyash provides 6 million CY of usable material to the IDOT. Replacing 500,000 CY in the dredged areas would create a lacustrine layer approximately 2 feet thick. Of the replaced material, it is anticipated that the entire 500,000 CY must be re-compacted to restore the pre-project seepage conditions from the area.

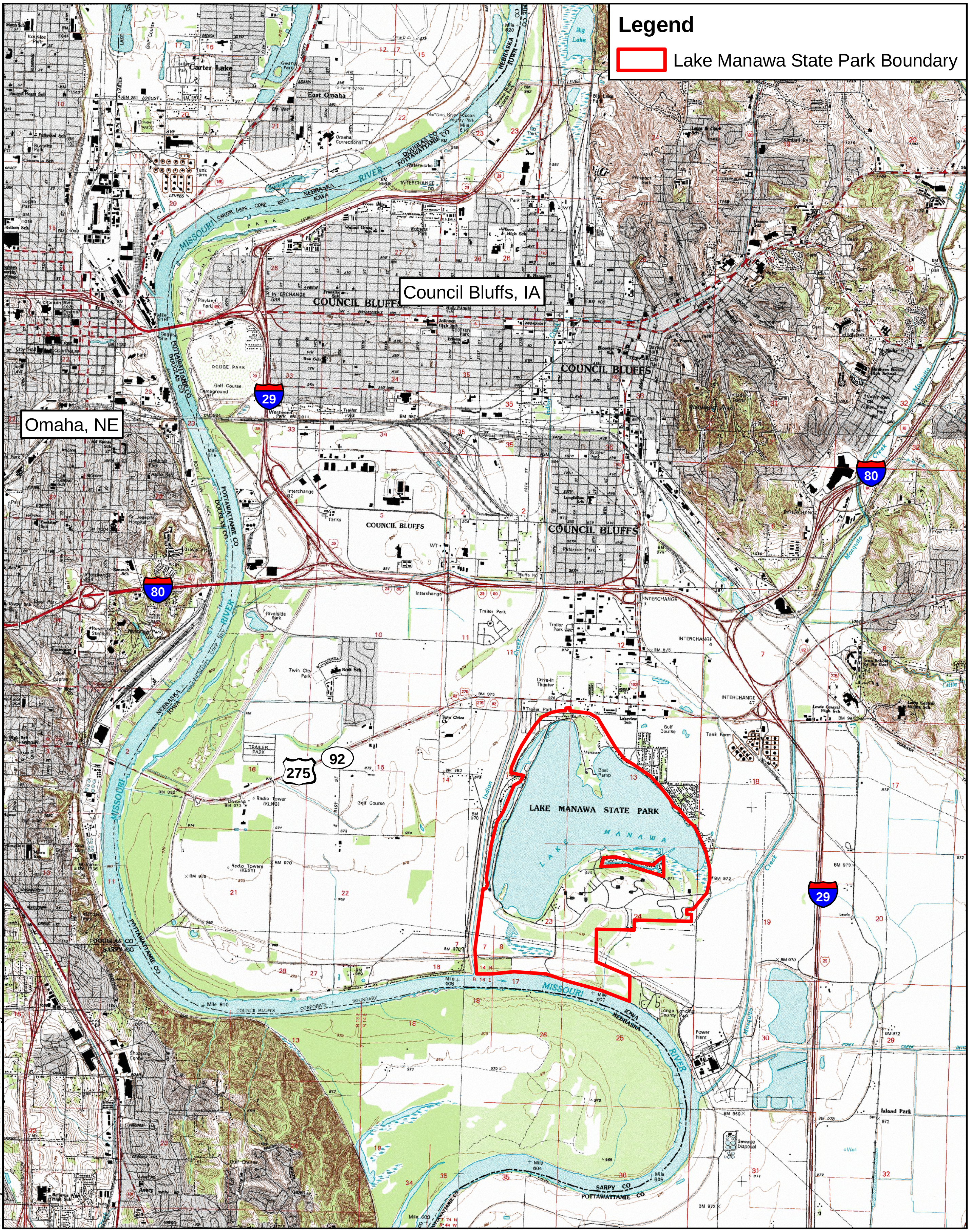
***Miscellaneous costs include any costs that include what it takes to access, move, store, process and maintain the dredged material.

7.3.2 Managing Project Costs

The example project above incorporates assumptions into the information provided, as it is intended to quantify approximate project costs and highlight the areas that can significantly change during final design. The majority of the sample project subject to significant change is wrapped up in the dredging component. Until the final volume of dredged material is known and the specific areas affected by the dredging can be further investigated, the total volume of usable and unusable material that must be moved and sometimes moved twice will not be known. Additionally, other factors can come into play that are not directly associated with the dredging component. For example; if the collapsible weir on Indian Creek is not constructed, additional measures may have to be taken in the dredging project to reduce or eliminate any additional seepage caused by the dredging operations.

Once the pilot dredging project is completed and the feasibility of using a portion of the overburden in the structural fill of IDOT's project (likely with the addition of flyash), and the total volume of fill from IDOT is known, a final dredging plan can be completed for the lake, and the pre- and post-project lake bathymetry can be analyzed with the cumulative effects of other planned water quality improvements. Until that time, the many "trade-offs" among all of the proposed water quality improvements make it difficult to identify one single project path.

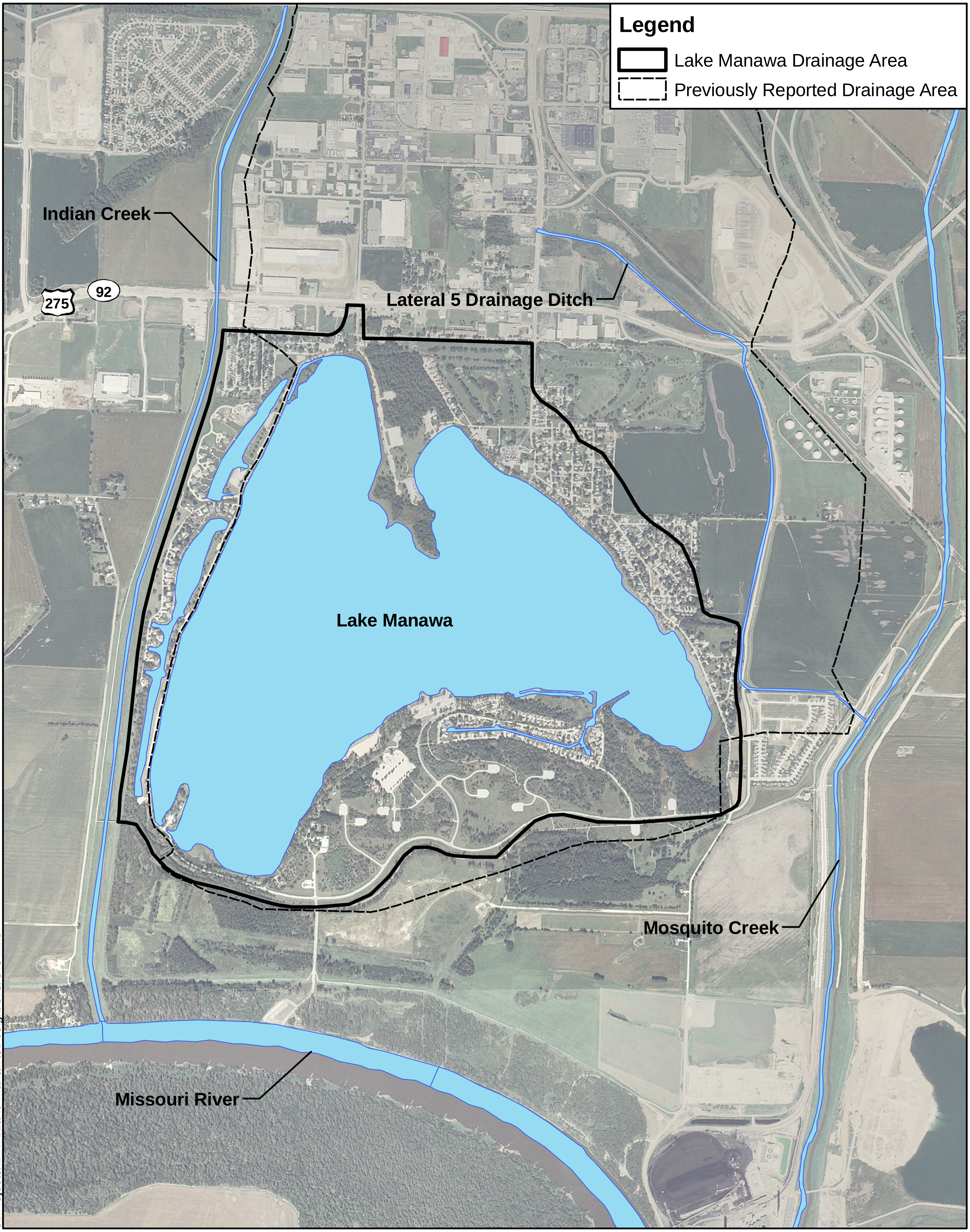
Appendix A



J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

12/17/08

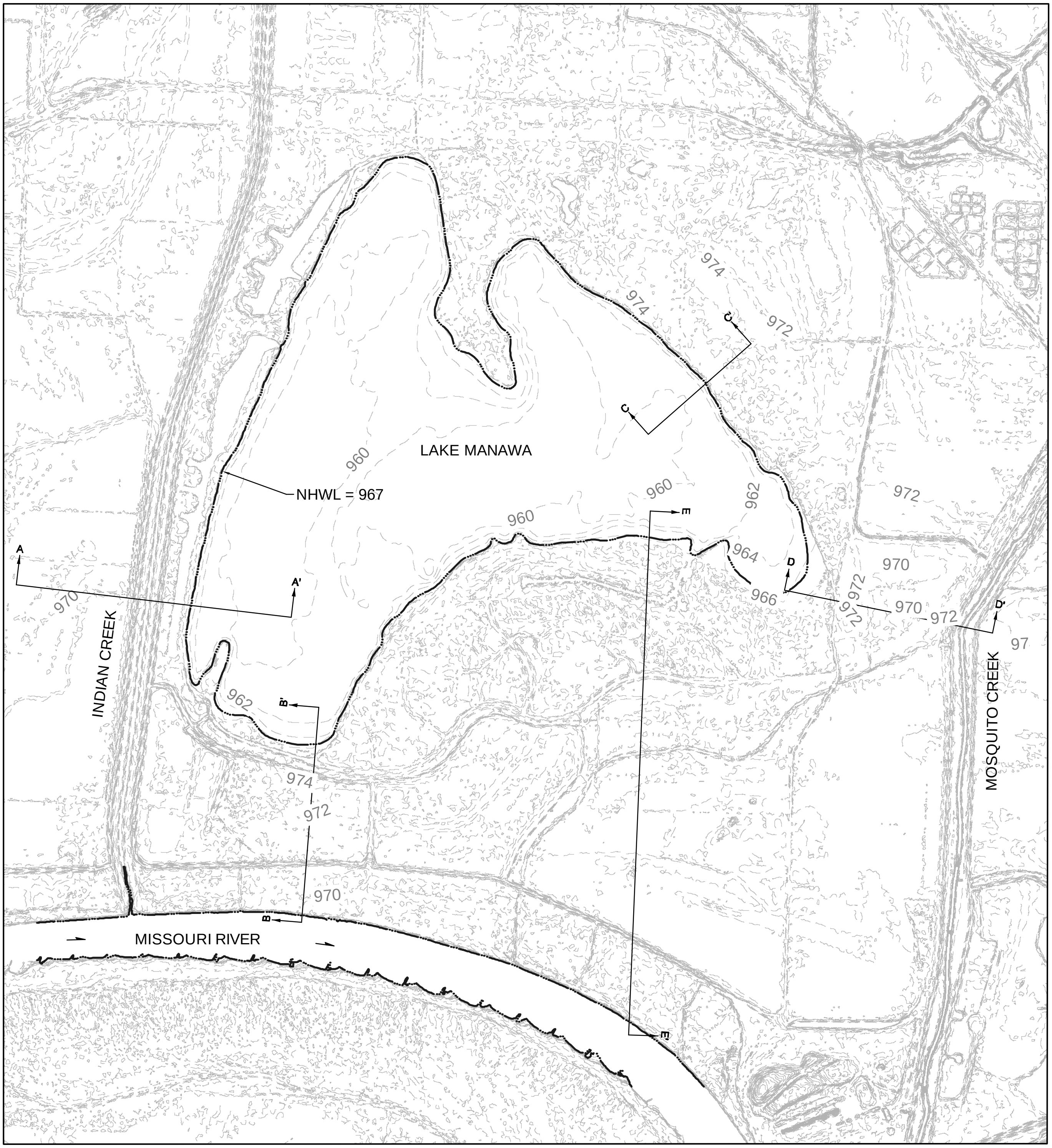
Figure 1
Location Map
Lake Manawa Diagnostic and Feasibility Study



J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

12/17/08

Figure 2
Site Map
Lake Manawa Diagnostic and Feasibility Study



LEGEND

D D' SEEPAGE ANALYSIS SECTION

BATHYMETRIC TOPOGRAPHY IN LAKE BASED ON A SEPTEMBER, 2006 SURVEY.

N

0 1000 2000 4000

SCALE IN FEET

CONTOUR INTERVAL = TWO FEET

12/16/08

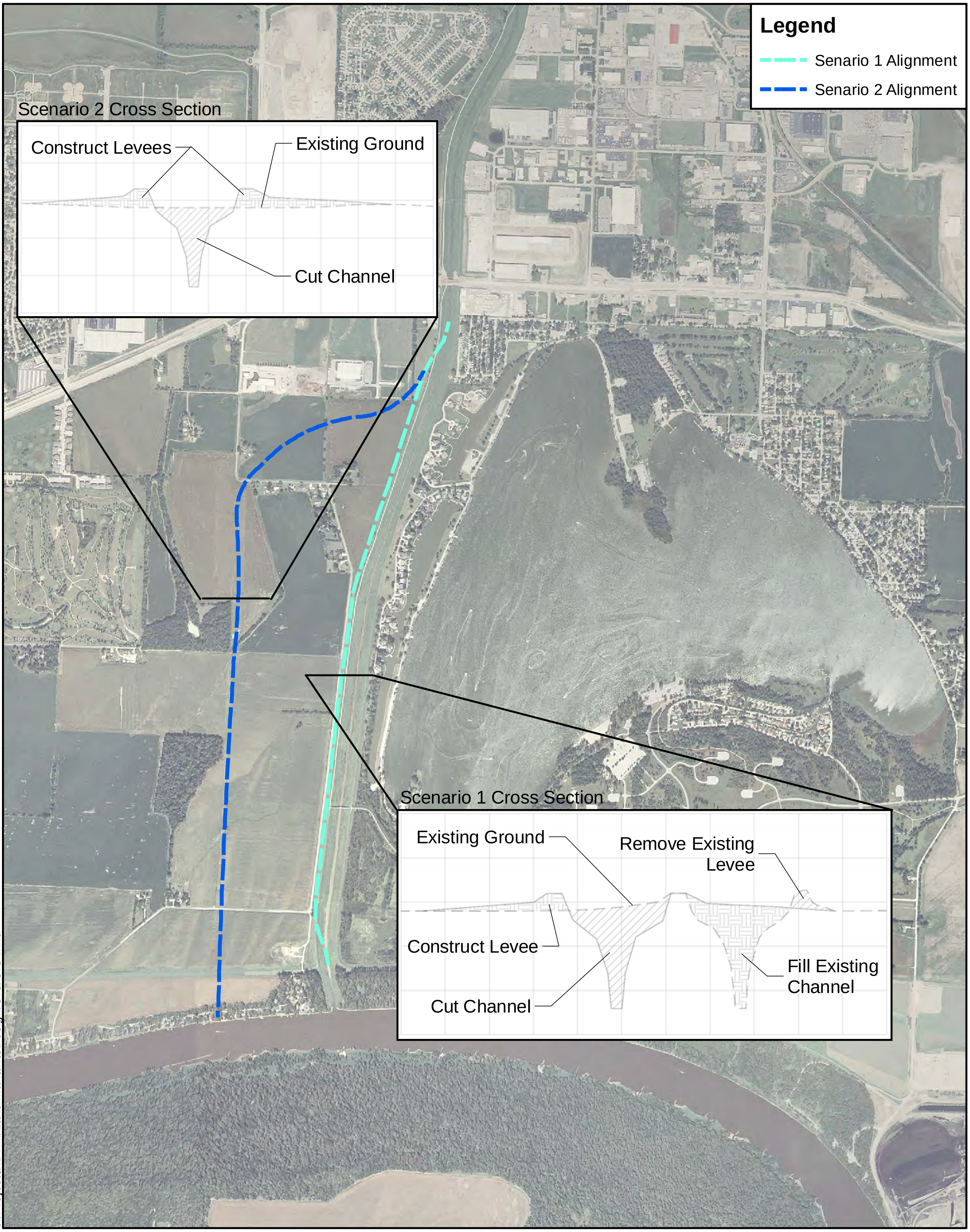
Figure 3
Lake Manawa
Location of Seepage Analysis Sections

P:\133-20192-08005 Lake Manawa\CAD\RefFiles\Manawa Lake FIG 1.dwg, 3/9/2009 1:57:44 PM, PDF-XChange for AcroPlot Pro

J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

12/19/08

Figure 4
Collapsible Weir Alternative
Lake Manawa Diagnostic and Feasibility Study

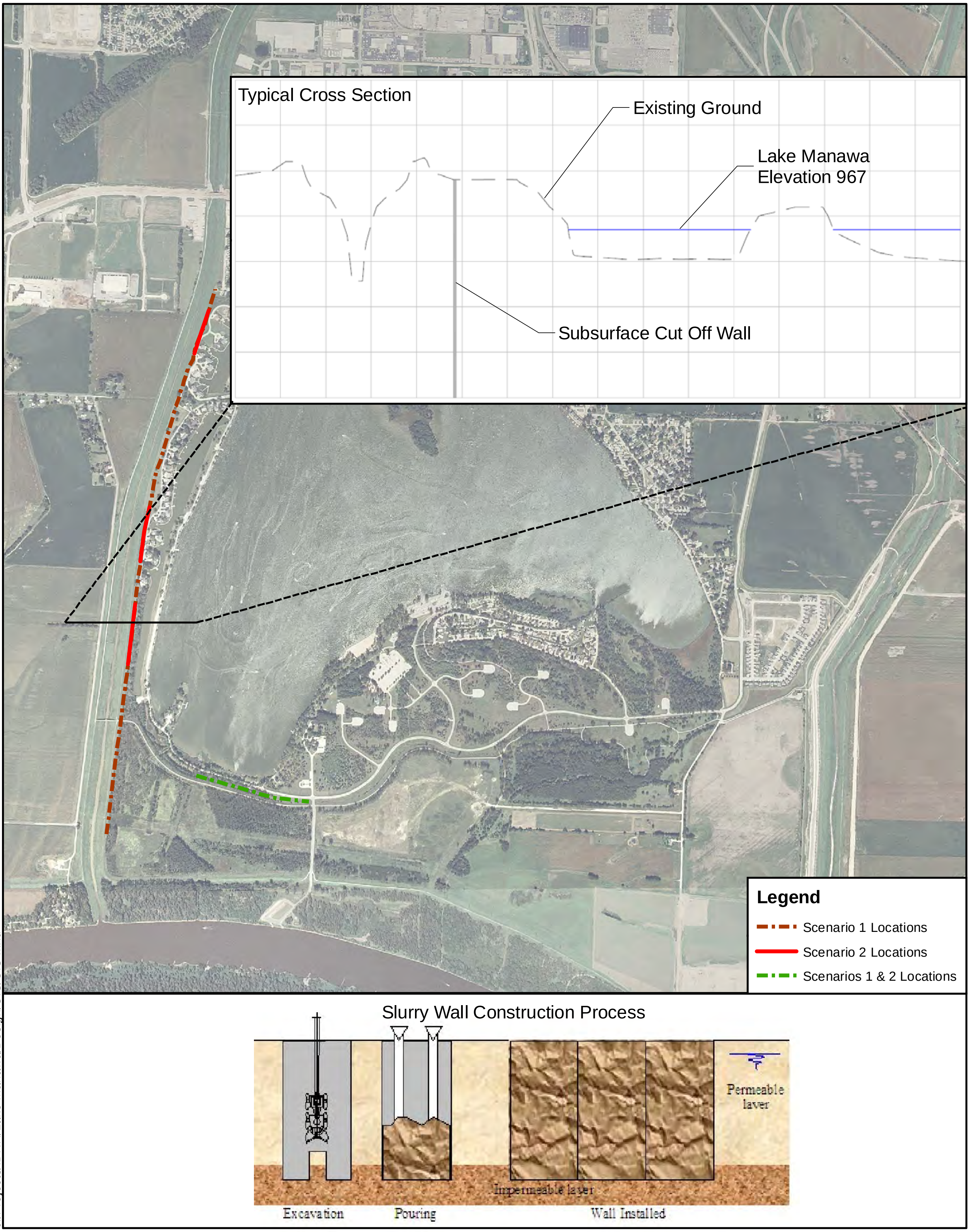


J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS mxd

SCALE IN FEET
0 2,000
N

12/19/08

Figure 5
Relocate Indian Creek
Lake Manawa Diagnostic and Feasibility Study



J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

12/19/08

SCALE IN FEET

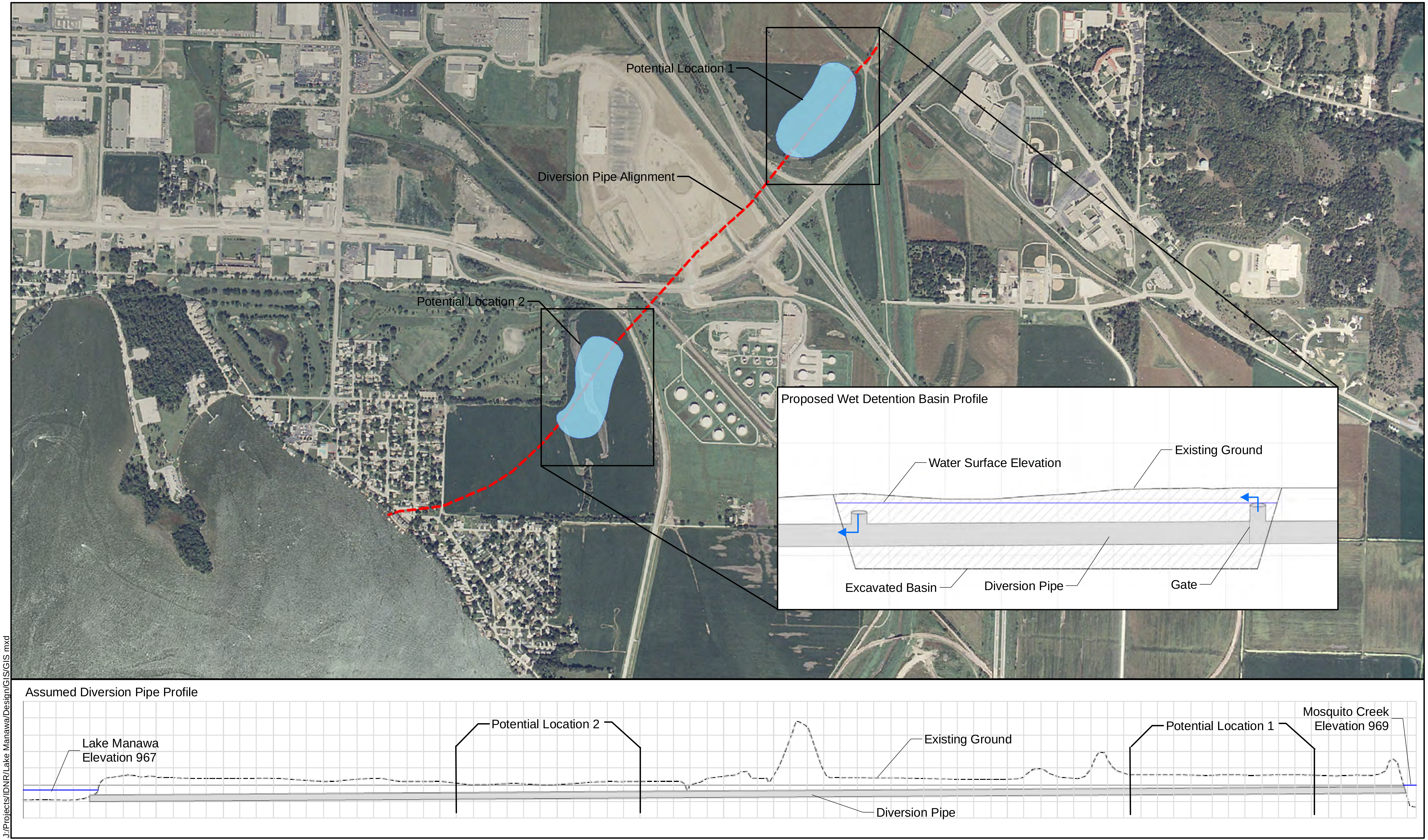
0 2,000

N

Figure 6

Subsurface Cut-Off Wall

Lake Manawa Diagnostic and Feasibility Study



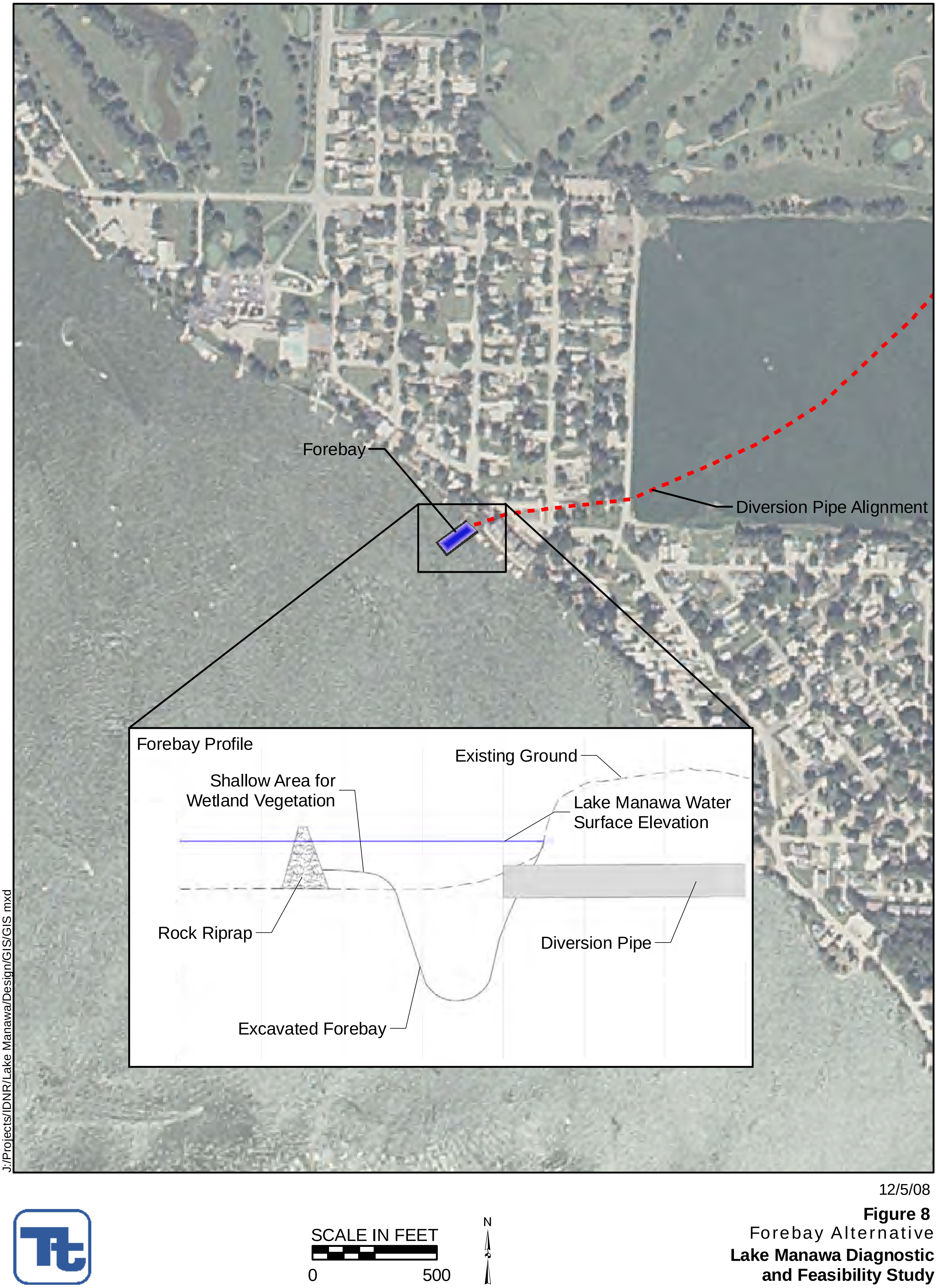
J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

SCALE IN FEET
0 1,000

N

12/5/08

Figure 7
Wet Detention Basin
Lake Manawa Diagnostic and Feasibility Study



12/5/08

Figure 8

Forebay Alternative

Lake Manawa Diagnostic and Feasibility Study

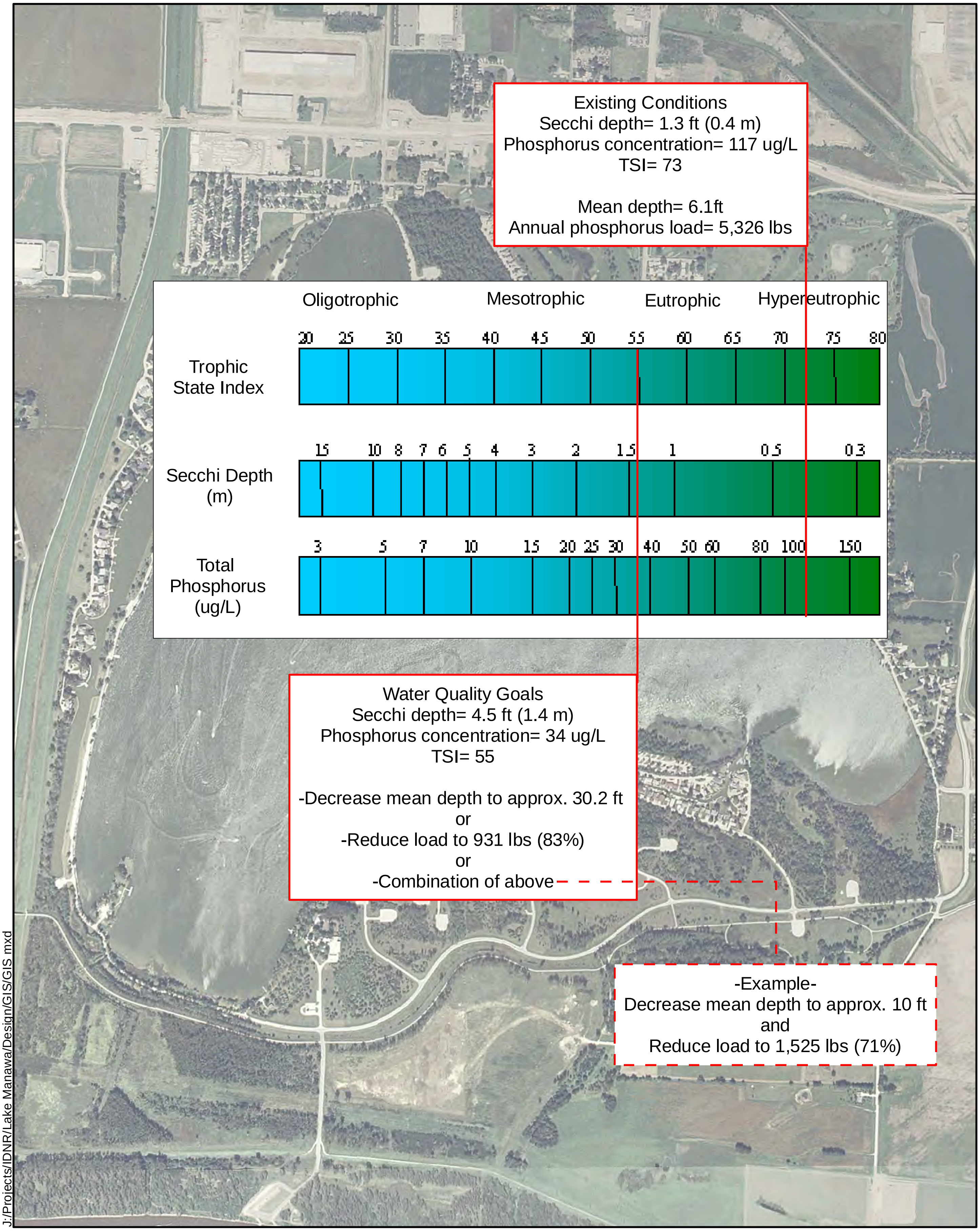
J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

12/5/08

Figure 9
Watershed Management Plan
Lake Manawa Diagnostic and Feasibility Study

SCALE IN FEET
0 1,000

N



Existing Conditions
Secchi depth= 1.3 ft (0.4 m)
Phosphorus concentration= 117 ug/L
TSI= 73

Mean depth= 6.1ft
Annual phosphorus load= 5,326 lbs

Water Quality Goals
Secchi depth= 4.5 ft (1.4 m)
Phosphorus concentration= 34 ug/L
TSI= 55

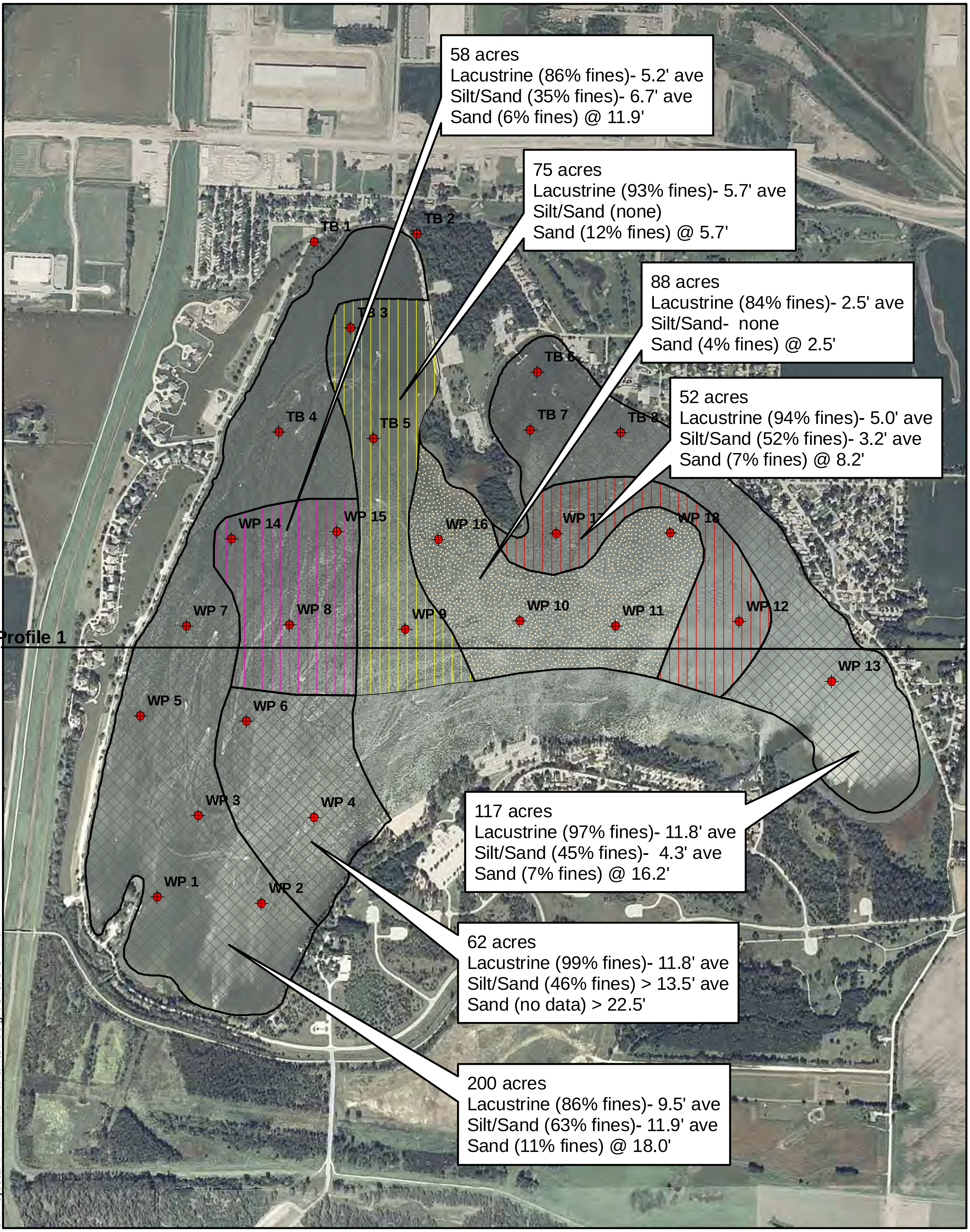
-Decrease mean depth to approx. 30.2 ft
or
-Reduce load to 931 lbs (83%)
or
-Combination of above

-Example-
Decrease mean depth to approx. 10 ft
and
Reduce load to 1,525 lbs (71%)

J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

12/17/08

Figure 10
Water Quality Summary
Lake Manawa Diagnostic and Feasibility Study



58 acres
Lacustrine (86% fines)- 5.2' ave
Silt/Sand (35% fines)- 6.7' ave
Sand (6% fines) @ 11.9'

75 acres
Lacustrine (93% fines)- 5.7' ave
Silt/Sand (none)
Sand (12% fines) @ 5.7'

88 acres
Lacustrine (84% fines)- 2.5' ave
Silt/Sand- none
Sand (4% fines) @ 2.5'

52 acres
Lacustrine (94% fines)- 5.0' ave
Silt/Sand (52% fines)- 3.2' ave
Sand (7% fines) @ 8.2'

117 acres
Lacustrine (97% fines)- 11.8' ave
Silt/Sand (45% fines)- 4.3' ave
Sand (7% fines) @ 16.2'

62 acres
Lacustrine (99% fines)- 11.8' ave
Silt/Sand (46% fines) > 13.5' ave
Sand (no data) > 22.5'

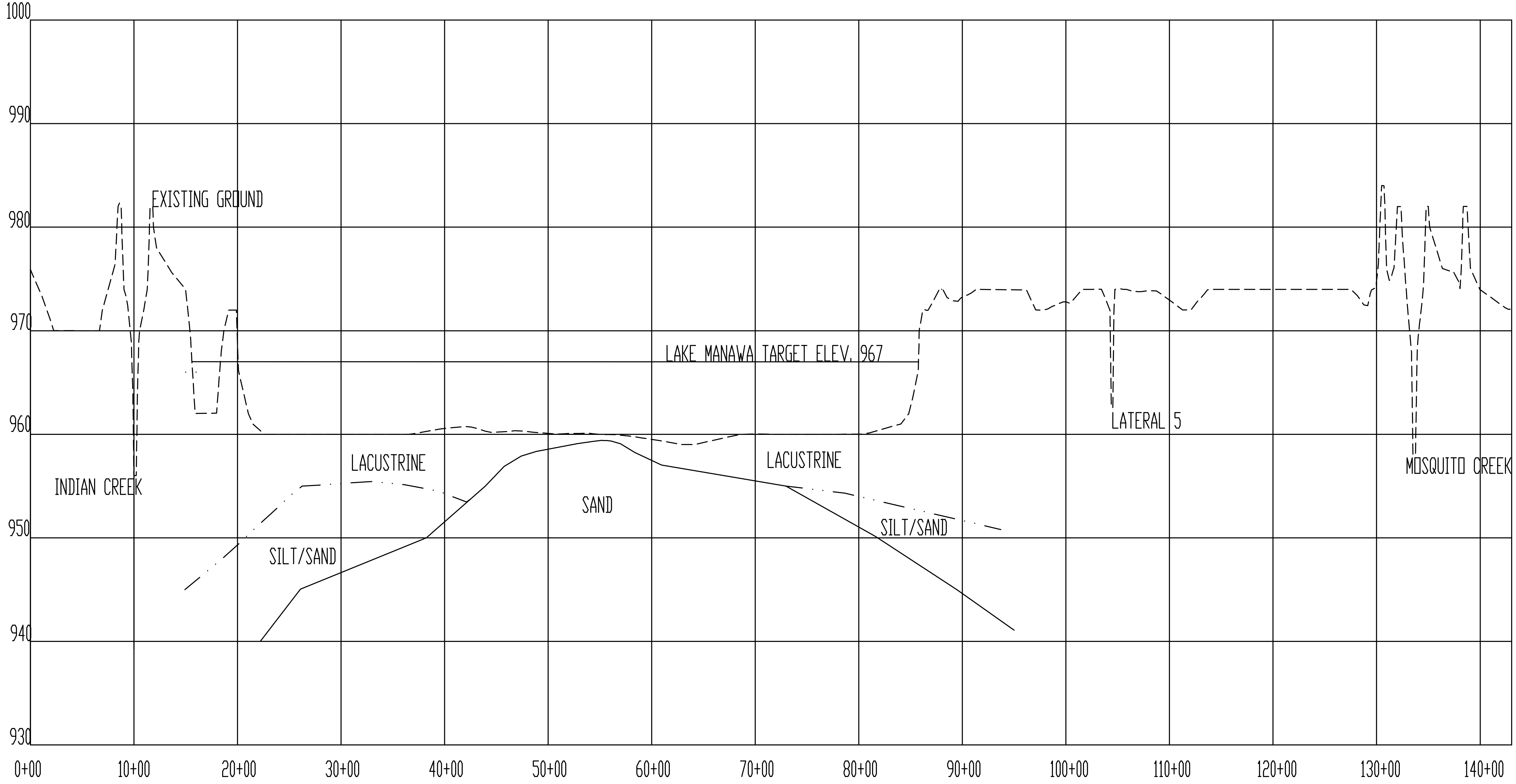
200 acres
Lacustrine (86% fines)- 9.5' ave
Silt/Sand (63% fines)- 11.9' ave
Sand (11% fines) @ 18.0'

J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS mxd

12/17/08

Figure 11
Subsurface Soils Map
Lake Manawa Diagnostic
and Feasibility Study

PROFILE 1



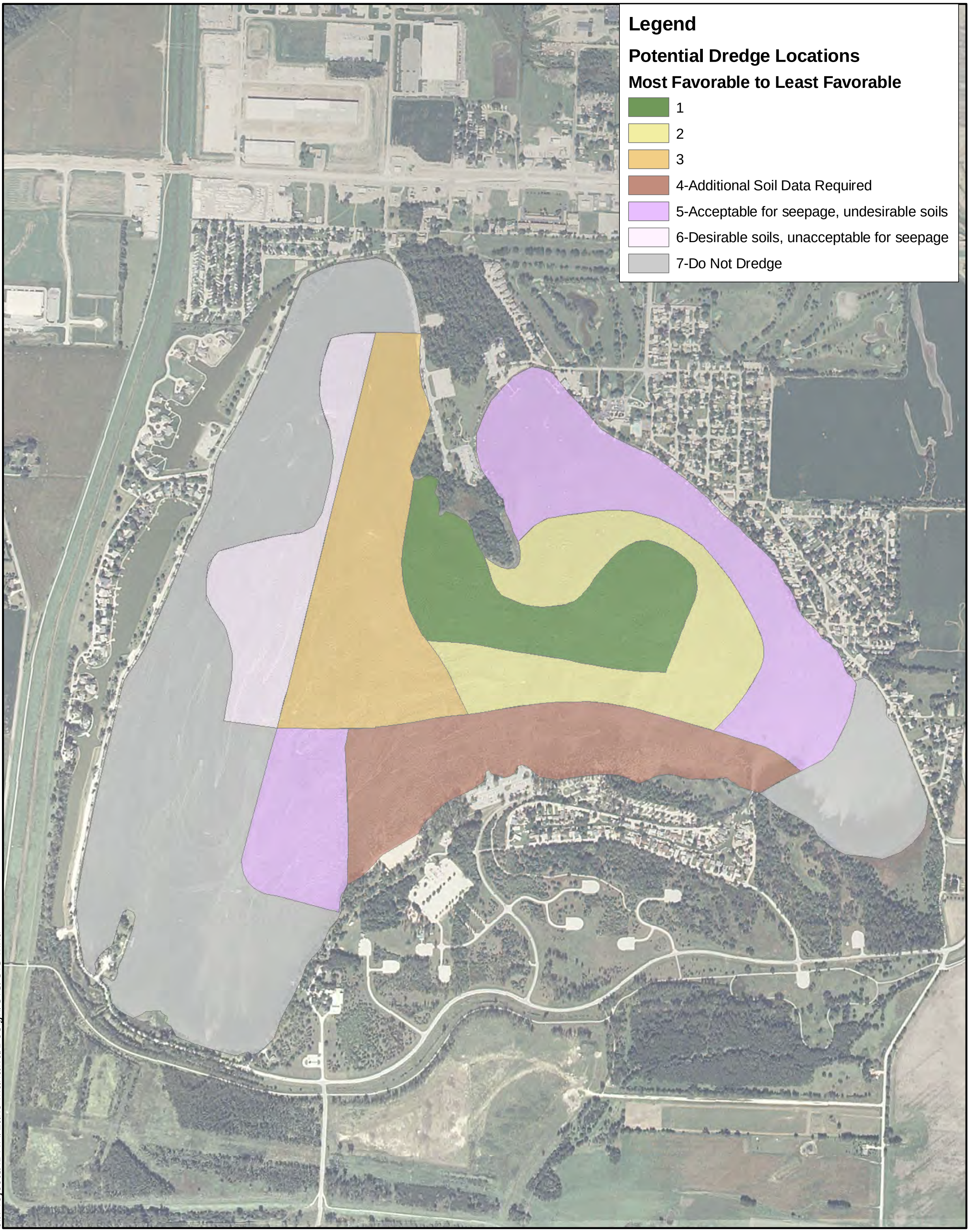
LAKE MANAWA

FIGURE 12
SUBSURFACE
SOIL PROFILE

PROJECT:	210375
DATE:	12/4/08
FILE:	BASE_MAP.DWG

TETRA TECH

J:\Projects\IDNR\Lake Manawa\Design\DWG\Manawa Base Map.DWG SAVED:12/22/08 PRINTED:2/11/09 BY:SARA.HANSON



J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

12/17/08

Figure 13
Dredging Prioritization Map
Lake Manawa Diagnostic
and Feasibility Study

J:/Projects/IDNR/Lake Manawa/Design/GIS/GIS.mxd

1-5-09

Miles

0 0.25

N

Figure 14

Potential Depths Map

Lake Manawa Diagnostic and Feasibility Study

Appendix B

ELECTRICAL RESISTIVITY SURVEY
LAKE MANAWA, POTTAWATTAMIE COUNTY IOWA

DRAFT GEOPHYSICAL SITE CHARACTERIZATION REPORT

December 23, 2008

Prepared for:

Iowa Department of Natural Resources

502 East Ninth Street
Des Moines, IA 50319

Prepared by:

TETRA TECH

7800 Shoal Creek Blvd.
Suite 253 East
Austin, Texas 78757
(512) 338-1667
FAX (512) 338-1331

Tetra Tech Project No. 114-210375

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

LIST OF ACRONYMS

AC	Alternating Current
AGI	Advanced Geosciences Incorporated
BGS	Below Ground Surface
IDNR	Iowa Department of Natural Resources
GPS	Global Positioning System
FS	Fine Sand
IDOT	Iowa Department of Transportation
MS	Medium Sand
CS	Coarse Sand
SG	Sand and Gravel
UTM	Universal Transverse Mercator
WGS	World Geodetic System

1.0 INTRODUCTION

A geophysical site characterization was completed by Tetra Tech, Inc. (Tetra Tech) for Iowa Department of Natural Resources (IDNR), on May 12th through May 20th, 2008. The geophysical survey was completed in the southwestern portions of the Lake Manawa State Park and vicinity of Lake Manawa (the site), and is located adjacent and southwest of Council Bluffs, Iowa in Pottawattamie County which is bounded to the south by the Missouri River and to the west by Indian Creek (Township 74N, Range 44W).

The objective of this geophysical investigation was to identify subsurface resistive and conductive features in relation to the local hydrogeologic framework and lithology, specifically, for the area adjacent to Indian Creek and the southwestern area between Lake Manawa and the Missouri River. This geophysical survey was conducted to assist in identifying areas of potential water loss from Lake Manawa into: Indian Creek, the Missouri River and the regional aquifer, preemptive to a proposed dredging project to provide fill for a local project being conducted by the Iowa Department of Transportation (IDOT). This report includes a general description of site background; including a brief geologic overview, the geophysical method and equipment used, field methodologies, data processing and interpretation.

2.0 BACKGROUND

During an 1881 flood, the Missouri River was redirected and subsequently re-channelized forming a 772 acre oxbow lake, Lake Manawa. In the years following, the newly formed lake became a regional recreational site and is part of the 1,529 acre Lake Manawa State Park, managed by IDNR.

The Site exists within the southwestern portion of Lake Manawa State Park and adjacent areas. Vegetative cover consists of low lying and/or managed cut grasses, short growth brush and tree covered areas. Cultural features that commonly may affect resistivity data include but not limited to: overhead and buried single phase electrical lines, high-tension overhead electrical transmission lines, buried communication lines, water lines, wire fences, and metal culverts.

Physiographically, the site is situated in the Missouri River Valley. Near-surface geology consists of Quaternary glacial, fluvial, and lacustrine deposits overlying Upper to Middle Pennsylvanian limestone bedrock of the Kansas City Group and Bronson Group, respectively. Additionally, geomorphologic glacial features are evident in the undulated surface and potential fracturing of the limestone bedrock.

Soil boring data collected in area indicates that the fine-grained alluvium typically extends from the surface to about 20 ft bgs and is generally underlain by coarser grain materials with alternating zones of finer grain material down to bedrock. Borings conducted on and through the Lake (Geotechnical Services, Inc., 2004 & 2007) indicate the presence of a layer of lacustrine deposits at the base of the Lake. These lake bed deposits are generally cohesive and are likely of lower permeability than the underlying fine-grained alluvium aquitard. However, areas exist in the north-central part of the Lake where the lacustrine deposits and the fine-grained alluvium are thin or absent. This constitutes an area capable of significant leakage and/or recharge from the Lake to the alluvial aquifer (HDR, 2007).

The bedrock of the Kansas City and Bronson Groups consists primarily of fossiliferous limestone and gray shales. HDR's 2007 report places depth to bedrock at 91.5 to 103.5 ft bgs near the site. Other soil borings in the area have bedrock as deep as 135 ft, Groundwater in the area of Lake Manawa flows to the south. The Missouri River is the regional discharge zone and Mosquito Creek and Indian Creek may act as localized discharge zones The HDR 2007 report indicates that mapping of groundwater elevations around the lake shows strong evidence of a groundwater mound beneath the Lake. The location of this mound correlates strongly with an area of higher geologic potential for leakage/recharge and may be caused by leakage from the Lake.

The work plan for this work was presented in the April 2008 *Technical Proposal to Provide: Diagnostic and Feasibility Study of Lake Manawa, Pottawattamie County; Solicitation No. 08-57HA-08 April 2008 (Tetra Tech)*, The scope-of-work for the geophysical phase of the work plan consists of using electrical resistivity to identify lithologic units with higher relative hydraulic conductivities (sands and gravels) and relative lower hydraulic conductivities (silts and clays) peripheral to Lake Manawa, to assist in mapping potential areas of seepage or groundwater flow away from Lake Manawa.

Differentiation and delineation of site lithology, with respect to electrical resistivity data, can provide additional information for understanding potential water budget deficiencies and seepage in site areas. This site characterization was completed to provide data to assist in engineering and development of a dredging program so that impact to the current water budget of Lake Manawa will be minimized. Resistivity data was collected at key locations around the lake perimeter specifically in the southwestern and western portions of the lake.

The geophysical survey was designed to characterize the local hydrogeologic framework utilizing available soil borings, known hydrogeologic parameters and the interpreted results of the resistivity data presented herein. The resistivity data was used to map relative changes in lithology based on the electrical properties of the materials measured. The resistivity data is typically related to the porosity of the subsurface hydrogeologic layers and can be used to assist in determining the location and thickness of more porous sands and gravel which will help in locating zones where more water is likely to move through.

3.0 RESISTIVITY THEORY AND INSTRUMENTATION OVERVIEW

The purpose of the electrical resistivity method is to characterize subsurface lithology and/or materials in terms of electrical resistance. The electrical resistivity method incorporates the injection of an electrical current, into the ground, through a pair of electrodes (current electrodes) while simultaneously measuring the potential or voltage between an offset electrode pair (potential electrodes) in contact with the ground. The subsurface resistance or apparent resistivity is then calculated from the measured voltages, according to electrode geometry.

The apparent resistivity (ρ_a) represents the bulk resistance of earth materials where the majority of injected current flows and subsequent potential measurements exceed noise levels and fall within the dynamic range of the field equipment. The geometry between (2) current electrodes and (2) or more potential electrodes defines an array. The distance between the potential electrodes is directly related to resistivity measurements with depth. The amount of current injected and distance between the current electrodes determines the depth potential, i.e. large spacing's force more available current to flow at depth. Theoretically, any array geometry can be solved for ρ_a from measured values, but only a few geometries are commonly used today. Each of these arrays exhibits a strength(s) which is minimal in all other arrays, thus array selection may be a critical part of survey design. The geophysical survey presented, herein, employed the dipole-dipole array (Figure 2).

Currently resistivity equipment exists to collect tremendous volumes of data using multiple recording channels over long lines using 10's of 100's of electrodes. Older single channel systems use (2) current electrodes and (2) potential electrodes, thus minimizing the number of people needed to collect data, but maximizing the number of times equipment must be relocated for resistivity depth soundings. Equipment relocation for depth soundings is eliminated with the multi-channel systems. In comparison single channel systems may be more efficient for lateral resistivity profiling. Data for a single resistivity depth sounding is collected by expanding an electrode pair about a single point, thus providing vertical variations with increasing depth and central offset. An electrode pair refers to either the current electrodes or the potential electrodes. Data for a lateral resistivity profile is collected by moving all electrodes while keeping electrode spacing constant. This provides lateral variations at some arbitrary constant depth. Resolution for a depth sounding is determined the central offset spacing of the expanding electrode pair. Resolution for a lateral profile is determined by the spacing between the potential electrodes.

Electrical resistivity is a physical property, which is diagnostic of the type of geologic material present. Unsaturated soils have higher resistivity (lower conductivity) than saturated soils. Sand and gravel with minimal silt/clay content have higher resistivity than soils with high silt/clay content. Sandstone, limestone, and granite typically have higher resistivities than shale and siltstone. Additionally, coarse grained sands and gravels typically have resistivity values similar to limestones, and may be indistinguishable solely by the resistivity method as may be silt and clays and shales. By determining the resistivity of the layers identified in a resistivity depth sounding, the nature and thickness of the geological material in each layer can be estimated. The nature of the subsurface topography and layer geometries can be determined by lateral resistivity profiling. The depth to bedrock can usually be estimated through data inversion techniques and resulting interpretation. Voids and cavities filled with air will typically have a relatively high resistivity compared to surrounding materials while water filled voids will typically have a relatively lower resistivity than surrounding materials. Materials saturated saline or brine waters have very low resistivities and can be analogous to highly conductive clays.

4.0 FIELD INVESTIGATION/METHODOLOGY

An electrical resistivity survey was performed using Advance Geophysical Systems Inc. (AGI) Super Sting R8 56-channel resistivity imaging system (the Sting). The survey equipment consisted of a transmitter/receiver, four 14-takeout electrode cables, each with evenly spaced takeouts. Each array consisted of 56 evenly spaced stainless steel electrodes placed in the ground at 20 foot intervals, creating a single array length of 1,100 ft. Data was collected from 26 single spread 56-channel resistivity dipole-dipole arrays for a total survey covering approximately 4.0 linear miles.

The electrodes were attached to a cable take-out and connected to the Sting which was positioned between electrodes 28 and 29, the center of an array. Once data was recorded, depending on site conditions and obstructions, the array was either moved to another site location completely or a method called 'roll-along' was employed. The roll-along method employs moving the first half of the array forward where data collection continues. Employing this technique along the same orientation, single long lines may be collected more efficiently. Additionally, this method allows for seamless measurements along a single line. Finally, lines along similar orientations were merged and processed creating seven resistivity profiles of varying lengths (Table 1). Figure 1 shows the location of each of these profiles on the site map.

Table 1 Summary of Resistivity Profiles

Profile #	Length (ft)	Orientation	Approximate Surface Elev. (ft)
1	1,060	South to North	972
2	1,060	South to North	982
3	1,620	West to East	968
4	1,600	South to North	972
5	3,680	South to North	972
6	4,380	South to North	972
7	6,580	West to East	980

The electrode spread geometry was controlled by the internal transmitter switching system of the Sting. For the dipole-dipole method, the switching system selects various electrodes to form dipole pairs of current electrodes and potential electrodes at increasing n-spacings and l-spacings (n is the distance between a current pairs and a potential pairs, l is the offset between each dipole pair). Multiple measurements were made along each profile line to measure the lateral and vertical changes in subsurface resistivity. The array geometry for the surveys was limited by the length of the resistivity cables, electrode spacing, and equipment parameters. The array geometry and the geology limit depth of penetration.

The location of the resistivity survey lines were surveyed with a hand held GPS unit (Garmin GPSMAP 76) after completion of each resistivity line, using map projection UTM Zone 15 and the WGS 84 geodetic datum. The GPS accuracy range is: $\pm 38\, ft \leq Accuracy \leq 6\, ft$, with an average of $\pm 7\, ft$. The most common factors affecting this accuracy include, satellite to receiver obstructions and satellite coverage, which is usually the greatest during mid-day.

5.0 DATA INTERPRETATION

The resistivity data was downloaded and converted for analysis using Advanced Geosciences Inc. (AGI) software, Supersting Administrator, after the completion of each line. The data was then checked for error and completion before moving the equipment to another location. Data was processing used AGI's 2D EarthImager software package for line to profile merging and profile inversion, using a robust inversion scheme, and error analysis. The inverted data was then exported as ascii files, imported into Golden Software's Surfer 8, and gridded. The data was then checked for resistivity distributions and contour color levels were chosen accordingly. These distributions were then cross checked with accepted geologic resistivity values (Telford, et. al.), and then interpretative geologic profiles were created (Figures 3, 4, 5, and 6). The measured and full inverted resistivity sections of each of the seven profiles are presented in Attachment 1.

The interpretation process involved the review of data to determine the nature of subsurface lithology and related hydrogeologic framework which includes but is not limited to:

- Presence, lateral extent, depth and thickness of low hydraulically conductive units, such as silts and clays;
- Presence, lateral extent, depth and thickness of moderate to high hydraulically conductive units, such as sands, gravels, and glacial deposits;
- Identification of bedrock depth and potential fractures.
- Anomalous structure which may currently represent restrictive or increased conduits for the flow of water away from Lake Manawa

The total depth of penetration for of the resistivity profiles is approximately 280 feet. However the interpreted sections are presented in Figures 3, 4, 5, and 6 to a depth of approximately 130 feet as the focus of this study in on the upper unconsolidated material. Resistivities in these figures was contoured from values of 0 ohm-meters up to 300 ohm-meters for comparative purposes some of the actual interpreted resistivities where higher but range adequately characterizes the materials measured. The ground surface elevation for each profile is shown at 0 ft where depth is in feet below ground surface. Approximate ground surface elevations for each profile are listed in Table 1. The average lake water surface elevation is 967 feet and the average lake bottom elevation is at approximately 960 feet.

The interpreted resistivity values were assigned a lithologic description based on the text book values and review of the resistivity data and area soil borings. Comparison of soil boring data along each resistivity profile was not possible as there are no known soil borings along profile locations. Soil boring data along the profiles would allow for a more accurate interpretation. However the interpreted lithologies represent a relative change in lithology and related hydraulic properties. Therefore the lower resistive material is related to silts, clays and shales (lower hydraulic conductivities) and the higher resistive material are related to sands and gravels(higher hydraulic conductivities). The following lithologies were assigned to the corresponding approximate ranges of resistivities.

- Clay – 0-20 ohm-meters
- Silty Clay – 20-30 ohm-meters
- Silt – 30 – 50 ohm-meters
- Fine Sand – 50-80 ohm-meters
- Medium Sand - 80-10 ohm-meters
- Sand and Gravel – 180+ ohm-meters
- Limestone – 220+ ohm-meters

Figure 7 shows where the presence o coarse grain material as interpreted by the resistivity data may be present near the ground surface and/or lake bottom. Noise in the data due to cultural features and equipment is present in some of records, and is seen as vertical striping and resistivity 'pull-ups' in some of the inverted section. This noise did not interfere with interpretation or overall quality of the data and generalizations concerning subsurface lithology are still valid.

The interpretations of the geophysical data for each profile are summarized in the following text.

Profile 1:

Profile 1 (Figure 1) is located west of Lake Manawa along the eastern toe of the eastern levee adjacent to Indian Creek. It is oriented approximately south to north at $N10^0 E$ and is 1,060 feet in length. The lithologic structure, from 0 ft - 25 to 30 ft bgs, is interpreted as a relatively low hydrogeologically conductive unit. Fine sands and gravels are present in the lower part of the section with some interbedded clay and silty clay at an apparent depth of 60 ft bgs. Groundwater flow may be present in this zone. A silty-clay lense is present at 60 bgs and is laterally continuous throughout the section and may act as aquitard in this area. Finally, there is an apparent depth increase to limestone bedrock in the southern portion of the profile. This anomalous feature is also present in Profile 6.

Profile 2:

Profile 2 (Figure 3), north of Profile 1, is along the top of the levee adjacent to Indian Creek. It is oriented $N30^0 E$ and is 1,060 feet in length. The upper stratigraphic layer has an average thickness of 20 ft and thins to approximately 15 ft at mid-profile, and consists of alternating clay and silt dominated matrix. The upper portion of this layer is representative of the levee materials. The next layer below averages 15 ft to 35 ft in thickness, with an apparent matrix of medium to coarse grained sands. This coarse grain layer appears to be relatively close in elevation to that of the lake bottom and may represent a potential seepage pathway. Figure 7 shows the approximate location of this area. The third layer is predominately a clay matrix with increased amounts of silt. Additionally, an inter-fingering layer of medium to coarse sand appears to overlay the undulating limestone bedrock thinning with the upper portions of the limestone to thickness of 5 ft to 10 ft, and thickening to 30 ft to 60 ft with deeper portions of the limestone bedrock..

Profile 3:

Profile 3 (Figure 4) is oriented $N105^0 E$ paralleling a portion of profile 7 and is 1,620 ft in length. The west to central portion of the profile is underlain by a clay matrix with some silt to a depth of 28 ft. A layer of fine to medium grained sand is present below the upper layer to an approximate depth of 60 ft which is underlain by a layer of silty-clay to an approximate depth of 90 ft. Below this a thin layer of fine sands overlies the undulating limestone bedrock and coarse grained sand and gravel (or weathered limestone) that fill lower topography in the bedrock. The eastern portion of Profile 3 consists of alternating layers of coarse grained sands and silty clays. The upper layer (0-30 ft bgs) of this section appears to be the same coarse grained sand and gravel as the upper layer in the southern section of Profile 4. The silt-clay layer present beneath this 30 foot thick sequence may act as an aquitard. The limestone bedrock surface appears to be present at a depth of 110 ft bgs in the central and western section of Profile 3.

Profile 4:

Profile 4 (Figure 4) is located near the eastern edge of the southwestern lobe of Lake Manawa, oriented approximately $N45^0 E$ and is 1,600 ft in length. A prominent feature along this line is the coarse grain sand and gravel layer extending north approximately 520 ft along the profile. This upper most layer grades to a fine sand towards the northern portion of the profile This layer exists to a depth of 30 ft bgs and is interpreted to be laterally extensive as it appears to be present in nearby sections of Profiles 3 and 7. It overlies an extensive silt-clay layer (30-60 ft bgs) approximately 30 ft in thickness that may act as an aquitard. Below this layer is a thick sand/gravel layer that is bounded to the north by another silt-clay sequencer. Limestone bedrock does not appear to be present above 130 ft bgs.

Profile 5:

Profile 5 (Figure 5) is along the southern peninsula between the lake and the southwestern inlets on the southwest side of the lake. It is oriented $N30^0 - 40^0 E$, is 3,680 feet in length and consists of three separate lines. The southern segment of Profile 5 is offset with a minimal separation from the northern segment due to the presence of a large metal culvert.

Profile 5 shows three to four normally graded horizontal and laterally extensive layers from the ground surface to approximately 80 ft bgs. A silt layer exists from the ground surface to 10 ft bgs and overlies a northward thickening (10-20 ft) clay layer. This clay overlies a fine to medium grained sand 5 to 20 ft in thickness that grades to coarse grain sand and gravels becoming nearly indistinguishable from basement at depth. Limestone bedrock depth is thought to be located approximately 90 to 110 ft bgs.

Profile 6:

Profile 6 (Figure 5) is located west of Lake Manawa along the eastern toe of the eastern levee adjacent to Indian Creek. It is oriented approximately south to north at $N10^0 E$ and is 4,360 feet in length. Profile 1 is located between 3,100 ft and 4,160 ft of the profile, and was collected to verify the lithologic variation seen in this profile. A silty-clay to clay layer exists across the profile from 0 to 30 ft bgs. This overlies a predominantly medium grain sand to 70 ft bgs. Below this sand layer is a silt and fine grain sand layer that exists to approximately 110 bgs overlying coarse sands and gravels and bedrock.

Profile 7:

Profile 7 (Figure 6) is located in the southern portion of the site is generally oriented west to east, and is 6,580 ft in length. No data exists across the Missouri River boat ramp access road and is shown in the profile.

Throughout most of the profile a clay layer exists to a depth of 30 ft bgs. The western portions of this clay layer include the vertical thickness of a levee where a bike path exists and extends from the beginning of the profile to approximately 3,000 ft. A distinct coarse sand and gravel layer is located between 2,500 ft and 4,000 ft along the profile and is 10 ft to 60 ft bgs. This appears to be the same sand-gravel layer seen in the eastern portion of Profile 3 and southern portion of Profile 4. This layer may form a zone whose limits are seen to the east and west along Profiles 3 and 7 and to the north along Profile 4. This area is shown on Figure 7. A medium to coarse grained sand and gravel layer is present approximately 30 to 70 ft bgs throughout most of the section, thinning between 4,000 ft to 4,700 ft along the profile. This appears to be underlain by a silty-clay layer with some zones of fine sand. Limestone bedrock appears to be present at

110 ft bgs across the profile. This agrees well with three boring's to basement, published in HDR 2007 Report.

6.0 SUMMARY

The resistivity survey was successful in assessing local lithology and respective hydrogeologic framework with respect to hydraulically conductive subsurface areas and confining lithology. In summary interpretation of the geophysical data indicates the following:

- A fine grained lithologic unit is present throughout most of the study area with a few exceptions to an approximate depth of 25 to 30 ft bgs. The southwest portion of Lake Manawa shoreline and nearby area is characterized by near surface (0-30 ft bgs) coarse grain materials and may be a source area of leakage from the lake.

- The upper 30 feet of material in the study area is underlain by alternating sequences of coarse and fine grain material. In areas where fine grain material is at the surface it is typically underlain by a 30 to 40 foot thick layer of coarser grain material. Near surface coarse grain materials are typically underlain by approximately 30 feet of fine grained material

- Groundwater flow in area and around the site is likely controlled by these coarse and fine grain layers. The coarser grain sands may act as preferential flow zones for groundwater while the finer grained silts and clay may act as an aquitard.

- Bedrock is interpreted as ranging from 90 to 135 feet bgs at the site. This correlates with regional soil boring data. In general the bedrock surface is shown in some profiles as undulating which may be due to pre-glacial weathering or the presence of shale where lower resistive data is present between higher resistive bedrock zones.

Resistivity, like any remote sensing technique, requires the interpretation of indirect methods of measurement. In addition, resistivity results can be non-unique, that is, differing subsurface conditions or features can generate similar anomalies. As such, there is an inherent margin of error, which is unavoidable. Our methods of data acquisition and interpretation are as complete as is reasonably possible, and we believe them to be a reasonable representation of the subsurface conditions.

We suggest that key features identified by this survey be confirmed by selective direct observation methods before final conclusions and/or designs are based on our findings. Additional direct observation methods such as test borings and test pits are recommended to confirm the sequence of subsurface lithology.

7.0 REFERENCES

Advanced Geosciences, Inc. Instruction Manual for EarthImager 2D Version 2.2.8 Resistivity IP Inversion Software. Advanced Geosciences, Inc., Austin, TX. April 4, 2008.

Geotechnical Services, Inc. Report of Geotechnical Exploration for: Lake Manawa Borrow Site STP-275-3(27)-2C-78. Geotechnical Services, Inc., Omaha, NE. August 31, 2004.

Geotechnical Services, Inc. Report of Geotechnical Exploration for: Lake Manawa Borrow Site Geotechnical Services, Inc., Omaha, NE. January 30, 2007.

HDR Engineering, Inc. Iowa Department of Transportation, Hydrogeological Evaluation Report, HDR Project No. 34269. HDR Engineering, Inc., Omaha, NE. September 2007.

Sotak, Michael K. (PE). Technical Proposal to Provide Service: Diagnostic and Feasibility Study of Lake Manawa, Pottawattamie County. Solicitation No. 08-57HA-08. Tetra Tech, Omaha, NE. April 2008.

Telford, W.M.; Geldart, L.P.; Sheriff, R.E.; Keys, D.A. Applied Geophysics. Cambridge University Press. Cambridge, London. 1982 (Reprint).

Witzke, Brian J., Anderson, Raymond R., Bunker, Bill J., Ludvigson, Greg A. Bedrock Geologic Map of Southwest Iowa. Iowa Department of Natural Resources and Iowa Geological Survey. Iowa City, IA. September 2003.

FIGURES