SOUTHERN HILLS LAKES PRELIMINARY EVALUATION AND MANAGEMENT PLAN:

SUMMARY REPORT

Prepared for:
The City of Springfield

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1.0 EXECUTIVE SUMMARY

1.1 Purpose

This report presents the results of a one-year investigation of the nature of water quality and associated algae problems with the Southern Hills Lakes in Springfield, Missouri.

The purpose of the study was to address the following questions:

- What were the historic uses of the lakes and which uses are currently affected?
- What problems characterize the lakes in their current condition?
- What is the present condition of the lakes in terms of water quality and weeds/algae?
- What are the causes of the observed problems?
- What are reasonable goals for improving the lakes?
- What short- and long-term alternatives exist for improving the lakes?

1.2 Background

The lakes are connected in series along a tributary to Galloway Creek, and are referred to as the "Upper," "Middle" and "Lower" lakes in this study. The lakes were constructed between 1955 and 1960 as amenities for the Southern Hills Subdivision.

The lakes receive stormwater runoff from a watershed that is almost fully urbanized. Each lake is fed by one or more known springs.

1.3 Problems With Lakes

Through interviews with the Southern Hills Neighborhood Association (SHNA) members and the Advisory Committee, the following list of problems emerged at the start of this evaluation:

1. Algae (largest problem)
2. Sediment accumulation and shallowness (significant)
3. Water clarity (significant)
4. Waterfowl (significant, both in terms of water quality impacts and impacts to vegetated areas adjoining the lakes)
5. Bacterial levels (significant)
6. Degradation of property value (significant)
7. Overall negative aesthetic effect (significant)
8. Eutrophication—lake aging process (significant)
9. Odor (minor)
10. Insects (minor)
11. Aquatic Weeds (not significant)

The largest problem at this time is excessive filamentous algae growth. Information indicates that this problem has become worse in recent years. Historically, excessive filamentous algae growth was primarily associated with the Upper Lake; however, during the summer of 2000, filamentous algae levels in the Middle Lake reached an all-time high, according to homeowner accounts. Both the Upper Lake and the Middle Lake exhibit extensive surface coverage of filamentous algae during the summer.

1.4 Historic Beneficial Uses

Interviews and documents reviewed suggested that the following beneficial uses were historically provided by the lakes (if the use is still occurring, this is noted):

- Visual/aesthetic enhancement (still occurring at Lower Lake, limited at Middle Lake)
- Conveyance of flood flows and modest reduction in downstream flood discharges (still occurring)
- Waterfowl and wildlife habitat (still occurring)
- Passive recreation, such as picnics and other outdoor activities next to lakes (reduced, but still occurring)
- Boating (minor use historically)
- Fishing (minor use historically)
- Pollutant removal (still occurring)
- In general, the lakes positively contributed to neighborhood "character"

1.5 Data Collection and Observations

Data were collected and observations made on the conditions of the lakes and the watershed beginning in the fall of 1999, and continuing until October 2000. Historical data were also utilized by WWE, as appropriate.

The physical characteristics of the lakes and their watersheds are summarized, as follows:

1. All of the study lakes are relatively small in terms of surface area and volume.
2. All the lakes are relatively shallow with average depths of roughly 5 to 6 feet, and maximum depths of around 9 to 11 feet.

3. The average depths of sediment accumulation from the Upper to Lower Lake are: 1.9, 1.1, and 0.9 feet, respectively. As much as 3 feet of sediment has accumulated at the north end of the Upper Lake. Interviews indicate that large-scale sediment removal from the lakes has never occurred.

4. The lakes do not have significant emergent vegetation around their edges in the littoral zone.

5. The lakes tend to have relatively flat side slopes, which promote safe use of the lakes, but also provide a relatively large area for weed and algae growth.

6. The three dams for the lakes are compacted earth fill with concrete overflow spillways. The dams do not have outlet pipes and do not have properly designed spillways.

7. The watersheds for the lakes are heavily urbanized, so that the runoff and pollution-generation potential is high. The current platted or developed area percentage is about 96 percent, which translates into an actual impervious area percentage of about 45 percent, per the City's calculations.

8. Given their position in the watershed, the lakes periodically receive large amounts of stormwater runoff. Large floods repeatedly pass through the lakes, based on information (including video footage) provided by the SHNA and City.

1.6 Water Quality Influences

There is an extensive sanitary sewer system in the recharge area to the three lakes including an interceptor in close proximity to the lakes. The sanitary sewer system periodically experiences leakage, which is typical for systems that were constructed of vitrified clay pipe during the 1950s through 1970s.

Some homes maintained individual sewage disposal systems (ISDS) into the 1990s, and there are reportedly still ISDS systems in the recharge area for the lakes.

Much of the watershed tributary to the Upper Lake developed without a planned drainage system and lacks basic drainage facilities. The watershed tributary does not have stormwater quality "best management practices," or BMPs. However, this is not surprising given that the watershed was largely developed during the 1950s through 1970s (by 1960, 63 percent of the watershed had been platted or developed), when few American communities had water quality BMPs.

A large number of waterfowl historically used and currently use the lakes. Published studies show that waterfowl can be a significant contributor of nutrients and coliform bacteria to lakes.

The lakes are approximately 45 years old. All lakes undergo a natural "aging" process known as *eutrophication* whereby they become more productive and weed and algae growth increases. Urbanization typically accelerates natural eutrophication by (among other reasons) contributing relatively large amounts of nutrients to lakes.

1.7 Water Quality Data Interpretation

In general, the water quality of the lakes and springs is similar. All lakes had relatively low levels of suspended solids during ambient conditions, and high levels of nitrogen and phosphorus. Average total nitrogen concentrations in the springs ranged from 1.52 to 3.59 mg/L. Several of the total nitrogen concentrations for the Upper Lake spring exceeded 2 mg/L, and the highest value measured was nearly 6 mg/L. These data show high nitrogen levels in the groundwater, and nutrient loading calculations in the report indicate that the springs contribute a disproportionate amount of nitrogen to the lakes.

Total phosphorus, which is commonly used to assess the trophic status of lakes, was relatively similar in the lakes and averaged 0.16 to 0.17 mg/L. Past studies have found that phosphorus is often the limiting nutrient for algae growth and lake productivity. Based on accepted lake classification schemes, all three of the study lakes are in a hypertrophic state, meaning that they have very high levels of nutrients and are very productive.

Levels of fecal coliform and fecal streptococci bacteria are often high in the lakes following precipitation. It is likely that both man-caused (sanitary wastewater and other) and natural (waterfowl and other) sources of bacteria exist.

Samples of the sediment in the bottoms of the lakes were collected, and show that the sediment contains high levels of nutrients, which could be available to support weed and algae growth in the lakes.

The total amount of sediment accumulation in the lakes (over 45 years) is estimated at approximately 33,000 cubic yards, or 16 to 37 percent of the lake depths. As explained within the report, 33,000 cubic yards is equivalent to a sediment yield of about 1.5 tons/acre/year, which is relatively low for an urbanized watershed.

Samples of stormwater runoff were taken four times at several locations upgradient of the lakes. The results show that levels of total suspended solids (TSS) were relatively low compared to regional and national data, but that total phosphorus concentrations were higher than in runoff from six drainage areas in Springfield that were monitored by the City during the municipal stormwater NPDES permit application process. By contrast, total nitrogen (nitrate plus Kjedahl nitrogen) levels in the runoff were lower than from the six basins monitored by the City.

1.8 Algae and Weed Surveys

Inventories of the predominant types of weeds and algae in the lakes were conducted on November 16-17, 1999 by Dr. Russell Rhoads and from July 21-August 6, 2000 by Dr. Larry Stauffer.

The inventories indicate that the dominant form of weed/algae in the lake is filamentous algae, particularly the families Spirogyra, Oedogonium, Zygnema, and Hydrodictyon. The algae identified are all classified as “green” algae, with the exception of gold/brown diatoms.

1.9 Water Balance

On an annual basis, most of the water (76 percent) in the Upper Lake is from stormwater runoff, while most of the water in the Middle and Upper Lakes is "pass through" from the upstream lake (62 and 73 percent, respectively). It is estimated that the known springs in the lakes contribute between 21 to 28 percent of the water in the lakes, on the average. A significant volume of water is supplied to the lakes; consequently, the hydraulic retention times (average number of days it takes to replace the volume of the lake) are between 8 to 11 days.

1.10 Nutrient Loading

The load (pounds per year) of nutrients contributed to the lakes was estimated from the water quality data collected for the study and estimated inflows. Nutrient loading from waterfowl wastes and sediment deposits were not estimated due to a lack of available data.

Most of the phosphorus contributed to the Upper Lake is from runoff. This would be expected since runoff provides most of the water to the lake. However, the spring in the Upper Lake contributes a disproportionately large amount of nitrogen and is the largest source of this nutrient.

Overall, the estimated nutrient loading to the lakes is very high, without including contributions from waterfowl or sediment. Even if it were feasible to significantly reduce total phosphorus and nitrogen loads in surface water and groundwater inflows, the loads would still be larger than necessary to cause excessive filamentous algae growth. This indicates that management strategies should focus on improving conditions in the lakes, with pollutant source control a lower priority.

1.11 Lake Management Goal

Following interviews with representatives of the SHNA and City, the following lake management goal was established.

<u>Recommended Overall Goal</u>: To manage the growth of weeds and algae in the lakes to maintain/restore the historic uses of the lakes (including as aesthetic amenities) to a reasonable degree.

Inherent in this goal is the notion that *it will not be feasible to eliminate weeds and algae in the lakes* and that there will be acceptance of some weed and algae growth by homeowners.

1.12 Algae and Weed Control Measures

A variety of potential weed and algae control measures were evaluated, including options at both ends of the spectrum: (1) do nothing and (2) major improvement (excavate to well below the original depth in all three lakes, install liners, and make various upgrades to the dams including outlet pipes, larger spillways, higher freeboard, forebays and other improvements). Control measures were evaluated based on multiple factors including, among others, proven effectiveness, cost, and implementatiblity.

1.13 Recommended Control Measures

The recommended control measures include "short-term" and "long-term" measures. A combination of measures is recommended in a phased approach to improve the lakes. The recommended plan is shown in Table ES-1, and includes use of algaecides and grass carp to provide short-term reduction in filamentous algae, with immediate implementation of three long-term measures and further feasibility analysis of five additional long-term measures. The recommendations are an initial proposal that can be modified by the lake owner, the SHNA and the City. An important aspect of the plan is to continue to monitor conditions in the lakes to assure the effectiveness of the controls being implemented.

TABLE ES-1

Recommended Lake Management Plan for Years 2001 – 2003 (Years 1 – 3) (1) (2)
(See Report for Detail)

Management Action	Upper Lake	Middle Lake	Lower Lake
Recommended Short-Term Control Measures			
1. Algaecides	Years 1-3	Years 1-3	Years 1-3
2. Stocking of grass carp	Year 1	Year 1	Year 1
Recommended Long-Term Control Measures			
1. Partial dredging	(3)	(3)	(3)
2. Outlet structure installation	(3)	(3)	(3)
3. Raise lake normal water surface elevation	(3)	(3)	(3)
4. Construction of a forebay	(3)	NA	NA
5. Conversion of some of the Upper Lake into a wetland	(3)	NA	NA
6. Continued monitoring of sanitary sewer system by city, with repairs and upgrades as necessary	Years 1-3	Years 1-3	Years 1-3
7. Waterfowl deterrents, including littoral zone establishment	Years 1-3	Years 1-3	Years 1-3
8. Stormwater quality control practices including structural BMPs, public education and stream channel stabilization	Years 1-3	Years 1-3	Years 1-3

(1) Program will need to be adjusted each year based on monitoring.
(2) Three-year timeframe provided to initiate lake management plan. Plan will eventually need to be extended beyond 2003. Plan assumes start-up in 2001.
(3) Further feasibility/financial analysis required to determine whether technically and/or financially feasible. Should be assessed after initial controls are implemented. See report for more information.
NA—not applicable.

2.0 INTRODUCTION, PURPOSE AND SCOPE OF REPORT

This report presents the results of a one-year investigation of the nature of water quality and associated algae problems with the Southern Hills Lakes in Springfield, Missouri. A lake management plan is presented to address the problems identified.

Wright Water Engineers, Inc. (WWE) completed this study at the request of the City of Springfield (City) and the Department of Public Works (Public Works). The City defined the specific scope of the study with input from an Advisory Committee,[1] and the Southern Hills Neighborhood Association (SHNA), including suggestions from community residents.

The purpose of the study was to address the following questions:

- What were the historic uses of the lakes and which uses are currently affected?
- What problems characterize the lakes in their current condition?
- What is the present condition of the lakes in terms of water quality and weeds/algae?
- What are the causes of the observed problems?
- What are reasonable goals for improving the lakes?
- What short- and long-term alternatives exist for improving the lakes?

The study is focused on evaluating the current situation with the lakes and offering short-term and long-term lake management recommendations.

Engineering analyses for the study were conducted at a conceptual level of detail. More detailed engineering is needed to design recommended lake improvements.

[1] Members of the Advisory Committee include: Mr. Fred Palmerton (Chairman), Dr. Steve Jones, Dr. Kenneth Thomson, Mr. Mark Harrell, Mr. Michael Giles, and Mr. Bob Smith (Ms. Susan Hansen serves as alternate for Bob Smith).

3.0 BACKGROUND AND GENERAL DESCRIPTION OF THE LAKES

The Southern Hills Lakes are located on a small tributary to Galloway Creek in southeastern Springfield that drains approximately 654 acres. The lakes are connected in series along a tributary, and are referred to as the "Upper," "Middle" and "Lower" lakes in this study. Figure 1 is a vicinity map of the lakes, and Figure 2 is a more detailed drawing of their watershed.

The lakes were constructed between 1955 and 1960 as amenities for the Southern Hills Subdivision. The lakes are privately owned and maintained by a corporation under the original developer, John Q. Hammons. There is currently no public access to the lakes. The physical characteristics of the lakes (depth, surface area, volume and other parameters) are described in Section 5.0 of this report.

The lakes receive stormwater runoff from a watershed that is almost fully urbanized. Each lake is fed by one or more known springs and there are likely other groundwater inflows, as well, according to Dr. Ken Thomson, member of the Advisory Committee. The stream channels upstream and downstream from the lakes, and in the reach between the Upper and Middle Lakes, have been observed to infiltrate flows (i.e., they are "losing"). A 1988 study completed by Dr. Thomson entitled: "Study of Southern Hills Lake to Determine the Possible Location of Water Leakage," supports this observation. This report is provided as Appendix A.

The lakes have experienced significant problems with filamentous algae since at least the early 1990s. Due to increasing concerns from Southern Hills residents with the lakes, the City retained WWE to conduct this study, which began in the autumn of 1999.

3.1 Watershed for Lakes

The watershed for the lakes is nearly fully developed. Based on estimates from the City, 96 percent of the watershed is currently developed or platted. The City has determined that the watershed area tributary to the Upper (northerly) Lake is about 511 acres with an average imperviousness of 44.5 percent and that the Middle Lake has an additional 100 acres of watershed (of residential land use), and the Lower Lake an additional 43 acres of watershed (also residential land use).

Dr. Thomson has characterized the geology of the area as follows (see Appendix A for more detail):

> *The Burlington Limestone, a medium bedded, light gray, crystalline crinoidal limestone, underlies the area around the north Southern Hills Lake. Outcrops of the Burlington can be seen on the west side of the lake near the dam. In the Springfield area, this rock is very susceptible to solution along bedding planes and fractures, thereby acting as the host for a great many caves and springs.*
>
> *Residuum covers the Burlington throughout the area to a variable depth. This is the material that is the weathering product of the limestone and it consists of chert and soil covering the irregular bedrock surface.*
>
> *No faults can be found locally, but a major photolineament has been found which cuts through the lake from the southwest to the northeast.*

The hydrologic and water quality implications of the karst geologic setting in Springfield are described in the 1996 report entitled: *Fulbright Spring Watershed Protection Plan*, prepared by the Watershed Committee of the Ozarks, City of Springfield, City Utilities and Greene County (WWE served as consulting engineer on this project). For example, this report indicates that shallow groundwater is highly susceptible to contamination by infiltration of stormwater runoff and other sources.

Soils in the watershed are typically silt loams, which have moderate to high erosion potential. Vegetation consists largely of residential landscaping that includes bluegrass and a mixture of shrubs and trees typical of metropolitan Springfield.

Sanitary sewer service was made available to the Southern Hills subdivision starting in 1972 and is currently available throughout the watershed. However, interviews indicate that an unknown number of onsite disposal systems (septic tanks and leach fields) remain in the recharge area for the lakes.

3.2 Lake Problems

Through interviews with the SHNA members and the Advisory Committee, the following list of problems emerged at the start of WWE's evaluation (the perceived level of the problem, as determined from interviews and documents reviewed, is in parenthesis):

1. Algae (largest problem)
2. Sediment accumulation and shallowness (significant)
3. Water clarity (significant)
4. Waterfowl (significant, both in terms of water quality impacts and impacts to vegetated areas adjoining the lakes)
5. Bacterial levels (significant)
6. Degradation of property value (significant)
7. Overall negative aesthetic effect (significant)
8. Eutrophication—lake aging process (significant)
9. Odor (minor)
10. Insects (minor)
11. Aquatic Weeds (not significant)

3.3 Historic Lake Beneficial Uses

Interviews and documents reviewed suggested that the following beneficial uses were historically provided by the lakes (if the use is still occurring, this is noted):

- Visual/aesthetic enhancement (still occurring at Lower Lake, limited at Middle Lake)
- Conveyance of flood flows and modest reduction in downstream flood discharges (still occurring)

- Waterfowl and wildlife habitat (still occurring)
- Passive recreation, such as picnics and other outdoor activities next to lakes (reduced, but still occurring)
- Boating (minor use historically)
- Fishing (minor use historically)
- Pollutant removal (still occurring)
- In general, the lakes positively contributed to neighborhood "character"

The SHNA has indicated to WWE that although it would be desirable to restore as many of these beneficial uses as feasible, the primary objective should be to reduce algae growth and restore the visual/aesthetic quality of the lakes.

4.0 STUDY PARTICIPANTS AND PROCESS

WWE prepared the initial scope of work for the study in the fall of 1999, which was reviewed and approved by the City and the Advisory Committee. WWE has provided technical assistance related to field data gathering and review of the data and other information throughout the project. WWE was also responsible for developing potential lake management actions, and for preparation of the recommended lake management plan. Water quality sampling and determination of the physical characteristics of the lakes were the responsibility of the City, under guidance from WWE and members of the Advisory Committee, including Dr. Steve Jones, Professor of Biology at Drury College. Dr. Larry Stauffer, Emeritus Professor of Botany at Drury College, conducted a weed and algae survey of the lakes in the summer of 2000. This survey information was combined with an algae survey prepared by Dr. Russell Rhodes in the fall of 1999. Both of the studies are included in Appendix B. Mr. Robert Smith of the SHNA collected stormwater runoff water quality data, and these data were included in this evaluation.

A December 2000 draft of this report was provided to the City and Advisory Committee for review and comment. Comments and suggestions received were addressed in a memorandum to the Advisory Committee dated March 22, 2001, and in a teleconference with the Advisory Committee dated April 5, 2001. Following this teleconference, the final version of this report was prepared.

The City held four Advisory Committee and two SHNA public meetings to obtain input and to discuss observations and findings. Suggestions and comments made at the SHNA and Advisory Committee meetings were incorporated into the study. There was also direct communication between WWE and the City and SHNA throughout the project.

4.1 Existing Information

WWE asked the City and the SHNA to provide any relevant background information on the lakes. WWE received the following background information and data from both the City and SHNA:

- Videotapes prepared by Mr. Robert Smith of the SHNA depicting the watershed and lakes during 1999 and 2000.
- Aerial photographs of the lakes and watershed dating from 1954, 1960, 1969, 1972, 1975, 1980, 1985, 1990 and 1995.
- Land use/zoning maps provided by the City.
- Subdivision plat maps that indicate when various developments in the watershed were platted.
- A series of reports prepared by the SHNA concerning the history of the neighborhood and the lakes, observations of water quality/algae over time, concerns with additional development in the watershed, historical information related to urbanization (development) of the watershed, neighborhood concerns, overview of lake management practices that have been attempted previously, and other information. This included,

among other documents, the report entitled *Southern Hills Lakes History*, which provided background information and photographs regarding these factors.

- Sanitary sewer system maps, as provided by City.
- Storm drainage system maps, as provided by City.
- Various maps, field surveys and physical data on the lakes and watersheds prepared by the City, including 1975 topographic mapping with 5 feet contours.
- Members of the Advisory Committee have provided helpful information on such topics as watershed geology and hydrogeology, waterfowl usage, algae growth, lake monitoring and other factors.
- The City has provided background stormwater quality data, and monitoring data for the three primary springs that discharge into the lakes.
- Both the City and members of the SHNA provided numerous photographs, background documents and observations (via e-mail and phone calls) that were utilized for this study.

Note that many of the documents assembled by the City at WWE's request, such as aerial photographs, plat maps, sanitary sewer system maps, topographic mapping, etc, are too large to attach to this report, but they are available at the City offices.

4.2 Field Data Collection

Data were collected and observations made on the conditions of the lakes and the watershed beginning in the fall of 1999, and continuing until October 2000. Historical data were also utilized by WWE, as appropriate. A sampling plan was prepared to collect data on water quality, sediment quality, and the various types of weeds and algae in the lakes to enable an assessment of their current condition. An initial sampling plan was prepared and implemented in November 1999. This plan was modified after review of existing data and discussion with City staff and the Advisory Committee, and a refined plan was issued on March 20, 2000 (see copy in Appendix C). Sampling commenced in November 1999 and continued through October 2000. A total of seven sets of lake samples were collected by the City, while stormwater inflows were sampled by the City and Mr. Smith of the SHNA on four occasions.

The scope of the sampling for this study is summarized in Table 1, and included the following:

- Ambient (dry weather) water quality samples from the lakes
- Sampling of the lakes during or after a storm
- Sampling of stormwater inflows to the lakes
- Lake sediment sampling
- Inventory of the types of weeds and algae in the lakes
- Inventory of the condition of the shorelines around the lakes

Water quality samples were taken from the lakes themselves, at three major springs adjacent to the lakes (one at each lake), at locations between the lakes, and at several stormwater inflow points to the Upper Lake. Figure 3 is a schematic of the sampling locations.

Samples were analyzed for parameters that are important for lake water quality, including nutrients (phosphorus and nitrogen). The parameters analyzed in each sample are shown in Table 2. Dissolved oxygen, water temperature, conductivity and pH were measured in the field. The other parameters listed in Table 2 were analyzed by the City's analytical laboratory (first six samples) and at a private laboratory (final sample, in October 2000).

Sediment samples were collected from the lakes to assess the extent that sediment may provide a source of nutrients to the lakes, and to determine whether sediment from any lake dredging would have special disposal requirements.

An inventory of the types of weeds and algae growing in the lakes was completed in July 2000, and of algae only in November 1999. The July 2000 inventory also included the types of vegetation growing along the shorelines of the lakes. In this study, the term "weeds" refers to aquatic macrophytes such as pondweed and water lilies; “algae” refers to phytoplankton, filamentous and macrophytic algae. Weeds have not been noted as a significant issue. Both of the inventories are provided in Appendix B.

The physical characteristics of the lakes were field surveyed by City staff using a combination of cross-sectional surveys by boat and existing information. Measurements were taken on the depth of water and sediment in the lakes, lake bottom configuration and lake dimensions. Engineering reports, drawings, photographs, construction reports, etc., for the dams and lakes could not be located for this study. City topographic mapping was used to determine the size and characteristics of the watershed tributary to the lakes. Appendix D contains the field survey data on the lakes collected by the City.

Relevant water quantity and quality data were used to prepare estimates of water balances and nutrient inputs to the lakes. Data on lake water quality and the types of weeds and algae were used to assess the condition of the lakes, the nature of existing problems, and to evaluate the suitability of various management methods.

5.0 PHYSICAL CHARACTERISTICS OF THE LAKES, WATERSHED, AND RECHARGE AREA

The physical characteristics of the lakes and their watersheds are summarized in Table 3. Certain observations are apparent from Table 3 and field inspections, as follows:

1. All of the study lakes are relatively small in terms of surface area and volume. The lakes increase in size and volume moving from north to south.

2. All the lakes are relatively shallow with average depths of roughly 5 to 6 feet, and maximum depths of around 9 to 11 feet. Lake depths and sediment deposit thicknesses decrease moving from north to south. Significant portions of each lake are shallow, especially near the inlets where sediment has accumulated. As an example, roughly the northern half of the Upper Lake is about 3 feet deep, with sediment accumulations in this area typically ranging from 1-3 feet. Based on the cross sections of the lakes in

Appendix D, the average depths of sediment accumulation from the Upper to Lower Lake are: 1.9, 1.1, and 0.9 feet, respectively. The lake cross sections in Appendix D indicate that portions of the lakes were relatively shallow (less than 6-7 feet deep) when they were constructed.

The shallowness is conducive to good mixing, due to wind and strong "flow through" during flood events. The shallowness also facilititates plant growth (due to sunlight penetration to the lake bottom) and heat transfer (shallow lakes change temperature more rapidly than deeper lakes).

3. The lakes do not have significant emergent vegetation around their edges in the littoral zone. Managed bluegrass lawns tend to surround the lakes. There are few trees around the lake perimeters to provide shade.

4. The lakes tend to have relatively flat side slopes, which promote safe use of the lakes, but also provide a relatively large area for weed and algae growth.

5. The three dams for the lakes are compacted earth fill with concrete overflow spillways. The City has stated that the dams are not subject to regulation by the Missouri State Engineer. The dams do not have outlet pipes and do not have properly designed spillways. The lack of bottom outlet pipes is problematic, as they would facilitate maintenance. The vertical distances between the lake normal water surface elevations and dam crests are typically around 3 feet, which is small for dams of this size.

6. The watershed for the lakes is heavily urbanized, so the runoff and pollution-generation potential is high. According to the City and as shown in Figure 4, 63 percent of the watershed was platted or developed by 1960. This value had increased to 69 percent by 1970 and 86 percent by 1980. The current developed/platted area percentage is 96 percent, which translates into an actual impervious area percentage of about 45 percent, per the City's calculations. Mr. Bob Smith of SHNA has also provided WWE with detailed information on the nature of development in the watershed.

7. Large floods repeatedly pass through the lakes, based on information (including video footage) provided by the SHNA and the City, and consistent with field observations (the lakes have up to 650 acres of urbanized area draining through them). All three lakes overtopped during a July 12, 2000 rainstorm because spillway capacity was exceeded, (this event ranged from a 100 to a 500-year return frequency in various parts of Springfield), and there was moderate damage to the dam for the Middle Lake.

There is a known submerged spring towards the inlet of the Upper Lake that flows year-round at an estimated average rate of 0.25 cfs[2].

There is one known perennial spring at the Middle Lake that is free flowing with an estimated average annual discharge of 0.5 cfs.

The outflow from the Middle Lake discharges into the Lower Lake, which has two known springs, with an estimated average annual flow of 0.5 cfs,[2] combined. There are several seeps at the north end of the Lower Lake that appear to be caused by seepage from the Middle Lake embankment. These seeps appear to be rich in iron and manganese, based on orange colored staining observed. This seepage is small in quantity compared to the springs feeding the lakes.

[2] Spring flows are likely variable depending on groundwater conditions. The reported flows are rough estimates, only, based on limited field observations.

5.1 Recharge Area and Subsurface Sources

As shown in Figure 5, the recharge area for the lakes (as defined by Dr. Thomson) is somewhat larger than the surface watershed tributary to the lakes. This was confirmed in 1995 when a sewer line near Glendale High School (which is outside of the surface watershed) broke and the municipal wastewater flowed underground to the Middle Lake (based on interviews with City staff and Dr. Thomson).

Dr. Thomson indicated that it is not feasible to quantify the non-spring groundwater interactions (inflows and outflows) with the lakes. The fact that the Southern Hills Lakes are located in a karst (limestone) setting is important, because of the potential for significant groundwater flows. Dr. Thomson described the potential for infiltration from the lakes in his 1988 report regarding lake leakage (Appendix A), including the presence of a photolineament (historic fracture). This is also consistent with contemporary observations of stream flow infiltration in the channels between the Upper and Middle Lakes, upstream of the Upper Lake, and downstream of the Lower Lake, and with observations throughout Springfield.

There is an extensive sanitary sewer system in the recharge area to the three lakes including an interceptor in close proximity to the lakes. Because this area largely developed in the 1950s through 1970s, vitrified clay sewer pipe (VCP) with gaskets was used. More recent developments and retrofits have utilized polyvinyl chloride (PVC) pipe. Older VCP networks inevitably experience leakage and exfiltrate wastewater when they are surcharged—this is common in many parts of the U.S. This undoubtedly occurs in the recharge area to the Southern Hills Lakes, although it was not feasible to quantify the magnitude and significance of this source as part of this study.

The City of Springfield Public Works Department conducts a comprehensive sanitary sewer inspection and maintenance program, which has received national recognition. The City's objective is, in general, to reduce leakage and surcharging and to respond to known problems promptly. Interviews with City staff indicate that particular attention has been directed to the Southern Hills Lakes watershed.

Despite the long-standing availability of sanitary sewer service, some homes maintained individual sewage disposal systems (ISDS) into the 1990s, and there are reportedly still ISDS systems in the recharge area.

5.2 Storm Drainage Systems and Stream Channel Erosion

According to Mr. Marc Thornsberry, P.E., City Public Works Director, much of the watershed tributary to the Upper Lake developed without a planned drainage system and lacks such basic drainage facilities as inlets and storm sewers. This was typical for Springfield in the 1950s and 1960s when the majority of the city was platted. This problem is being addressed during 2000/2001 with nearly $1.75 million of drainage improvements, primarily north of Sunshine Street and through channel stabilization improvements north of the Upper Lake and in the channel reach between the Upper Lake and Middle Lake.

There are several significant culverts beneath Sunshine Drive that convey flows from north to south, and ultimately into the Southern Hills Lakes. Channel erosion is apparent in some locations in the watershed. Watershed soils are erodible and slopes are significant. For example, there is a storm sewer outlet on the south side of the Southern Hills shopping center which discharges into a channel that flows into the uppermost lake—this channel has experienced significant erosion. There is not an energy dissipater at this culvert outlet, nor at some of the other culverts in the watershed observed by WWE. Residents of Southern Hills have noted that the channel that connects the Upper and Middle Lakes (referred to as the "Edgewater channel") has experienced significant widening over time.

The watershed tributary to the lakes does not have stormwater quality "best management practices," or BMPs. This lack of BMPs is typical for urbanized areas in the U.S. that were largely developed before the mid- to late 1990s, when federal stormwater quality regulations for larger municipalities became effective.

5.3 Other Considerations Regarding Physical Characteristics of Lakes and Watershed

Inspection of topographic mapping of the watershed and field inspections indicate that the Southern Hills Lakes represent the first significant opportunity for sedimentation/removal of settleable solids, nutrients, and other constituents. Due to the relatively steep slope of the watershed tributary to the lakes, the high degree of development, nature of the storm drainage conveyance system, and absence of stormwater quality BMPs, pollutants are effectively transported through the watershed downstream to the lakes where significant retention occurs.

A large number of waterfowl historically used and currently use the lakes. Published studies show that waterfowl can be significant contributors of nutrients and coliform bacteria to lakes. In addition, in some of the upland areas adjacent to the Southern Hills Lakes, waterfowl have denuded vegetated areas.

The lakes are approximately 45 years old. Interviews indicate that large-scale sediment removal from the lakes has never occurred. They are located in a watershed that rapidly urbanized shortly after their construction. At the time of lake construction, much of the watershed was reportedly a dairy farm (based on information provided by SHNA and the City). All lakes undergo a natural "aging" process known as *eutrophication* whereby they become more productive and weed and algae growth increase. Urbanization typically accelerates natural eutrophication by (among other reasons) contributing relatively large amounts of nutrients to lakes (Urban Land Institute 1992 and USEPA 1990).

6.0 LAKE AND SPRING WATER QUALITY DATA

Lake and spring water quality was sampled seven times for this study. The results from this sampling are provided in Table 4, which includes samples taken during both dry weather conditions, and during or immediately following rainstorms. Table 5 provides average, minimum, and maximum values for dry weather conditions for the lakes and springs. It should be noted that 2000 was somewhat anomalous for precipitation. The spring was very dry until late May. June had normal precipitation; July had major storms on three separate days; and from July 29 through the autumn, conditions were relatively dry.

In general, the water quality of the lakes and springs is similar. All lakes had relatively low levels of suspended solids during ambient conditions, and high levels of nitrogen and phosphorus. These nutrients can be used to assess the trophic status (i.e., the extent of nutrient enrichment) of a lake. For example, average values of total nitrogen[3] ranged from 0.75 to 0.81 mg/L in the Southern Hills Lakes. Average total nitrogen concentrations in the springs ranged from 1.52 to 3.59 mg/L. Several of the total nitrogen concentrations for the Upper Lake spring exceeded 2 mg/L, and the highest value measured was nearly 6 mg/L. These data indicate that springs contribute a disproportionate amount of nitrogen to the lakes.

Total phosphorus, which is commonly used to assess the trophic status of lakes, was relatively similar in the lakes and averaged 0.16 to 0.17 mg/L. Past studies (OECD 1982, USEPA 1990) have found that phosphorus is often the limiting nutrient for algae growth and lake productivity. Extensive work has been conducted to relate levels of total phosphorus to lake trophic status and several schemes have been developed to classify lakes based on total phosphorus concentrations (Carlson 1977, Porcella et al. 1980). A scheme developed by Vollenweider and Kerekes (1980) found that lakes with an average total phosphorus concentration of 0.035 to 0.1 mg/L are typically in a eutrophic (i.e., nutrient enriched) condition, and lakes with concentrations greater than 0.1 mg/L are associated with hypertrophic (very enriched) lakes. Based on this scheme, the Southern Hills Lakes would all be classified as hypertrophic. This is consistent with the excessive growth of algae observed in the lakes.

Table 6 provides an evaluation of the lakes with respect to several parameters commonly used to assess lake trophic condition. This table shows the average total phosphorus concentrations just discussed along with the ratio of total nitrogen to total phosphorus. Values of this ratio ranged from 4.7 to 4.9. A value of less than 10 is typical of eutrophic lakes, and could indicate a nitrogen limitation, at least part of the growing season. This condition could eventually favor

[3] Total nitrogen = (nitrate/nitrogen) + (total Kjeldahl nitrogen). See values in Tables 4 and 5.

undesirable species of blue green algae, which have the ability to “fix” nitrogen from the atmosphere. Thus far, based on the two inventories conducted, blue green algae have not been found in the lakes. It will be important to monitor for blue green algae in the future as lake management measures are implemented, because as green algae are reduced, blue green algae could increase in abundance.

City staff collected dissolved oxygen and temperature profiles for the Southern Hills Lakes on April 6, August 10 and October 13, 2000. These profiles show that the lakes did not have a well-defined temperature stratification during 2000. In April, which is early in the growing season, water temperature was generally three to five degrees (C) cooler at the bottom of the lakes compared to the surface water. There was more variation in water temperature in the Upper and Middle Lakes in April than the Lower Lake. Water temperature was higher in August in all the lakes, though the variation from top to bottom was still relatively small. The lack of defined stratification was likely due to the relatively shallow depths of the lakes, constant spring inflows and their high flushing rates. Despite the data collected during 2000, under prolonged drought conditions, stratification could develop. This could result in depressed oxygen levels at the lake bottoms.

There was no clear pattern with regard to dissolved oxygen levels in the lakes. Dissolved oxygen was found to both increase and decrease with depth, when the profiles were collected on three occasions in 2000. Some of this variation could be due to the presence of phytoplankton at different levels in the lake. None of the profiles indicate anaerobic conditions at the lake bottoms. As with water temperature, this may be due to the shallow, well-mixed nature of the lakes.

Tables 4 and 8 indicate that levels of fecal coliform and fecal streptococci are often high following precipitation. Fecal coliform and streptococci are indicators of bacterial contamination. When detected in high concentrations, they can be an indication of sanitary wastewater and septic tank/leach field contamination, although wildlife are significant fecal coliform contributors, as well. For example, a single duck can produce 12 *billion* fecal coliform in 24 hours (Tchobanoglous and Schroeder 1987). Fecal coliform concentrations in stormwater inflows to the Southern Hills Lakes (Table 8) ranged from 9,800 to 60,600 colonies per 100 ml. Fecal streptococci ranged from 40,000 to 187,000 colonies per 100 ml. By contrast, stormwater NPDES permit monitoring conducted by the City in six other watersheds around Springfield indicated much lower concentrations, with mean fecal coliform concentrations of 48 to 1,192 colonies per 100 ml and streptococcus mean values of 1,231 to 6,265 colonies per 100 ml. The man-caused (sanitary wastewater) and natural (waterfowl and other wildlife) sources of coliform also tend to be significant contributors of nitrogen and phosphorus, which contribute to excessive algae growth in the lakes.

WWE has had discussions with City staff regarding the coliform and streptococci data. The City Public Works Department recognizes that the reported concentrations are high, and intends to continue its rigorous assessment of the sanitary sewer system in the Southern Hills Lakes recharge area (delineated in Figure 5) to assess sanitary sewer leakage/surcharging. The City will also assist the SHNA with testing to determine whether certain residences are not connected to the sanitary sewer system.

6.1 Lake Sediment Quantity and Quality

Samples of the sediment in the bottoms of the lakes were collected, and the results of the nutrient analyses of these samples are shown in Table 7. Results of metals analyses are included in Appendix E. As shown in Table 7, the sediment in the lakes contains high levels of nutrients, which could be available to support weed and algae growth in the lakes. The importance of sediment in sustaining algae growth depends on several factors that were not specifically determined in this study. However, it is likely that sediment in the lakes provides a large source of nutrients given the shallow nature of the lakes. Resuspension of sediment from wave action, scour during larger floods, and waterfowl usage would increase the availability of nutrients from sediment in the water column.

The total amount of sediment accumulation in the lakes (over 45 years) is estimated at around 33,000 cubic yards (Table 3). This represents an average of about 1.5 tons/acre/year from the 654-acre watershed. Compared to published rates for sediment yields in the literature, which vary from less than 1 ton/acre/year for native forests and grasslands to 20 to 100 tons/acre/year for agricultural areas, and over 200 tons/acre/year for areas under construction (see, for example, sediment yield rates summarized in Leopold's 1978 reference, *Water in Environmental Planning*), 1.5 tons/acre/year is relatively small. However, this estimate does not account for the sediment load that has moved into and out of the three lakes.

Mr. Mike Giles, P.E., with the City of Springfield, Department of Public Works, reviewed the sediment quality data with Public Works Solid Waste Division staff that are knowledgeable in sediment disposal restrictions. From these discussions, it appears that if sediments were to be removed from the Southern Hills Lakes, there would be no special restrictions associated with their reuse/disposal from a quality standpoint.

6.2 Stormwater Inflow Quality

Samples of stormwater runoff were taken four times at several locations upgradient of the lakes. The results of these samples are shown in Table 8 and compared to regional and national data in Table 9. It is important to recognize that although substantial water quality data were collected for this evaluation by the City and Mr. Smith of the SHNA, only four wet weather events were monitored and samples collected during events were "grab" rather than "continuous." Thus, the collection of additional stormwater data could modify these observations.

The results in Tables 8 and 9 show that levels of total suspended solids (TSS) were relatively low, compared to regional and national data. For comparison, the average concentration from residential areas in Kansas City from the "National Urban Runoff Program" (NURP) was about 220 mg/L, and 80 mg/L for commercial areas, compared to an average of 60 mg/L in this study (Table 9). (The NURP study was conducted in the late 1970s and early 1980s by the USEPA in 26 American cities, and it provides the best comprehensive urban runoff data set available.) The national median suspended sediment concentration in the NURP study was 101 mg/L for residential areas.

Total phosphorus concentrations in the stormwater runoff tributary to the Southern Hills Lakes are higher than total phosphorus concentrations in runoff from the six drainage areas monitored by the City, but lower than data from Kansas City, and the national median value from the NURP study.

Total nitrogen (nitrate plus Kjedahl nitrogen) levels in the runoff tributary to the Southern Hills Lakes are significantly lower than from the six basins monitored by the City, and the values from Kansas City and the national median value.

6.3 Weed and Algae Surveys

Inventories of the predominant types of weeds and algae in the lakes were conducted on November 16-17, 1999 by Dr. Russell Rhodes and from July 21-August 6, 2000 by Dr. Larry Stauffer. This latter survey also included an inventory of the vegetation types along the lake shorelines. The results of these surveys are included in Appendix B and summarized in Table 10. Chorophyll a, which is a plant pigment in phytoplankton (free-floating unicellular algae), was measured in lake water samples to assess levels of this type of algae.

The inventories indicate that the dominant form of weed/algae in the lake is filamentous algae, particularly the families Spirogyra, Oedogonium, Zygnema, and Hydrodictyon. The algae identified are all classified as "green" algae, with the exception of gold/brown diatoms. Although blue green algae (which are highly undesirable) were not identified in either of the inventories, conditions appear favorable for their development and this needs to be accounted for when evaluating management strategies, and with future monitoring.

Filamentous algae often proliferate in warm, shallow lakes where the algae grow on the bottom of the lake and form mats that float to the surface. The "horsehair"-like algae in the lake includes pithophora, which is difficult to manage, being less susceptible to algaecides than other filamentous algae.

Vascular plants that occur in the lakes include water primrose, duckweed, and broad leaf pondweed. The inventories, WWE's field surveys and reports by residents indicate that vascular plants have not been a problem. It is important to recognize that if management techniques for algae are effective, vascular plant densities could increase due to improved water clarity and increased substrate available for weed growth.

The chlorophyll a data (Table 4) and observations on the lakes indicate that levels of phytoplankton are relatively low. This may be due to the short hydraulic retention times of the lakes, which tend to flush phytoplankton from the water column of the lakes.

7.0 ESTIMATED LAKE WATER BALANCE AND NUTRIENT LOADING

7.1 Water Balance

A coarse water balance was developed for the lakes, which accounts for various inflows and outflows. The purpose of the water balance is to quantify the relative importance of the various inflows. The general water balance for the lakes can be described as follows:

P + RO + S = E +/- GW +/- ST, where:

P = direct precipitation on the lake surface

RO = stormwater runoff into the lake

S = spring flow

E = evaporation from the lake

GW = groundwater inflow and outflow (aside from flow from the known springs)

ST = change in lake storage volume

An unknown in the above equation is GW. Observations of the lakes during extended periods of no precipitation indicate that the water levels of the lakes remain relatively constant or decrease slightly, in the case of the Middle and Upper Lakes. Therefore, GW was assumed to be negligible (equal to zero). This assumption may not be correct during prolonged wet periods, when shallow groundwater levels would rise.

The change in lake storage should be relatively constant from year-to-year so that this term was dropped from the equation. This results in the following simplified water balance equation:

P + RO + S = E

The terms in this equation were estimated using climatic data from the Springfield Regional Airport weather station, information on watershed conditions provided by the City, and measurements taken during the study. Average year conditions were used. The estimated water balances for the lakes are shown in Table 11.

Table 11 shows that on an annual basis, most of the water (76 percent) in the Upper Lake is from stormwater runoff, while most of the water in the Middle and Upper Lakes is "pass through" from the upstream lake (62 and 73 percent, respectively). It is estimated that the known springs in the lakes contribute between 21 to 28 percent of the water in the lakes, on the average. A significant volume of water is supplied to the lakes so that the hydraulic retention times (average number of days it takes to replace the volume of the lake) are between 8 to 11 days (Table 11).

7.2 Estimated Nutrient Loading

The load (pounds per year) of nutrients contributed to the lakes was coarsely estimated from the water quality data collected for the study and estimated inflows (Table 11). Average nutrient concentrations were used for stormwater inflows and the springs (Tables 4 and 9). The average concentration of a parameter in the upstream lake was used to estimate the load to the next downstream lake.

Estimates of nutrient loadings to the lakes are included in Table 12. The percent breakdown by source is shown in Table 13.

Nutrient loading from waterfowl wastes and sediment deposits were not included in Table 12 because WWE was not able to quantify these with sufficient accuracy based on the available data. Uncertainty regarding sediment bottom chemistry (such as the potential for anoxic conditions to develop on the lake bottoms during prolonged dry conditions) and sediment resuspension make it infeasible to quantify sediment loading of nutrients.

Studies have found that waterfowl can contribute significant amounts of nutrients to lakes. For example, waterfowl (primarily geese) were estimated to account for 14 and 63 percent of the average annual load of nitrogen and phosphorus, respectively, to a lake in the Denver area (DRCOG 1982). The literature contains other case studies of lakes adversely affected by waterfowl. In the case of the Southern Hills Lakes, if we assume an average annual population of geese, swans and other waterfowl of 200 birds, and that 1/3 to 2/3 of the phosphorus in their excrement enters the lakes, based on phosphorus loading rates in the published literature, the phosphorus load could range from 10 to 50 pounds/year. Although significant, the waterfowl contribution is much smaller than the total phosphorus load from surface water and groundwater, as shown in Table 12.

Tables 12 and 13 show that, of the sources quantified, most of the phosphorus contributed to the Upper Lake is from runoff. This would be expected since runoff provides most of the water to the lake. However, the spring in the Upper Lake contributes a disproportionately large amount of nitrogen and is the largest source of this nutrient.

The contributions of nutrients to the Middle and Lower Lakes are more evenly split between the springs and the upstream lake. The springs in these lakes contribute a disproportionately high amount of nitrogen.

The key observation that emerges from the nutrient analysis is that the estimated nutrient loading to the lakes is very high, without including contributions from waterfowl or sediment. Even if it were feasible to significantly reduce total phosphorus and nitrogen loads in surface water and groundwater inflows (such as cutting these loads in half), the loads would still be much larger than necessary to cause the filamentous algae problem at the lakes. This indicates that management strategies should be based on the assumption that nutrient loads in groundwater and surface water inflows will remain high. This, in turn, leads to the observation that improving conditions in the lakes will be more a function of in-lake management techniques than of pollutant source control.

8.0 PROBLEM IDENTIFICATION AND ASSESSMENT

Problem identification is important for establishing lake management goals and to develop effective control actions. A “problem” develops when conditions in a lake or on its shoreline interfere with uses of the lake. Problems in lakes are usually caused by changes in water quality, sedimentation that reduces the depth of the lake, or by excessive growth of weeds and algae.

Problems with the shoreline of a lake may include growth of undesirable vegetation and shoreline erosion. These factors often act synergistically to compound effects on lake uses. For example, degradation of the quality of inflows to a lake will typically reduce in-lake water quality, result in sediment build-up, and favor growth of weeds and algae.

Based on the data collected, interviews, photographs, documents reviewed, and field observations of the lakes, the dominant problem in the study lakes is excessive filamentous algae growth, which appears to be getting worse with time. The following characterizes the extent and nature of the problem:

- Historically, excessive filamentous algae growth was primarily associated with the Upper Lake; however, during the summer of 2000, filamentous algae levels in the Middle Lake reached an all-time high, according to homeowner accounts.

- Both the Upper Lake and the Middle Lake exhibit extensive surface coverage of filamentous algae. For example, at times, essentially the entire surface of the Upper Lake has been covered.

- Residents indicate that the Lower Lake had more algae in 2000 than in any previous year.

- Once the algae are flushed out of the lake during heavy rainfall-runoff events, re-growth reportedly occurs quickly. For example, video from Mr. Bob Smith of SHNA during July and August 2000 showed that within 5 days following complete flushing of the lakes, there was excessive growth of filamentous algae in the lakes.

- One species of filamentous algae, pithophora, is present and is more difficult to control.

9.0 RECOMMENDED LAKE MANAGEMENT GOAL

A goal needs to be set to guide development and implementation of the recommended lake management plan. The goal should consider the current condition of the lakes, the factors responsible for the condition of the lakes, and the feasibility of restoring the lakes. The goal needs to recognize that it will not be feasible to control certain factors affecting the lakes (such as the urbanized nature of the watershed), and that there will be practical limits to the degree that the lakes can be fully restored, given the natural aging process (eutrophication) of lakes. The goal must acknowledge that elimination of one problem in a lake can result in another problem. For example, reduction of high levels of phytoplankton can result in increased growth of aquatic weeds due to greater penetration of light.

Given the overall situation with the lakes, WWE has determined that it is not practical or technically feasible to restore the lakes to their original condition, or to a state of moderate enrichment referred to as "mesotrophy." A more realistic overall goal that is consistent with the findings of this study and which would address the current problems with the lakes is as follows:

> **Recommended Overall Goal:** To manage the growth of weeds and algae in the lakes to maintain/restore the historic uses of the lakes (including as aesthetic amenities) to a reasonable degree.

Inherent in this goal is the notion that *it will not be feasible to eliminate weeds and algae in the lakes*. The stated goal assumes that there will be acceptance of some weed and algae growth by homeowners, and that a satisfactory outcome will be a *significant reduction* in the current problem.

10.0 LAKE MANAGEMENT OPTIONS AND RECOMMENDATIONS

10.1 Initial List of Control Measures Evaluated

Various measures can be used to manage the growth of weeds and algae in lakes. These measures vary greatly in terms of their effectiveness, cost, and applicability, and include both short-term measures to remedy an immediate problem and long-term measures to reduce the magnitude of the problem or prevent the problem from reoccurring. Of key importance is the specific type of weed or algae that a measure may control.

Table 14 is a matrix of potential weed and algae control measures for lakes that shows the specific type of weed/algae controlled. Certain control measures are listed several times in Table

14 since they fall under more than one overall control strategy. Some of the potential controls listed in Table 14 do not address filamentous algae, which is the main problem in the lakes, or provide other potential benefits. Other potential control measures are relatively unproven (e.g., bacterial inoculation).

Potential advantages and disadvantages exist for certain management options, for example:

- A primary advantage of removing sediments (dredging) is to increase lake depth and to remove the nutrients that are bound up in the sediments. However, dredging would increase the hydraulic retention time, which could encourage algae growth.

- It might be feasible to capture spring discharges, which are high in nitrogen, and bypass these around the lakes, but this would deprive the lakes of water during dry conditions.

- Removal of filamentous algae could expose the lake bottom and encourage growth of macrophytes.

WWE assessed the potential application of the measures listed in Table 14 to the Southern Hills Lakes. These measures were described and reviewed with the City and the SHNA in late October 2000 when Jonathan Jones of WWE was in Springfield to present initial observations and findings.

WWE briefly assessed the feasibility of options at both ends of the spectrum of alternatives: (1) do nothing and (2) major improvement (excavate to well below the original depth in all three lakes, install liners, and make various upgrades to the dams including outlet pipes, larger spillways, higher freeboard, forebays and other improvements). Both of these options are not feasible and do not merit further evaluation. The do nothing option would allow the current, unacceptable situation to remain (and likely get worse) while the major improvement option would be prohibitively expensive.

10.2 Recommended Control Measures

The recommended control measures that currently appear applicable, or which *may be applicable depending on the results of further feasibility analysis* are presented below. It is likely that no single measure listed in Table 14 will mitigate the observed filamentous algae problem; instead, a combination of measures will be needed.

The control measures are listed below as "short-term" and "long-term." Short-term refers to measures that provide immediate control. These measures are typically easy to implement, but provide limited long-term benefits. On the other hand, control measures that provide long-term benefits address the underlying causes of the problem and are effective for years without repeated application (although some require occasional maintenance).

The recommended measures were selected on the basis of these criteria:

- Ability to mitigate the specific observed problems
- Proven ability to address problem (untested measures are not recommended)
- Cost
- Anticipated acceptance within community
- General "implementability"

Table 15 provides more detail—including conceptual costs—for selected measures, while Table 16 is a recommended three-year plan of controls for the years 2001 through 2003. Table 16 can be modified by the City, lake owner, and/or the SHNA.

Recommended Short-Term Control Measures

1. Algaecides
2. Stocking of grass carp

Recommended Long-Term Control Measures That Can be Implemented Immediately

1. Continued monitoring of sanitary sewer system by City, with repairs and upgrades as necessary

2. Waterfowl deterrents, including littoral zone establishment

3. Stormwater quality control practices including structural BMPs, public education and stream channel stabilization

Potential Long-Term Control Measures (Recommended for Further Evaluation)

(Note: These measures require further engineering analysis to determine if they are feasible. If the measures are shown to be feasible, it would be beneficial to implement them.)

1. Sediment removal

2. Outlet structure installation

3. Raise normal water surface elevations of lakes

4. Construction of a forebay

5. Conversion of some of the Upper Lake into a wetland

All of these measures are discussed below.

10.3 Short-Term Controls

1. Algaecides

Algaecides (e.g., copper sulfate, Cutrine-plus) can control algae when properly applied. Table 15 provides details on various algaecides. Previous copper sulfate applications at the lakes were likely not successful because proper application protocols were not followed and/or the copper chemically complexed with the hardness/alkalinity in the water, rendering it non-toxic to algae.

Special measures need to be taken for effective control of filamentous algae using algaecides. These include the need to break up floating mats while applying the algaecide and treating the lake in phases, if the algae covers more than one-half of the lake surface, to prevent oxygen depletion from the dead algae. This is important if grass carp are stocked. In addition, the effectiveness of copper-based algaecides is greatly reduced in hard or dirty water. Cutrine or Cutrine-plus, both of which have the copper in a chelated form, are more effective in hard or dirty water. Cutrine-plus is recommended for the Southern Hills Lakes.

Periodic re-treatment (roughly once per month in the summer) is also typically required with algaecides, and can increase the cost of this option. There can be environmental concerns with continued application of algaecides to a lake, although if Cutrine-plus is utilized, this is not likely to be a problem in the Southern Hills Lakes, nor in Galloway Creek (the receiving stream for discharges from the Lower Lake). Also, applications should be timed to coincide with periods of no rain, to the extent possible. Flushing of algaecides from the lakes will reduce their effectiveness. Ideally, algaecides need to be in a lake for 3 to 5 days for maximum effectiveness. Aside from potential wash-out, a primary drawback with algaecides is that they do not address the underlying causes of the problem.

2. <u>Stocking of Grass Carp</u>

Grass carp (white amur) can be very effective in controlling excessive growth of algae and weeds in lakes. WWE has used these fish in ponds and lakes to control filamentous algae, and found them highly effective. Studies have shown that adult grass carp can consume two to three times their body weight in weeds a day. Grass carp prefer aquatic weeds, but will eat filamentous algae in the absence of weeds. Sterile carp need to be stocked to prevent overpopulation.

Although grass carp could be introduced immediately, they are also a long-term management tool that does not have the adverse environmental effects of certain herbicides. They are relatively inexpensive (about $10 per adult fish, with a stocking density of 15 to 25 fish per acre of lake surface area). Restocking is typically required every five to seven years. Disadvantages to the use of grass carp include the fish "stirring up" sediment (and nutrients) in shallow water, and the potential for fish to be washed out of the lakes during large storms. However, fish will tend to resist being washed out of a lake during high flow, and screens can be used to reduce the number of fish washed out. WWE believes that the previous attempts to introduce grass carp to the Southern Hills Lakes were probably not successful because not enough fish were introduced.

10.4 Recommended Long-Term Control Measures that can be Implemented Immediately

1. **Continued Monitoring of Sanitary Sewers System by City, With Repairs and Upgrades as Necessary**

This subject has been discussed earlier in this report. The City is committed to continued monitoring of the sanitary sewer system in the lake recharge area, with repairs/upgrades as necessary. The City's track record in this area is strong, including fast response to observed problems. The City is also willing to assist the SHNA with testing the homes that surround the lakes to assure that they are connected to the sanitary sewer system.

2. **Waterfowl Deterrents, Including Littoral Zone Establishment**

For improving lake water quality (nutrient, bacteria and turbidity), it will be valuable to reduce the numbers and durations of stay of waterfowl at the lakes.

It may be feasible to reduce the number of waterfowl by modifying the shorelines of the lakes or by using deterrent devices. One way to modify the shoreline is to plant vegetation in the "littoral zone" and along the lake edge (Figure 6). A relatively large littoral zone (wetland) around the perimeters of the lakes would be desirable from a water quality standpoint, although homeowner reaction may be mixed, because the lake edges would change from the current "clean" appearance to a wetland with plants such as bulrush, sedges and cattails. A wide littoral zone would reduce the sight distance and desirability of the lakes to Canada geese. Sound-making devices and visual devices (e.g., plastic alligators) have also been effective at deterring waterfowl. In the upland areas adjoining the lakes, it would be helpful to plant shrubs and trees, place boulders, construct short reaches of split rail fence, plant flower gardens, etc., to impair the sight distance for the birds and to create a “closed-in” feeling. Waterfowl are not comfortable when sight distance is limited. The City and/or homeowners could contact state wildlife personnel to discuss other waterfowl deterrents.

Disadvantages to the use of waterfowl deterrents include that homeowners may desire to have waterfowl using the lakes, and that the effectiveness of deterrents can decrease with time as waterfowl acclimate to them.

3. Stormwater Quality Control Practices Including Structural BMPs, Public Education and Stream Channel Stabilization

Because most of development in the watershed dates back to the 1960s and 1970s, stormwater quality “best management practices” (BMPs) (e.g., detention ponds, wetlands and infiltration basins) are not found in the watershed. Use of BMPs was not a standard practice at that time.

It is not currently feasible to integrate large, structural stormwater quality BMPs into the watershed on a widespread basis since the watershed is nearly built out. Few undeveloped lots are available and they are privately owned. The costs of retrofitting would be very high. The total runoff volume is much larger than the BMP treatment capability that is likely available, given the amount of urbanization of the watershed. Finally, even if it were feasible to widely implement structural BMPs, the amount of phosphorus in the runoff following treatment via BMPs would still likely be enough to keep the lakes in a eutrophic condition. Also, the springs are rich in nitrogen and they would not be controlled by BMPs throughout the watershed.

However, to the extent that it is feasible to implement stormwater BMPs in future construction/retrofitting projects, this would be desirable. Stormwater quality controls are considered both short-term and long-term measures. Some controls are now being implemented, such as public education to reduce fertilizer use, and stream channel stabilization near LaMonta and Edgewater streets.

The City should evaluate the feasibility of converting the dry detention basins immediately downstream from the Sunshine/Highway 65 Interchange into water quality treatment facilities. As properties are redeveloped, it would be desirable to integrate stormwater quality BMPs into their site plans. As roadway improvements occur, it may be feasible to integrate water quality features in some areas, such as grass-lined swales.

Nonstructural BMPs, such as public education related to reduced fertilizer and pesticide use, are strongly encouraged. This program is off to a good start with strong public interest in Southern Hills in fertilizer reduction, limiting car washing, cleaning up after pets and other such activities.

Although construction in the watershed will be modest in scope in the future (and focused on redevelopment and infill), rigorous erosion and sediment controls should be implemented and strictly enforced.

Channel stabilization measures would complement structural and non-structural BMPs. During large storms, erosion from channels contributes sediment and associated pollutants to the lakes, especially the Upper Lake.

WWE recommends that the City stabilize actively degrading channels in the watershed over time, as is currently planned in the vicinity of LaMonta and in the Edgewater channel. Aside from improving the quality of inflows to the lakes, channel stabilization could protect existing structures and reduce maintenance costs. When feasible, as channels are stabilized, WWE encourages the use of drop structures and flat channel slopes to promote wetland vegetation growth and in-channel ponding, which will enhance pollutant removal. Many of the culverts in the watershed would benefit from energy dissipaters.

10.5 Potential Long-Term Control Measures (Recommended for Further Evaluation)

1. Sediment Removal

Sediment removal would address several of the underlying causes of the observed problems. In particular, this could reduce the amount of shallow area available for filamentous algae and weed growth, and remove nutrient-laden sediments from the lakes. Partial sediment removal is particularly applicable to the lakes due to: (1) the progression of sediment depths from the Upper to Lower Lake (this argues for focusing on the Upper Lake first), (2) cost, and (3) potential for infiltration of stored water through the lake bottoms if over-excavation occurs.

For sediment removal to be effective at reducing filamentous algae growth, the bottom should be deepened to greater than the limit of light penetration (6-7 feet), over as large an area as practical.

A significant concern with sediment removal is that it could potentially "puncture" the bottom of a lake and increase seepage, or otherwise affect the hydrogeology of a lake. Mr. Bob Smith of the SHNA has stated that, based on his observations during the limited sediment removal from the Upper Lake conducted several years ago, there is a clear line of demarcation between the deposited sediment and underlying, original lake bottom. Prior to proceeding with any sediment removal method, WWE recommends that field-testing be conducted to define the depth of bedrock in the lakes.

Sediment removal is often easier and less costly if it is conducted "in the dry" (i.e., the lake is drained and sediments dry out so that conventional earthwork equipment can be used). Provision must be made to either bypass inflows around the lake, or runoff will need to be siphoned or pumped out of the lake following runoff. Mr. Bob Smith has reported that based on a previous attempt by the SHNA to remove sediment from the Upper Lake, due to spring flows and occasional runoff, it was difficult to keep the lake sediments dry enough to permit excavation. Installation of a permanent outlet works in the lakes would help to address this issue and facilitate sediment excavation with conventional earthmoving equipment.

Hydraulic or barge-mounted dredging is considerably more expensive and would require large amounts of land near the lakes for sediment dewatering.

Drawbacks to sediment removal include relatively high cost and potentially large disturbance. Off-site disposal of removed sediment would be required. Selective (rather than complete) sediment removal will be necessary to keep costs manageable. If it is not feasible to significantly deepen the lakes, dredging may not significantly reduce algae growth. For example, Sequiota Lake was dredged at considerable cost in 1997 to relieve a major algae problem, but within two years, algae were back at pre-dredge levels. A Section 404 permit from the U.S. Army Corps of Engineers may need to be obtained for a dredging operation.

Dredging should be considered along with other long-term controls. It may be practical to construct several long-term controls coincidently and more cost effectively. For example, the Upper Lake could be dredged to create a deep-water area, and at the same time, a forebay and/or wetland could be constructed.

2. <u>Outlet Structure Installation</u>

Construction of bottom outlets in one or more of the lakes is an option for dewatering the lakes that would also facilitate long-term lake water quality management. A possible outlet structure for each lake would include a concrete tower with a weir inside consisting of removable "flashboards." The tower would be located just upstream from the dam, and it would have an inlet pipe extending a short distance into the lake with a screened entrance, and an outlet pipe running through the embankment and discharging into the downstream channel with a suitable energy dissipater. Controls (gates) would be on the upstream side of the system to avoid pressure within the conduit, which should be ductile iron pipe. A small diameter pipe (roughly 6 to 8 inches) would be acceptable, to keep boring and jacking costs manageable. The tower with flashboards would permit withdrawals to various lake levels.

Discussions with City staff indicate that building a pipeline (siphon) over the top of the dam may be more practical than boring in outlet pipes through the embankments, although this cost comparison should be made during later studies. Boring through an existing dam poses safety concerns, due to the potential for soil within the dam to migrate along the wall of the pipe (a phenomenon known as "piping") in response to seepage. This would need to be carefully evaluated.

Further analysis is needed to evaluate the benefits and costs of outlet construction in conjunction with other long-term controls. There is not evidence of oxygen depletion near the lake bottoms. However, if oxygen depletion occurs under drought conditions and the bottom waters were to be drawn-out (via the outlets), the springs may not produce enough flow to raise lake levels back to normal, which would be negative in many respects.

3. Raise Lake Normal Water Surface Elevation

A means to reduce filamentous algae growth is to increase lake depths. This can be accomplished by removing the accumulated sediment. Another approach is to raise the normal water surface elevation in each lake. This could be accomplished by modifying the concrete overflow spillway structures, probably via the installation of elevated concrete "sills." The new sill elevations would range from perhaps 0.5 to 1.0 feet.

WWE's field visits, coupled with physical data on the lakes collected by the City and a videotape prepared by Bob Smith of SHNA in late October 2000, indicate that there are significant feasibility issues that must be evaluated for this alternative including:

- The structural integrity of the existing dams could be compromised by a water surface increase. Mitigation measures would be expensive.

- The existing spillways would probably need to be widened to offset the loss in hydraulic conveyance capacity due to increasing the current overflow elevations. This would be expensive.

- The risk of dam overtopping would increase without an increase in spillway capacity. The current spillway capacity and freeboard (distance from the water surface top to the dam crest) are low in reference to common dam safety standards. A water surface increase would compound these concerns.

- Lake water surface increases would increase the width of the 100-year floodplain through the Southern Hills neighborhood. Flood risks to homeowners near the lakes would be increased, although to an unknown extent. Regulatory requirements related to the National Flood Insurance Program would be triggered, as would City requirements related to 100-year floodplain easements.

- Gaining the approval of all of the relevant property owners could be problematic.

- How would the lake surface areas/boundaries change relative to current conditions, and what would the implications be for existing property owners? This is primarily a function of the slope of the upland areas towards the ponds—the steeper the drop-off, the less the amount of property inundation. A potential approach to addressing this concern would be to place backfill at the lake edge in relevant reaches. The backfill would prevent the lake from "pushing out" onto private property.

- What adverse consequences are likely to occur as a result of water surface elevation increases? For example, are there trees near the lake edges that would die? Could locally increased groundwater levels cause any adverse effects?

- Are there any special regulatory constraints that apply? For example, would a Section 404 permit be necessary? Would dam safety regulations be triggered?

To summarize, although it would be desirable to increase the normal water surface elevations of the lakes, significant feasibility questions arise with the concept.

4. <u>Construction of Forebay Upstream From Upper Lake</u>

A potentially beneficial long-term option is to construct a sediment forebay at the inlet to the Upper Lake to capture and treat stormwater runoff. One of the reasons that the Middle and Lower Lakes are in better condition than the Upper Lake is that the Upper Lake acts as a forebay, thus improving water quality to the downstream lakes.

A sketch of a typical forebay is provided in Figure 7. A forebay would detain inflows to allow for settling of heavier sediment particles and associated pollutants. The longer the detention time, the better the pollutant removal. However, space constraints could limit the size of a forebay. WWE recommends that a minimum detention time of 5 to 10 minutes be used for the 80^{th} percentile annual event (80 percent of all storms that occur each year are smaller than this amount). The 80 percent annual event is based on recommendations of ASCE and WEF in their 1988 reference, *Manual of Practice on Storm Drainage Quality*.

The forebay should be designed to allow for routine sediment removal via a backhoe/front-end loader. A firm bottom is recommended. Vegetation could be placed strategically around the forebay to limit its visibility.

Forebay construction could occur with dredging or wetland creation at the Upper Lake. Conducting these activities in tandem offers advantages and could provide a use of dredged materials.

Potential constraints that need to be evaluated include:

- Depth to bedrock
- Hydraulic effect on upstream channel, especially during flood flows
- Ability to provide elevated water surface relative to the Upper Lake

- Infringement on private-property
- Need for long-term maintenance easement
- Long-term operation and maintenance activities and costs
- Routine sediment removal will be required
- Buried utilities
- Available space given necessary storage volume
- Ability to drain forebay to facilitate sediment removal

5. **Conversion of Some of the Upper Lake Into a Wetland**

It may be feasible to convert some of the Upper Lake into a wetland to improve the appearance of the lake, and water quality in the Middle and Lower Lakes. Wetlands have been shown to be very effective for enhancing stormwater quality. The effectiveness of a wetland would be improved by a forebay immediately upgradient. Wetland construction could involve a combination of filling and lowering of the lake water surface to create a marsh wetland. An area of open water near the dam would remain.

Conversion of some of the Upper Lake into a wetland can happen only with the approval of the homeowners around the lake. Mr. Bob Smith of the Advisory Committee has indicated that the relevant homeowners may react negatively. This is understandable; however, based on WWE's wetland construction experience, it should be feasible to create a wetland that would be visually appealing to neighbors.

It would be relatively expensive to convert some of the lake into a wetland. The potential for a washout of the wetland and associated soils during large flows into the Lower Lakes is also a concern. It would be desirable to design the wetlands to bypass high, damaging flows, while allowing small storm flows and the Upper Lake spring to "sheet flow" through the wetland, thereby promoting nutrient removal. A forebay could be designed to concentrate trash and debris build-up and increase the effectiveness of the wetland. A wetland could also increase mosquitoes by creation of stagnant water areas. Mosquito fish or chemicals have been used with some success to control mosquitoes.

11.0 IMPLEMENTATION

A final, recommended plan for implementation of control measures is shown in Table 16. This plan was developed with input from the City and SHNA, including comments on the proposed plan in the draft report. Our recommendations are not "cast in stone," but are an initial proposal that can be modified by the City, lake owner and/or the SHNA.

Factors considered in developing the plan include costs, maintenance, and effectiveness of control measures. Before the recommended plan is implemented, the following will need to be addressed by the lake owner, the SHNA, and the City:

- Need for additional data on bedrock depths to assess dredging and forebay feasibility
- Need for continued monitoring
- Near-term and long-term financing
- Any required permitting

11.1 Phasing, Schedule and Monitoring

The key to implementing the lake management plan is to adopt a phased approach. Specifically, measures should be implemented, their effectiveness on lake water quality should be monitored, and any changes in the lake management program made in response to observations.

The effectiveness of measures needs to be regularly assessed and documented. It is recommended that at the end of each growing season, the SHNA, lake owner and City meet to discuss the effectiveness of the controls implemented. If current controls are not meeting the goals of the effort, then additional measures may be needed.

Lake monitoring should include: (1) regularly documenting the presence of weeds and algae in the lakes, (2) some water quality monitoring, (3) hydrologic monitoring of inflows and lake levels, and (4) other observations on the lakes.

Additional monitoring will be necessary for certain control measures. For example, if a forebay is constructed, sediment accumulation depths should be routinely monitored so that the forebay is maintained on an appropriate schedule. If sediment is not removed from the forebay at the necessary time, a large storm will scour out the sediment and transport it into the lakes. Erosion and sediment control practices on construction projects in the watershed should be monitored. If a wetland is established in part of the Upper Lake, or if an attempt is made to establish a zone of emergent vegetation around the lake perimeters (i.e., to create a littoral zone), the health of the plants will need to be assessed.

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13.0 GLOSSARY

Algae	Small aquatic plants that lack roots, stems and leaves and occur as single cells, colonies, or filaments
Anaerobic	Lacking or without oxygen
Aquatic weeds	A general term that refers to plants that have roots, leaves and stems (a vascular plant) and grow in or adjacent to a lake (i.e., not algae). Also referred to as "macrophytes"
Best management	Structural and nonstructural devices and methods used to

practices (BMPs)	improve stormwater and other nonpoint source water quality. Examples of BMPs include grass-lined swales, detention ponds, infiltration pits, and siltation fencing (for erosion control)
Chlorophyll a	A plant pigment found in phytoplankton, the concentration of which is used to determine the tropic status (degree of enrichment or aging) of a lake
Cutrine-Plus	A trade name for a type of algaecide that is produced by Applied Biochemists, Inc. that consists of elemental copper complexed with organic compounds (copper alkanolamine complexes)
Diatoms	A variety of algae that is either unicellular or exists in colonies and has an outer shell with silica
Eutrophic	A lake that is in an enriched and productive state that typically has high levels of nutrients, weeds and algae
Eutrophication	The natural aging process of water bodies
Fecal coliform/fecal streptococci	Two different types of bacteria derived from warm-blooded animals that are often used to indicate the bacteriological quality of water
Filamentous algae	A variety of algae in which the cells grow in long chains causing filaments. The filaments often form floating mats on the surface of a lake.
Forebay	An extra storage area provided near an inlet of a lake or pond to trap incoming sediments before they reach a larger body of water. Forebays often have an access ramp for equipment for periodic sediment removal
Hydraulic retention time	The time (typically expressed as the number of days or years) that it takes for all water in a lake or pond to be completely replaced by inflows
Hydrogeology	The study of the movement of water beneath the soil surface
Hypertrophic	A lake that is in a very enriched and productive state with large amounts of nutrients, algae and weed growth
Individual sewage disposal systems	Tanks and/or leachfield systems, often referred to as "septic tanks," that are used to treat wastewater from a single-family

(ISDS)	residences or small buildings.
Infiltration	The process of water entering the soil or bottom of a lake. Water that infiltrates is no longer available as surface flow
Karst geology	Geology in a limestone setting
Littoral zone	The portion of a lake extending from the shoreline towards the middle of a lake to the limit of rooted plant growth.
Macrophytic algae	A variety of algae that has leaf-like structure in a whirled pattern about a stem. May be mistaken for a macrophyte (i.e., vascular plant).
Macrophytes	Used synonymously with “aquatic weeds” in this report to refer to aquatic plants that have roots, stems, and leaves (e.g., water lilies, pond weed).
Marsh wetlands	A very common type of wetland that typically has shallow flooding or saturated soils throughout most of the growing season and is dominated by plants such as bulrushes, cattails, and other rooted, emergent plants
Mesotrophy	An intermediate state of a lake in terms of age or extent of enrichment that lies between oligotrophy and eutrophy
NPDES permit (National Pollutant Discharge Elimination System)	A permit issued by a state or by the U.S. Environmental Protection Agency under the Clean Water Act for a discharge to a lake or stream.
Phytoplankton	Microscopic algae that float freely in the open water of a lake
Recharge area	The portion of the land surface where water entering the ground contributes to the groundwater at a certain point
Sediment	Material that may be mineral or organic that has been deposited on the bottom of a lake
Stratification	Used to refer to development of a “layering” of water in a lake due to different water temperatures from the top to the bottom of the lake
Trophic status	The condition of a lake in terms of the amount of nutrients, weeds and algae in the lake (also see eutrophication)

Watershed	The area that drains to or contributes surface flow to a lake or stream