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PROJECT NO. 812
ON-CALL ENGINEERING SERVICES

TASK 6
FINAL
LIBERTY RESERVOIR WATERSHED ASSESSMENT

April 2003

GANNETT FLEMING, INC.

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ACRONYM LIST

Acronym	Description
#/ml	Number per milliliter
AST	Above Ground Storage Tanks
BMP	Best Management Practices
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	Cubic Feet per Second
DBP	Disinfection By-Products
DBPR	Disinfection By-Products Rule
DBPP	Disinfection By-Products Precursor
DOC	Dissolved Organic Carbon
DPW	Department of Public Works
EPA	U.S. Environmental Protection Agency
F	Degrees Fahrenheit
fps	Feet per Second
GIS	Geographical Information Systems
GPS	Global Positioning Systems
HAA	Haloacetic Acids
ICR	U.S. EPA Information Collection Rule
IDEE	Initial Distribution System Evaluation
kg/km^2	Kilograms per Square Kilometer
LRRA	Locational Annual Average
LUST	Leaking Underground Storage Tank
MCL	Maximum Contaminant Level
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
mgd	Million Gallons per Day
mg/L	Milligrams per Liter
MGS	Maryland Geological Survey
mi^2	Square Miles
MPN	Most Probable Number
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Units
RAA	Running Annual Average
SOC	Synthetic Organic Compounds
STORET	U.S. EPA Storage and Retrieval
SVOC	Semi Volatile Organic Compounds
SWA	Source Water Assessment
TDS	Total Dissolved Solids
THM	Trihalomethanes
TMDL	Total Maximum Daily Limit
TOC	Total Organic Carbon
TOT	Time of Travel
TSI	Trophic State Index
TTHM	Total Trihalomethanes
µg/L	Micrograms per Liter
µmhos/cm	Micromhos per Centimeter
USACE	U.S. Army Corp of Engineers
USGS	U.S. Geological Survey
VOC	Volatile Organic Compounds

ACKNOWLEDGEMENTS

The Liberty Reservoir Source Water Assessment (SWA) was conducted by the City of Baltimore Department of Public Works Bureau of Water and Wastewater under a memorandum of understanding with the Maryland Department of Environment (MDE) Water Supply Program. Primary funding was provided by MDE through the U.S. Environmental Protection Agency's State Revolving Fund. The City of Baltimore supplemented this funding by providing field equipment, field staff, and administrative staff in support of the SWA. Carroll County and Baltimore County agencies provided information pertaining to their respective portions of the watershed, thereby enhancing the SWA. The MDE Water Supply Program administers Maryland's Source Water Assessment Program.

EXECUTIVE SUMMARY

The 1996 Safe Drinking Water Act Amendments require states to develop and implement source water assessment programs to evaluate the safety of all public drinking water systems. A Source Water Assessment (SWA) is a process for evaluating the vulnerability to contamination of the *source* of a public drinking water supply. This SWA was completed for Liberty Reservoir, one of three reservoirs that serve the Baltimore Metropolitan area.

Liberty Reservoir is located on the North Branch Patapsco River on the boundary between Baltimore and Carroll Counties, Maryland. The reservoir collects water from a 163.8 square mile (mi^2) watershed that includes eastern Carroll County and southwestern Baltimore County. The North Branch Patapsco River was selected as the site for Liberty Reservoir to meet increased demands for water in the early 1950's. Liberty Dam was completed in 1954. Water from Liberty Reservoir is transmitted through a tunnel to Ashburton Water Filtration Plant in Baltimore, Maryland for treatment. Liberty Reservoir's storage capacity of approximately 36.8 billion gallons represents about 50 percent of the storage capacity of the City of Baltimore reservoir system. Water withdrawals from Liberty Reservoir vary depending on the demand for water. For the period 1992 to 2002, the Ashburton Water Filtration Plant treated an average of 109 million gallons per day (MGD), which represented 40 percent of the 273 MGD average water usage for the City of Baltimore system. From 2000 to 2002, the average water usage from the Ashburton Plant was 83 MGD.

Liberty Dam and the water supply intake structure have been inspected by various regulatory agencies. Liberty Dam has received inspections from the U.S. Army Corps of Engineers (USACE) and the Maryland Department of the Environment (MDE), Dam Safety Division. The USACE inspection found that Liberty Dam was in good structural condition. The inspections performed by MDE found some minor deficiencies. The intake structure is in good condition, however, the intake screens are in poor condition and are in need of replacement.

The Liberty Reservoir watershed and its seven subwatersheds were delineated using mapping and digital data provided by MDE. Most of the watershed is rural. Portions of Westminster, Hampstead, Eldersburg, and Finksburg are the primary commercial/industrial and medium- to high-density residential areas. Only a small portion of Reisterstown is located within the watershed. A comparison of the 1990 and 1997 land uses for the Liberty Reservoir watershed identified two trends: Commercial and industrial land uses have increased surrounding Westminster, Hampstead, and Eldersburg, and conversion of agricultural land to residential land is ongoing in some subwatersheds.

During the SWA, time of travel (TOT) studies were performed to determine contaminant mobility in the watershed. TOT studies were performed under low flow conditions for several tributaries of the reservoir. A higher flow TOT study was performed on Morgan Run. In addition, a TOT study was performed in the reservoir itself.

Potential sources of contamination for the Liberty Reservoir include point and non-point sources, including industrial sites, transportation (e.g. highways), a railroad, a petroleum product pipeline, agriculture, and septic tanks in rural portions of the watershed. The majority of point sources are located in the North Branch and Liberty subwatersheds.

The City of Baltimore maintains an extensive water quality monitoring program for Liberty Reservoir and its tributaries, as well as the Ashburton Water Filtration Plant. Routine sampling is performed at Ashburton Water Treatment Plant, six tributaries of Liberty Reservoir, and four in-reservoir locations in an effort to monitor and improve the water quality conditions of the Liberty Reservoir water supply. Additional sources of water quality data reviewed were the MDE TMDL data and MDE historical data from EPA's STORET database system.

The susceptibility analysis (Section 8) identified suspected contaminants and contaminant sources, the natural conditions that may decrease or increase the likelihood of a contaminant reaching the intake, and the impacts that future changes within the watershed may have on the susceptibility of the water intake. An increasing trend for total dissolved solids, chlorides, and conductivity in the tributaries indicates that human activities, such as development, are having an increasing affect on reservoir water quality. Turbidity is a concern and could significantly increase water treatment costs. Liberty Reservoir is susceptible to protozoa, viruses, and coliforms, as are all surface water sources. However, sampling data indicate that Liberty Reservoir poses a much lower risk from pathenogenic organisms than most source waters drawing directly from rivers or streams. Changing land use and algal growth may increase disinfection byproduct precursors in Liberty Reservoir, thereby making the source water susceptible to disinfection byproducts. A study is underway to determine whether significant sedimentation has occurred in Liberty Reservoir. Nutrients are a primary concern and threat to the reservoir because algal blooms, caused by nutrient inputs, threaten the intakes with low quality raw water. Liberty Reservoir is also susceptible to contaminant spills, both directly into the reservoir and into the tributaries. A spill from the eastern Route 26 bridge is most likely to affect the water intake due to its proximity.

Recommendations of the SWA are explained in detail in Section 9. Recommendations include:

- Strengthening the watershed agreement between Baltimore City, Baltimore County and Carroll County;
- Instituting protective low density zoning in the watershed;
- Implementation of an expanded water quality sampling program and further water quality trend analyses;
- Continue tributary storm event sampling;
- Control of nutrient loading;
- Disinfection byproduct precursor source evaluation;
- Phosphorus control;
- Improvements in raw water turbidity;
- Additional dissolved solids monitoring in problem watersheds;
- Install engineering controls for spills at the eastern Route 26 bridge;
- A review of traffic accident statistics involving hazardous materials;
- Gathering more specific information on potential contaminant sources; and
- A review of sedimentation.

1.0 BACKGROUND

The 1996 Safe Drinking Water Act Amendments require states to develop and implement source water assessment programs to evaluate the safety of all public drinking water systems. A Source Water Assessment (SWA) is a process for evaluating the vulnerability to contamination of the *source* of a public drinking water supply. The assessment does not address the treatment processes, or the storage and distribution aspects of the water system, which are covered under separate provisions of the Safe Drinking Water Act. The Maryland Department of the Environment (MDE) is the lead state agency in this SWA effort.

There are five main steps in the assessment process:

1. Delineating the watershed drainage area that is likely to contribute to the drinking water supply;

2. Identifying potential contaminants within that area;

3. Assessing the vulnerability of the system to those contaminants;

4. Developing recommendations for the source water protection plan; and

5. Communicating the assessment findings with the local stakeholders.

This document reflects all of the information gathered and analyzed that is required by the five main steps. Baltimore City investigated many factors to determine the vulnerability of Liberty Reservoir to contamination, including the size and type of water system, available water quality data, the characteristics of the potential contaminants, and the capacity of the natural environment to attenuate any risk.

Maryland has more than 3,800 public drinking water systems. Approximately 50 of the public water systems in Maryland obtain their water from surface supplies, either from a reservoir or directly from a river. The remaining systems use groundwater sources. Maryland's Source Water Assessment Plan was submitted to the Environmental Protection Agency (EPA) in February 1999, and received final acceptance by the EPA in November 1999. MDE has until May 2003 to complete SWAs for all of the public drinking water sources in the state. A copy of the Source Water Assessment Plan can be obtained at the MDE website, www.mde.state.us ,or by calling the Water Supply Program at 410–631–3714.

2.0 DEVELOPMENT OF LIBERTY RESERVOIR AS A WATER SUPPLY

Liberty Reservoir was built to serve the City of Baltimore and surrounding areas with water for industrial and residential uses in the years after World War II (Baltimore City DPW, 1981). Presently, the Baltimore City water system serves approximately 1.8 million people in Baltimore City and parts of Baltimore, Howard, and Anne Arundel Counties from three reservoirs and three water treatment plants.

Liberty Reservoir is located on the North Branch Patapsco River on the boundary between Baltimore and Carroll Counties. It collects water from a 163.8 square mile (mi^2) watershed that includes eastern Carroll County and southwestern Baltimore County.

The North Branch Patapsco River was selected as the site for Liberty Reservoir to meet increased demands for water in the early 1950's. Liberty Dam was completed in 1954. The reservoir impounds an estimated 43.3 billion gallons of water. Water from Liberty Reservoir is transmitted through a 12.7-mile long, 10-foot diameter tunnel to Ashburton Water Filtration Plant for treatment. The tunnel was constructed in solid rock (Baltimore City DPW, 1981).

The Ashburton Water Filtration Plant was completed in 1956. It has a maximum treatment capacity of 165 million gallons per day (MGD), with an average daily treatment of approximately 100 MGD. Ashburton supplies finished drinking water using several basic steps, including:

1. Prechlorination;
2. Coagulation;
3. Flocculation;
4. Sedimentation;
5. Filtration;
6. Corrosion control;
7. Post-chlorination; and
8. Fluoridation.

The plant adjusts individual treatment procedures in response to changes in the character of the raw water.

The Ashburton Water Filtration Plant serves four zones within the Baltimore metropolitan area (Figure 2-1), Zones 2 through 5. The second zone is supplied by gravity, while the third, fourth, and fifth zones are supplied by pumping. Zone two extends from southeastern Baltimore County southwest through central Baltimore City and into northern Anne Arundel County. Zone three extends from southeastern Baltimore County southwest through northwestern Baltimore City and into northern Anne Arundel and Howard Counties. Zone four includes south central and southwestern portions of Baltimore County. Zone five includes several small areas in north central and western Baltimore County.

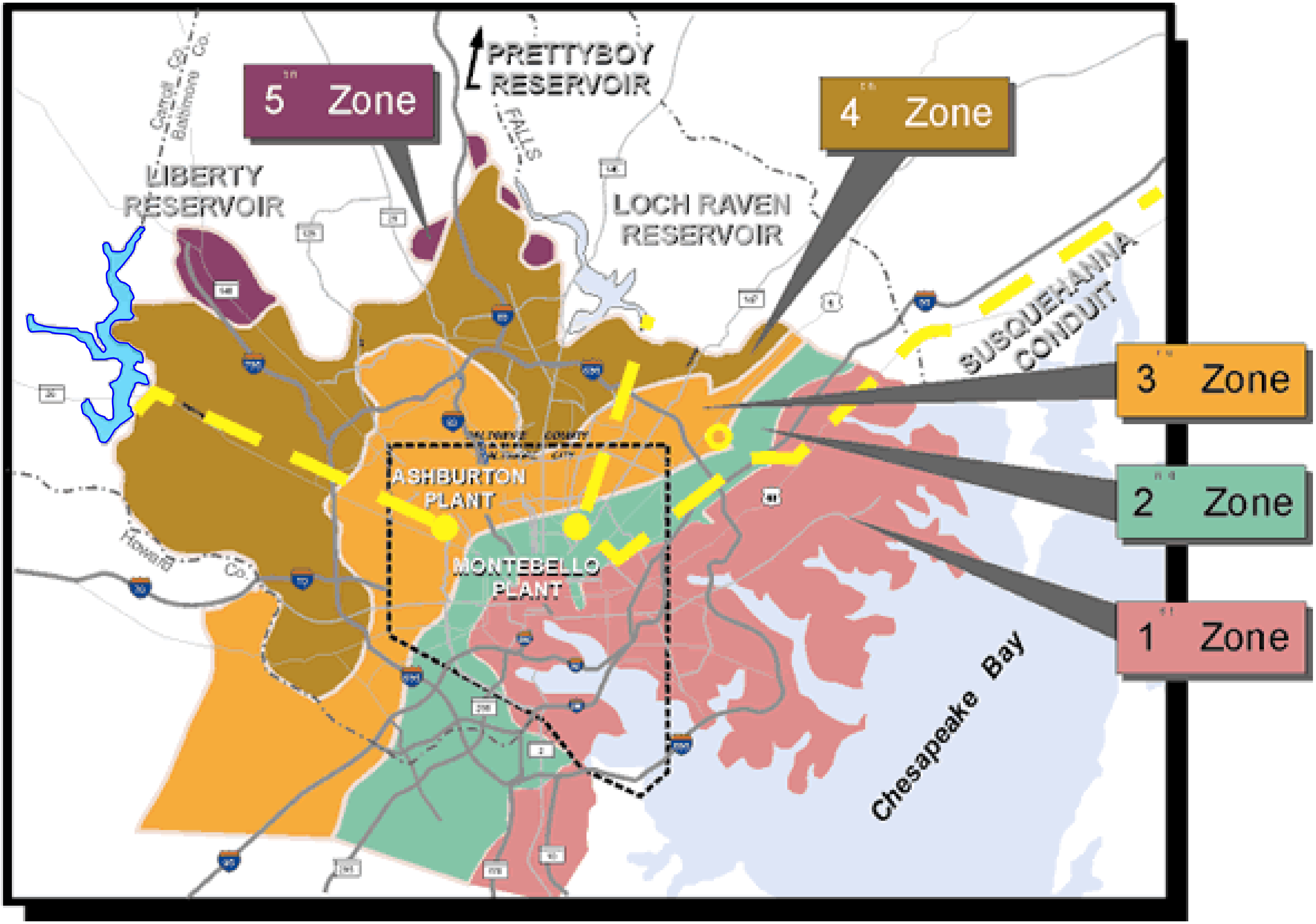

Figure 2-1. Site Vicinity Map

3.0 DESCRIPTION OF SURFACE SOURCE

Liberty Reservoir is located on the North Branch Patapsco River on the boundary between Baltimore and Carroll Counties. It collects water from a 163.8 square mile watershed that includes eastern Carroll County and southwestern Baltimore County. The reservoir length is approximately 12 miles and has an estimated maximum depth of over 140 feet. A bathymetric survey is currently being conducted by the Maryland Geological Survey (MGS).

Liberty Dam is a concrete gravity dam. The crest of the dam is at elevation 420 feet above mean sea level (MSL), approximately 160 feet above the original stream bed (Baltimore City DPW, 1981). The total length of the dam is 704 feet with a spillway length of 480 feet (Baltimore City DPW, 1981).

Numerous streams contribute water to Liberty Reservoir. The seven major subwatersheds and their drainage areas are described in Section 5.

Outflow discharged from the dam flows into the Patapsco River. Discharge from the dam flows into the North Branch Patapsco River. Discharge from the dam consists only of flow over the top of the dam. There are no gates in the dam to control water levels in the reservoir. The dam overflow is not gaged, but by using the elevation of the reservoir and the length of the dam spillway, the discharge into North Branch Patapsco River can be calculated. Downstream of the dam, the North Branch Patapsco River joins the South Branch Patapsco River forming the Patapsco River, which continue for approximately 25 miles before discharging to the Chesapeake Bay near Baltimore Harbor.

The reservoir is located in the Piedmont Physiographic Province. This province is characterized by gently rolling to moderately rugged terrain with some deeply entrenched stream valleys. The reservoir and its western watershed are underlain by the gneiss, schist, and phyllite bedrock of the Gillis Group, Marburg, Morgan Run, Pleasant Grove, Prettyboy, Sam's Creek, and Sykesville Formations. The Maryland Geologic Survey has documented some localized occurrences of limestone and marble in the Gillis Group and Sam's Creek Formation near the Westminster area. The eastern watershed is primarily underlain by the schists of the Sykesville and Loch Raven Formations, and by serpentine in the Soldiers Delight area of Baltimore County.

Soils in the flat to gently sloping areas of the Piedmont typically form from *in situ* decomposition of the underlying bedrock. The combined soil and weathered bedrock layers are generally thick, often exceeding 50 feet. The soil profile is generally thinner where slopes are steeper and where stream erosion actively removes soil from valley bottoms.

Carroll County, where most of the watershed for the reservoir is located, has a humid, continental climate (U.S. Department of Agriculture, Soil Conservation Service, 1969). The mean temperature for Westminster, in the northwestern portion of the watershed, is 54 degrees Fahrenheit (F). The latter portion of July and the beginning of August is the hottest portion of the year, averaging approximately 88 degrees F. The coldest portion of the year is the end of January, when minimum daily temperatures are approximately 22 degrees F. Annual precipitation at Westminster averages 45 inches with a range from 27 to 59 inches. Precipitation is distributed fairly evenly throughout the year; February averages the least precipitation with 2.87 inches, whereas the wettest month is August with 4.79 inches of precipitation on average. Snowfall at Westminster averages 27.5 inches, but varies greatly from year to year.

Several municipalities are located within the watershed. Portions of Westminster (population 16,731) (U.S. Census, 2000), Hampstead (population 5,060), Eldersburg Census Designated Place (population 27,741) and Finksburg are the primary commercial/industrial and medium- to high-density residential areas. Only a small portion of Reisterstown is located within the watershed. A detailed description of the land use within the Liberty Reservoir Watershed is provided in Section 5.

4.0 SOURCE WATER ASSESSMENT

4.1 Intake Integrity/Description

Liberty Dam is a concrete gravity dam with a spillway crest of 420 feet MSL and a spillway length of 480 feet. The construction of the dam was completed in 1954. The reservoir's design capacity is 43 billion gallons, however, over time the reservoir has lost capacity due to sedimentation. The Maryland Geological Survey is conducting a study to determine the current capacity of the reservoir. The drainage area includes eastern Carroll County and southwestern Baltimore County. The drainage area has a safe yield of 94 million gallons per day (MGD).

Water is withdrawn from Liberty Reservoir through an intake structure located approximately one mile north of Liberty Dam (Figure 5-2). The intake structure consists of a separate tower constructed over the terminus of the 10-foot diameter raw water conduit that carries water to the Ashburton Water Filtration Plant (Ashburton). The intake structure consists of a concrete riser that is 23 feet in diameter, with eight sluice gates. Each sluice gate is 36 inches wide by 60 inches high. Two gates are situated with their centerline at 410 feet MSL, four at elevation 365 feet MSL, and two at elevation 320 feet MSL (City of Baltimore, 1998).

At a reservoir elevation of 420 feet the maximum capacity of the raw water tunnel is approximately 225 MGD. Based on the original hydraulic diagram for the dam, the gravity raw water flow to Ashburton ranges from 180 MGD at reservoir elevation 399 feet to 120 MGD at reservoir elevation 382 feet. The pumped raw water flow ranges from 180 MGD at reservoir elevation 347 feet to 120 MGD at reservoir elevation 352 feet.

Three vertical turbine raw water pumps are present at Ashburton. Each pump has a capacity of 60 MGD. The raw water pumps were installed as a precautionary measure for future droughts and the upcoming renovation of the Montebello Filtration Plant (Water Contract No. 1111), which may require Ashburton to operate at maximum flows for a prolonged period of time.

The safe yield of the North Branch Patapsco River (94 MGD), compared to the safe yield of the Gunpowder Falls (148 MGD), indicates that Liberty Reservoir is a slow recovering impoundment, that is, once the water level has been drawn down, it takes quite some time for the reservoir to refill. As a result, the City of Baltimore utilizes a Firming Program to protect this source by limiting the withdrawals from Liberty Reservoir based on the elevation of water in the reservoir and the time of the year. As the water level drops in Liberty Reservoir, the allowable daily withdrawal from the reservoir decreases. When withdrawal at Liberty Reservoir decreases, the Gunpowder Falls supply, which consists of Loch Raven and Prettyboy reservoirs, is then utilized to augment the Liberty supply. If the Loch Raven and Prettyboy Reservoirs cannot make up the difference, then water from Conowingo Reservoir on the Susquehanna River can be pumped to Baltimore via the Deer Creek Pumping Station. The Firming Plan is currently under review by Water Contract No. 1111 – Phase II, primarily as a result of court action by the Susquehanna River Basin Commission against Baltimore City to restrict the withdrawal of water from the Susquehanna River.

Liberty Dam has received inspections from the U.S. Army Corps of Engineers (USACE) and MDE, Dam Safety Division. The USACE inspection found that Liberty Dam was in good structural condition, with no tendency for tipping or sliding under the probable maximum flood.

The inspections performed by the Dam Safety Division of MDE found some minor deficiencies, including the need for: upgrades to the electrical system and the replacement of gallery lighting; correction of problems concerning the clogging of several vertical drains; and fixing drain valve operation problems. Water Contract No. 5814 is currently active to address the deficiencies noted by MDE.

4.2 Operator Concerns and Observation

The Liberty Reservoir intake structure was modified to combat the threat of zebra mussel infestation. The modifications consisted of a building to house equipment to deliver a solution of either potassium permanganate or chlorine to the intake structure for the disinfection of the raw water tunnel. This zebra mussel system has never been used. Although the intake structure is somewhat cluttered by the addition of the zebra mussel solution piping, the structure is in good condition and is not infested by zebra mussels. Mechanically, the sluice gates and the overhead hoist system for the removal of the intake screens are also in good operating condition. However, the intake screens are in poor condition and are in need of replacement. During the installation of the zebra mussel diffuser piping, the contractor reported that the screens at the water surface were severely corroded and, at lower depths, aquatic growth and debris covered portions of the screens restricting flow as much as 100 percent.

The Ashburton Water Filtration Plant was designed to process 120 MGD on average and it has demonstrated the ability to handle flows up to the current maximum plant flow of 165 MGD. As part of Water Contract No. 8652, a total rehabilitation of Ashburton is under design and Baltimore City has requested the removal of certain head-loss factors that would allow the maximum flow to increase to 180 MGD. Based on these numbers and short duration flow tests, the tunnel is capable of providing the flows. However, the reduction in “C” value, or pipe roughness (Hazen – Williams) from original value for Ashburton has caused some concerns. To determine the cause of the capacity loss, an inspection of the tunnel is being considered as part of the plant renovation.

Due to the success of the Firming Program, the raw water pumps have never been utilized for their intended purpose. Therefore, preventative maintenance and routine test operations have been limited. Since it is unknown when the Raw Water Pumps will be needed, the operators strongly suggested that proper preventative maintenance and exercising of the pumps be resumed as soon as possible.

5.0 WATERSHED CHARACTERIZATION

5.1 Source Water Assessment Area Delineation Method

An important aspect of the source water assessment process is to delineate the watershed area that contributes to the source of drinking water. A source water protection area is defined as the whole watershed area upstream of the intake of a water plant (MDE, 1999). The source water area for Liberty Reservoir was delineated by MDE and provided as Geographic Information System (GIS) data.

5.2 Liberty Reservoir Watershed

The Liberty Reservoir Watershed is a roughly rectangular area that is approximately 19.2 miles long (north-south) and 13.6 miles across at its widest point.

Land use within the Liberty Reservoir watershed is varied (Table 5-1 and Figure 5-1) (Maryland Department of Planning [MDP], 1997). Cropland occupies the most land area at 36.6 percent, followed by forest (31.6 percent), and low-density residential (16.1 percent). Commercial/industrial land use occupies approximately 3 percent of the watershed. These areas are concentrated around Westminster, Eldersburg, Finksburg, Hampstead, and the Baltimore Boulevard (MD 140) corridor. Table 5-1 provides the land uses present within the Liberty Reservoir watershed.

5.3 Major Subwatersheds

Maryland's Source Water Assessment Plan states that larger source water areas will be segmented into smaller subwatersheds to assist in the assessment and identify watersheds of concern. The Liberty Reservoir watershed was segmented into seven major subwatersheds for this assessment (Figure 5-2). The subwatersheds were delineated based on watershed boundaries provided by MDE. Each subwatershed is depicted and described in the following pages in Figures 5-3a through 5-3g. Refer to Figure 5-3a for the legend for the small land use maps.

5.4 Time of Travel Study

Time of travel (TOT) studies were performed to determine flow characteristics within the Liberty Reservoir watershed. The purpose of these studies was to determine the time of travel of dye, which represents a hypothetical contaminant, from the headwaters of Liberty Reservoir watershed to the water supply intake. Studies were performed for three major tributaries of Liberty Reservoir under low-flow conditions, for one tributary under higher-flow conditions, and for three segments within the reservoir.

5.4.1 Low Flow Tributary Time of Travel Study

The low flow TOT study was conducted during three days in August 2001. Three major tributaries of Liberty Reservoir, Morgan Run, the West Branch, and the North Branch Patapsco River were selected for study. A conservative non-toxic dye was released into each of the tributaries and was monitored as it flowed in the stream toward Liberty Reservoir.

The dye used during the study was Rhodamine WT (20 percent), as approved by the MDE and the City of Baltimore. The dye was released from five locations, and monitored at 11 locations during the study (Table 5-2 and Figure 5-4). The dye concentrations were measured using a Turner Designs 10-AU fluorometer that was provided by the City of Baltimore. Estimates of stream flow were calculated prior to dye release to determine the amount of dye to release.

The goal was to collect downstream dye concentrations at set time intervals (e.g. every 10 minutes) until the field-measured concentrations were below 10 percent of the peak concentration. This was not logistically feasible in some instances due to the long TOT periods. The discharges measured during the study days were representative of typical low flow periods based on the historical U.S. Geological Survey (USGS) discharge data. The USGS data for the Morgan Run gaging station (USGS 01586610 Morgan Run Near Louisville, MD) for the period of record (1982 through 2001) show that lower average daily discharges than those during the study period occur only 5 percent of the time. The USGS data for the North Branch Patapsco River gaging station (USGS 01586000 North Branch Patapsco River at Cedarhurst, MD) for the period of record (1945 through 2001) show that lower average daily discharges than those during the study period occur only 9 percent of the time. The station discharge measurements conducted during the study are presented in Table 5-2.

After release, the dye forms a plume in the stream, much like that of a dissolved contaminant. The plume travels downstream with stream flow and, through the processes of advection and dispersion, is spread out over a length of the channel as it travels to the reservoir (Figure 5-5). Measurements of dye concentration and time since dye injection were collected as the plume passed a monitoring station. Dye concentrations varied throughout the plume, but generally represented a bell-shaped curve. The leading and trailing edges of the plume had very low dye concentrations, while the peak dye concentration generally was collected at the midpoint of the plume. Table 5-3 presents the TOT for the leading edge and peak concentration of the dye plume for each segment along with other tributary characteristics.

The TOT study indicates that for low flow conditions, a hypothetical contaminant would move slowly from the headwaters to the reservoir. Flow was not sufficient to flush the dye downstream at a fast rate and transport was retarded by cattle watering holes and other pools. The dye plume became more spread out as it traveled downstream. As a result, the time interval between arrival of the leading edge of the plume and peak dye concentration increased the further the monitoring station was from the dye injection point. These data also indicate that travel velocities varied between segments. This is dependent on local valley slope and flow contributed by tributaries. Table 5-3 provides the cumulative TOT for each segment.

The cumulative low flow stream TOT for Morgan Run and the North Branch Patapsco River were calculated. A hypothetical contaminant spilled at Old Washington Road into Morgan Run would arrive at London Bridge Road, just upstream of the reservoir, in approximately 13 hours under the studied flow conditions. The peak contaminant concentration would arrive approximately 3 hours later. A hypothetical contaminant spilled at Route 27 on the West Branch would arrive at Emory Road (Route 91) approximately 50 hours later. The arrival of the peak concentration is estimated at approximately 62 hours.

5.4.2 Higher-Flow Tributary Time of Travel

A higher-flow tributary TOT study was performed on September 25, 2001, for Morgan Run. Precipitation began falling in the watershed on September 24, 2001, and continued through the overnight hours. The storm produced 0.50 inches of rain at Baltimore-Washington International Airport (National Oceanic and Atmospheric Administration, 2001). At 6:30 AM on September 25, 2001, Morgan Run at London Bridge Road was flowing at approximately 100 cfs. For comparison, during the low flow TOT study, this location was flowing at approximately 32 cfs. The USGS data for the Morgan Run gaging station (USGS 01586610 Morgan Run Near Louisville, MD) for the period of record (1982 through 2001) show that higher average daily discharges than those during the study period occur only 16 percent of the time.

The methods for conducting the study were consistent with those above for the low flow TOT study. Dye was released at Old Washington Road and monitored at Klees Mill Road and London Bridge Road (Figure 5-4).

Several differences between the low and higher flow TOT study are evident. Flows were much higher, therefore the dye plume traveled faster downstream and was not spread out as much as during the low flow TOT study (Figure 5-6). Table 5-3 presents the TOT for the leading edge and peak concentration of the dye plume for each segment along with other tributary characteristics.

The TOT study indicates that for higher-flow conditions, a hypothetical contaminant would be flushed downstream at a rapid rate, approximately 1.3 feet per second (fps), from the headwaters to the reservoir. As expected, the dye plume became more spread out as it traveled downstream, however, less than that during the low flow TOT study. As a result, the peak dye concentration arrived sooner after the leading edge of the plume for the higher-flow event than the low flow event. Table 5-3 provides the cumulative TOT for each segment.

The cumulative higher-flow stream TOT for Morgan Run was calculated. A hypothetical contaminant spilled at Old Washington Road into Morgan Run would arrive at London Bridge Road, just upstream of the reservoir, in approximately 4.5 hours under similar higher-flow conditions. The peak contaminant concentration would arrive approximately 1 hour later. This is much faster than the low flow TOT when the leading edge of the dye plume arrived at London Bridge Road in approximately 13 hours and peaked at 16 hours.

5.4.3 Time of Travel for Unstudied Tributaries

The results of the TOT studies were extrapolated to provide an estimate of the TOT for other tributaries within the Liberty Reservoir watershed that were not included in the field studies. Estimates were calculated for the major tributaries, emphasizing the TOT from built-up areas and locations where highly traveled roads crossed the tributaries. These are considered to be the most probable locations that spills could occur. Table 5-4 and Figure 5-7 provide the estimated TOT from selected locations on the tributaries to the reservoir.

The extrapolation procedure involved several steps. Current land use percentages were compiled, including cropland, pasture, forest, and low and medium density residential land uses. Approximate channel slope was calculated from the selected upstream location to the channel endpoint (either the reservoir or the confluence with a larger tributary). Lastly, a channel length was calculated. Land use and channel slope were comparable for Beaver Run, Bonds Run, Little Morgan Run and Middle Run, therefore field-derived TOT data from Morgan Run were used to estimate TOT in these unstudied tributaries. Field-derived TOT data from the West Branch was used to extrapolate to the East Branch using the same rationale. To derive the higher-flow TOT, all tributaries were extrapolated from field-derived data from Morgan Run. Extrapolation was calculated by computing the ratio of the unstudied channel length to the channel length of the tributary included in the TOT study. This ratio was then multiplied by the TOT for low and higher-flow to obtain the extrapolated TOT.

The extrapolated TOT data provided in Table 5-4 and Figure 5-7 are an approximation of actual field conditions. It is expected that the actual TOT for extrapolated reaches may be longer due to tributary-specific conditions such as in-stream cattle watering ponds. For example, dye was released into Morgan Run at Warfieldsburg Road during low-flow conditions, however the downstream movement of the dye plume was extremely slow due to cattle ponds. The dye could not be measured at the next station downstream over 7 hours later. This indicates that the extrapolated TOT for this segment of Morgan Run may be much faster than actual conditions. Small dams that would slow the progression of the dye, such as near the Westminster Water Filtration Plant, were also observed during the TOT studies.

These data can be applied to potential contaminant spills into the tributaries. The results indicate that there is sufficient time to respond to a contaminant spill for many locations under low flow conditions. For higher-flow conditions, there is appreciably less response time. The solubility of the contaminant must also be taken into account when responding to a spill. Contaminants that are insoluble (float on top of the water) may be easily contained. Dissolved phase contaminants are not easily contained because they are mixed throughout the water column.

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Table 5-1: Liberty Reservoir Land Use (1997)

Land Use	Area (mi^2)	Area (acres)	Percent of Watershed
Barren Land	0.10	64	0.1
Commercial	4.17	2,666	2.5
Concentrated Agriculture	0.33	209	0.2
Cropland	60.05	38,431	36.6
Extractive	0.02	13	< 0.1
Forest	51.67	33,068	31.6
High-Density Residential	0.39	247	0.2
Industrial	1.00	638	0.6
Low-Density Residential	26.29	16,825	16.1
Medium Density Residential	4.36	2,792	2.7
Open Urban Land	0.76	487	0.5
Pasture	9.36	5,990	5.7
Water	5.26	3,369	3.2
Wetlands	0.02	10	<0.1
Total	**163.8**	**104,809**	**100.0**

Table 5-2: Station Locations and Discharges for the Tributary Time of Travel Study

Station ID Letter	Station Location	Station Type	Discharge at Station (cfs)[1]
Morgan Run Low Flow Study - August 21, 2001			
Station A	Warfieldsburg Road	Dye Release	No Data
Station B	Nicodemus Road	Dye Monitoring	3.4
Station C	Bloom Road	Dye Monitoring	14.6
Station D	Old Washington Road	Dye Release & Dye Monitoring	18.7
Station E	Klees Mill Road	Dye Monitoring	26.1
Station F	London Bridge Road	Dye Monitoring	32.9
Morgan Run Higher Flow Study - September 25, 2001			
Station D	Old Washington Road	Dye Release & Dye Monitoring	No Data
Station E	Klees Mill Road	Dye Monitoring	No Data
Station F	London Bridge Road	Dye Monitoring	102 (estimated)
West Branch Low Flow Study - August 23, 2001			
Station H	Route 27	Dye Release	8.8
Station TR	Tannery Road	Dye Monitoring	8.0 (estimate)
Station I	Gorsuch Road	Dye Release & Dye Monitoring	12.9
Station J	Dutrow Road	Dye Monitoring	16.1
Station K	Patapsco Road	Dye Monitoring	24.1
North Branch Patapsco River Low Flow Study - August 29, 2001			
Station Q	Wesley Road	Dye Release	No Data
Station R	Lawndale Road	Dye Monitoring	47.2
Station S	Emory Road (Route 91)	Dye Monitoring	47.8

[1] The discharge in cubic feet per second (cfs) was gaged at each station prior to dye injection.

Table 5-3: Results of Tributary Time of Travel Study for Tested Tributary Segments

Tributary Segment	Dye Injection Station, Volume and Mass of Dye[1]	Segment Length (ft)	Cumulative Distance from Dye Injection Station (ft)	Plume Leading Edge Cumulative Time of Travel[2] (Hours:Minutes)	Plume Peak Concentration Cumulative Time of Travel[3] (Hours:Minutes)	Average Velocity for Segment[4] (fps)
Morgan Run Low Flow Study - August 21, 2001						
Station D to E	Station D 0.25 L, 59.5 g	13,200	13,200	7:50	9:03	0.47
Station E to F		7,700	20,900	12:51	16:06	0.43
Morgan Run Higher Flow Study - September 25, 2001						
Station D to E	Station D 3.0 L, 714 g	13,200	13,200	2:39	3:19	1.38
Station E to F		7,700	20,900	4:29	5:24	1.17
West Branch Low Flow Study - August 23, 2001						
Station H to TR	Station H 0.1 L, 23.8 g	7,730	7,730	11:44	15:34	0.18
Station TR to I		4,200	11,930	17:09	-	0.22
Station I to J	Station I 0.3 L, 71.4 g	8,500	8,500	7:16	10:56	0.32
Station J to K		13,800	22,300	19:19	23:56	0.32
North Branch Patapsco River Low Flow Study - August 29, 2001						
Station Q to R	Station Q 0.1 L, 23.8 g	10,300	10,300	5:00	6:30	0.57
Station R to S		10,800	21,300	13:20	17:20	0.36

1 The volume of 20 percent Rhodamine WT dye solution injected in liters (L), and the mass of active ingredient injected in grams (g).

2 The time required for the leading edge of the dye plume to reach the downstream end of the tributary segment expressed as the time since the dye was injected.

3 The time required for the peak concentration within the dye plume to reach the downstream end of the tributary segment expressed as the time since the dye was injected.

4 Average velocity was calculated as the segment length divided by the time of travel of the leading edge of the plume through the tributary segment and is expressed in feet per second (fps).

Table 5-4: Estimated Time of Travel for Tributaries

Tributary	Length (ft)	Segment	TOT Estimates (Hours:Minutes)			
			Low Flow (Leading Edge)	Low Flow (Peak)	Higher Flow (Leading Edge)	Higher Flow (Peak)
Beaver Run	1,491	MD 91 to Reservoir	1:00	1:00	0:18	0:22
	21,687	Greens Mill Rd to Reservoir	13:00	16:30	4:30	5:30
Bonds Run	35,663	Bortner Rd to MD 91 (Reservoir)	30:30	39:30	10:30	12:30
Little Morgan Run	19,154	MD 97 to Reservoir	12:00	15:00	4:00	5:00
Middle Run	13,973	MD 91 to Reservoir	8:30	11:00	3:00	3:00
East Branch	61,187	MD 482 to Reservoir	55:30	69:30	13:00	15:30
Morgan Run	34,000	Warfieldsburg Rd to London Bridge Rd (Reservoir)	21:00	26:30	7:30	9:00
Morgan Run	20,900	Old Washington Rd to London Bridge Rd (Reservoir)	13:00	16:00	4:30	5:30
West Branch	56,195	MD 27 to MD 91 (Reservoir)	50:00	62:00	12:00	14:30

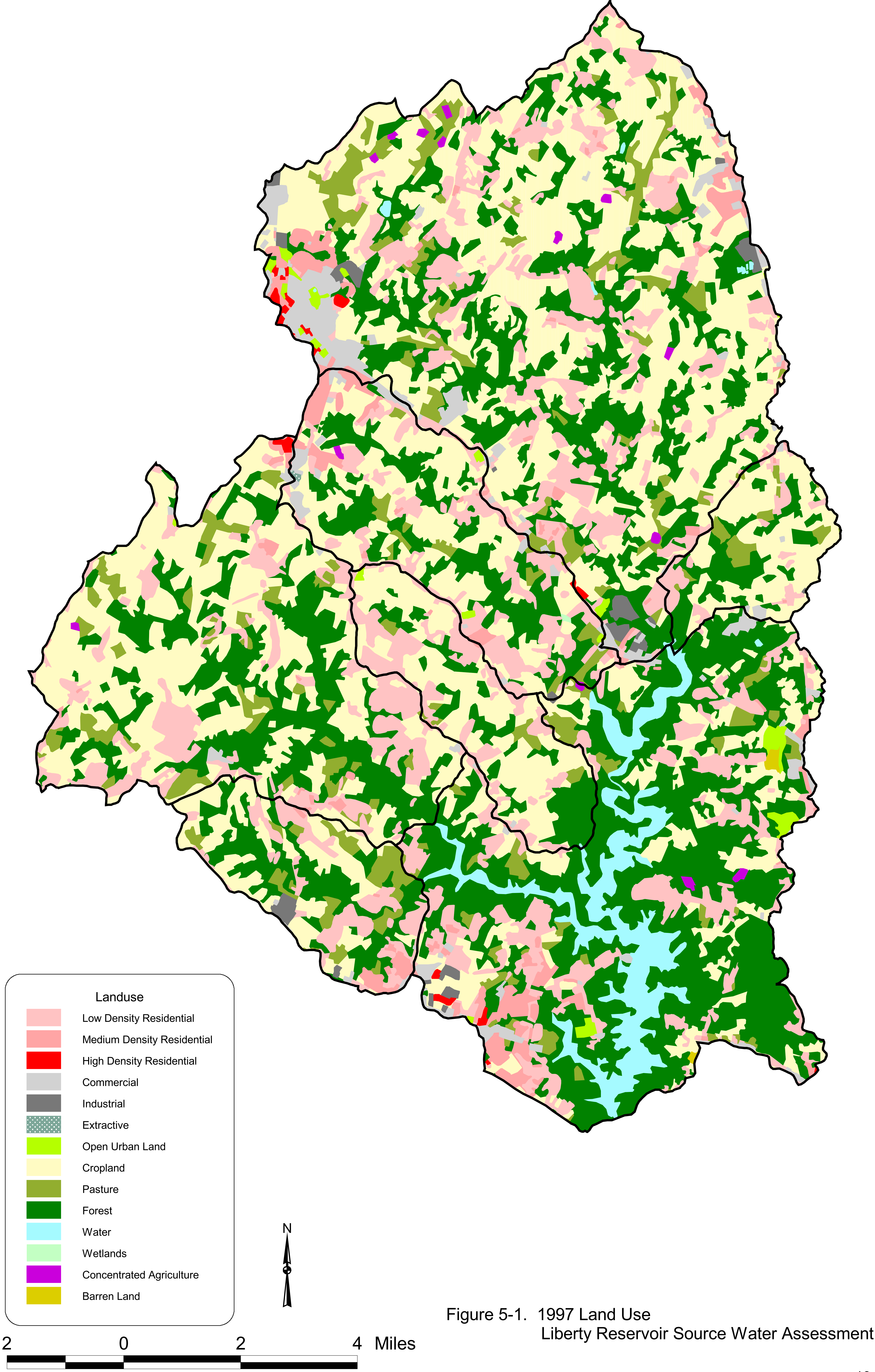
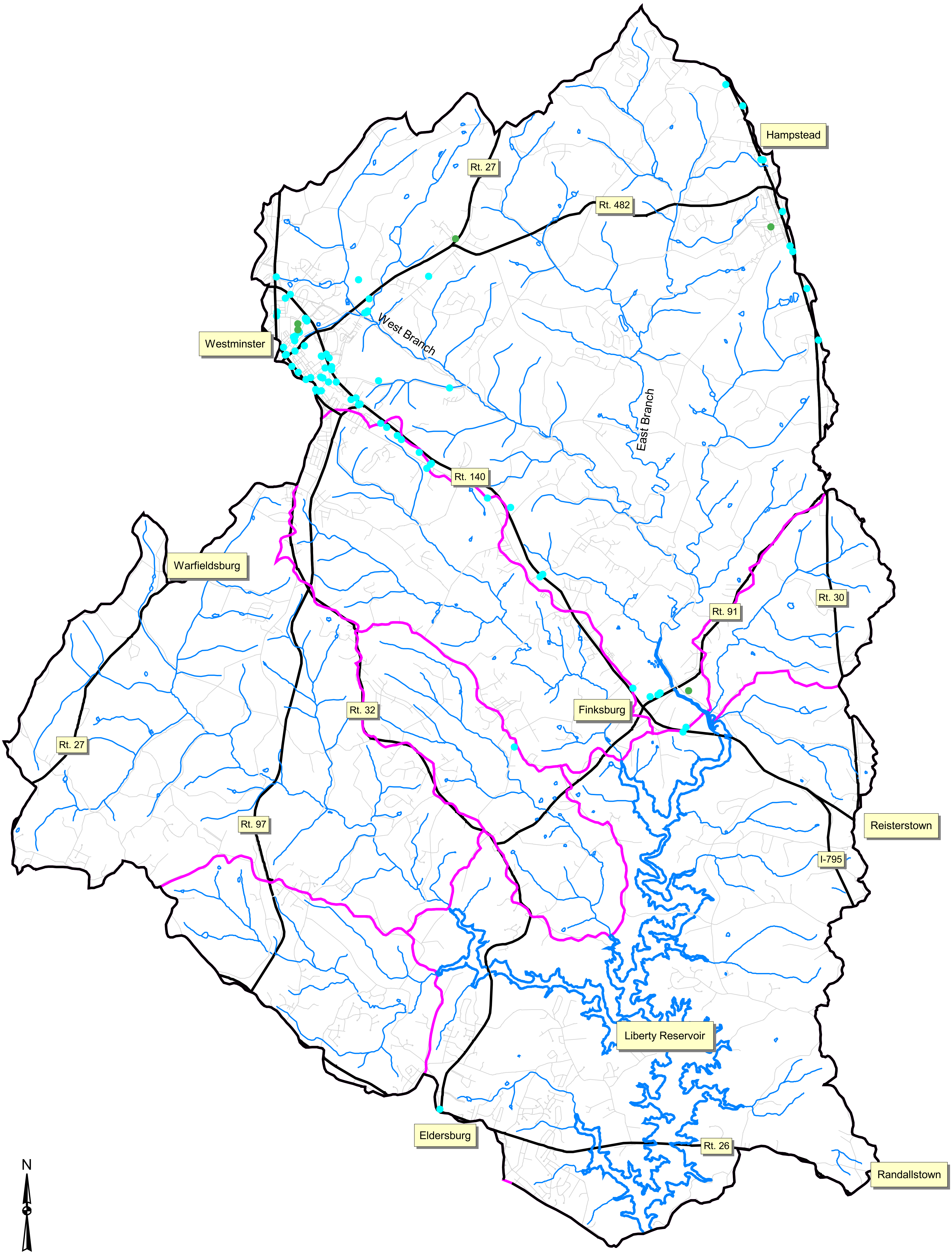


Figure 5-1. 1997 Land Use
Liberty Reservoir Source Water Assessment



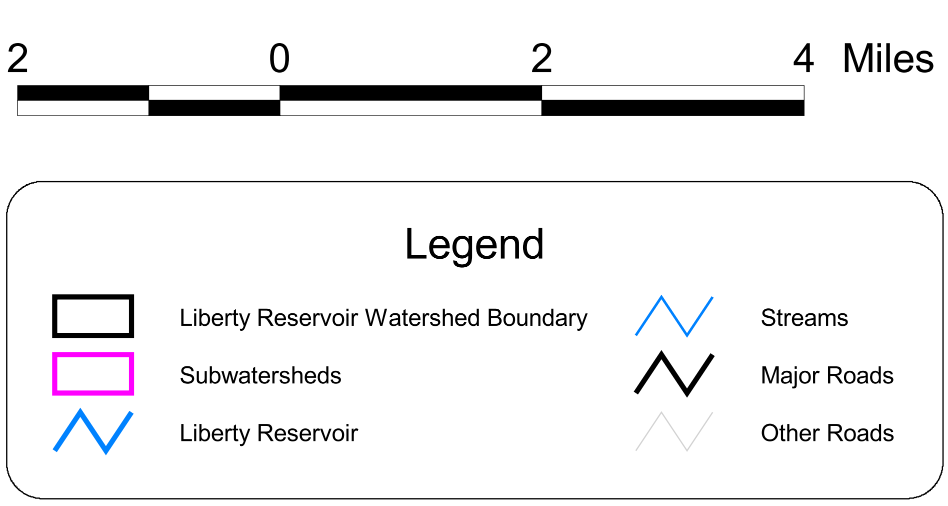
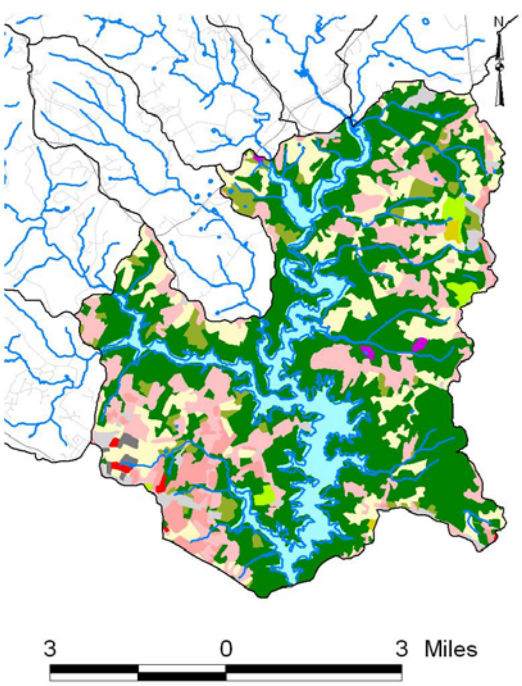


Figure 5-2. Subwatersheds
Liberty Reservoir Source Water Assessment

Legend for Figures 5-3a through 5-3g:

Figure 5-3a: Liberty Subwatershed Land Use and Description

LIBERTY SUBWATERSHED	1997 Land Use	Total Acres	% Watershed
Total Area= 54.7 square miles	Barren Land	64.8	0.2
	Commercial	560.0	2.2
	Concentrated Agriculture	55.5	0.2
	Cropland	3,771.2	14.5
	Forest	12,264.7	47.2
	High Density Residential	65.1	0.3
	Industrial	95.0	0.4
	Low Density Residential	3,744.0	14.4
	Medium Density Residential	860.3	3.3
	Open Urban	249.5	1.0
	Pasture	946.4	3.6
	Water	3,295.2	12.7
	Total	25,971.7	100.0

The largest of the subwatersheds within the Liberty Reservoir watershed, the Liberty subwatershed surrounds the reservoir itself. It is mainly forested (42%) with some cropland (22%) and rural low-density residential areas (15%).

Baltimore City has four in-reservoir water quality stations to monitor the reservoir within this subwatershed.

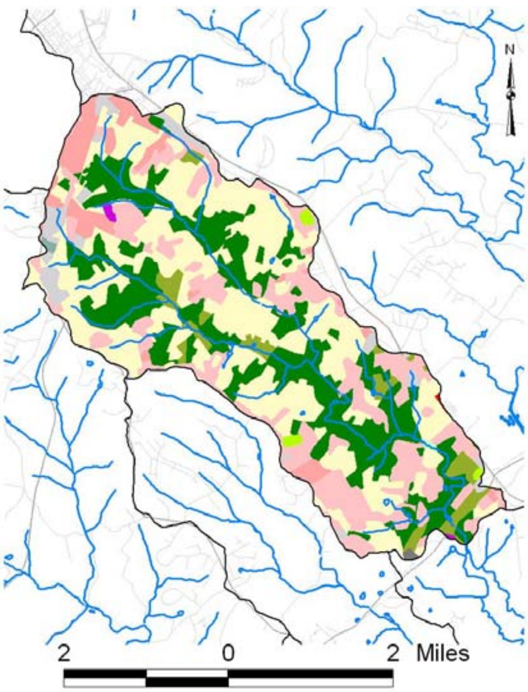
Municipalities within the subwatershed include Finksburg and portions of Eldersburg and Reisterstown.

Major routes of transportation through the Liberty subwatershed include Liberty Road (MD 26) and Hanover Road (MD 30). Commercial and industrial activities are concentrated around these roads.

Figure 5-3b: Beaver Run Subwatershed Land Use and Description

BEAVER RUN SUBWATERSHED

Total Area= 14.3 square miles



1997 Land Use	Total Acres	% Watershed
Commercial	316.3	3.4
Concentrated Agriculture	18.9	0.2
Cropland	3,528.2	38.4
Extractive	12.3	0.1
Forest	2,490.0	27.1
High Density Residential	4.4	0.05
Industrial	11.4	0.1
Low Density Residential	1,888.7	20.6
Medium Density Residential	501.6	5.5
Open Urban Land	41.3	0.5
Pasture	367.9	4.0
Wetlands	10.5	0.1
Total	9,191.5	100.0

The Beaver Run subwatershed is composed of mainly cropland (38%), forested areas (27%) and rural low-density residential areas (21%).

Baltimore City has one water quality monitoring station on Beaver Run. The USGS maintains a gaging station on Beaver Run.

Municipalities within the subwatershed include a small portion of Westminster in the western part of the watershed.

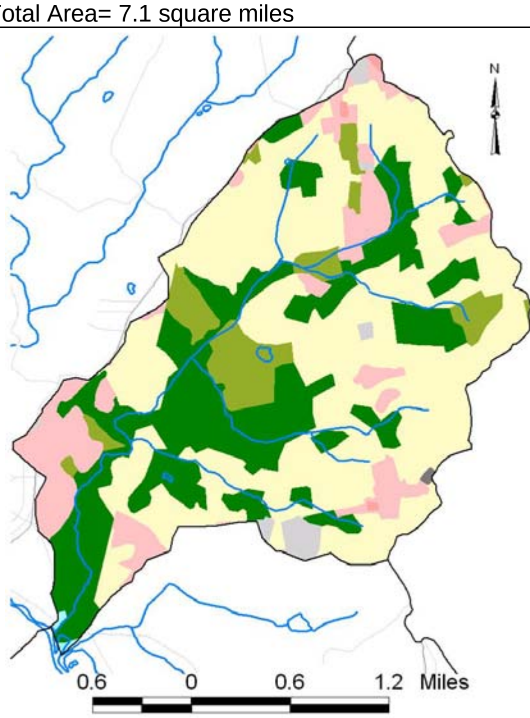
Major routes of transportation within the subwatershed include Baltimore Boulevard (MD 140) and MD 97. Commercial and industrial activities are concentrated around MD 140.

Several sinkholes are reportedly present within the eastern and central portions of the watershed.

Figure 5-3c: Bonds Run Subwatershed Land Use and Description

BONDS RUN SUBWATERSHED

Total Area= 7.1 square miles



1997 Land Use	Total Acres	% Watershed
Commercial	56.4	1.5
Cropland	1,962.4	52.2
Forest	1,012.5	26.9
Industrial	3.3	0.1
Low Density Residential	430.7	11.5
Medium Density Residential	10.9	0.3
Pasture	275.2	7.3
Water	6.1	0.2
Total	3,757.5	100.0

The Bonds Run subwatershed is the smallest of the subwatersheds located within the Liberty Reservoir watershed. This subwatershed contains mainly cropland (56%) and forested areas (28%).

Baltimore City has one water quality monitoring station on Bonds Run.

There are no municipalities within the Bonds Run subwatershed. Only 8% of the total subwatershed area is classified as low or medium density residential areas.

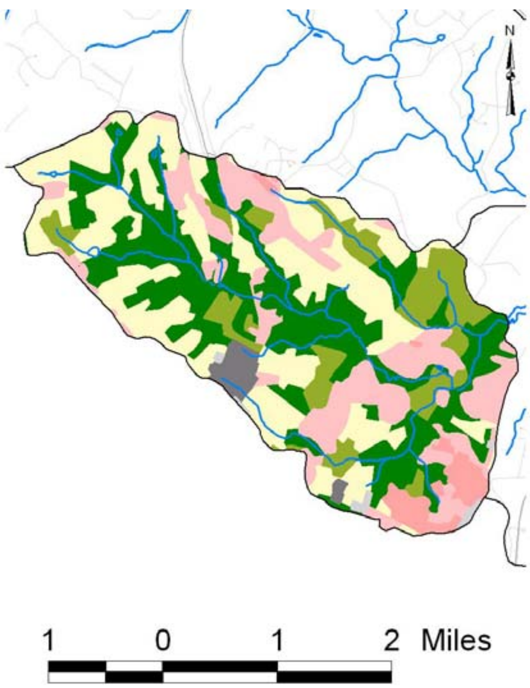
Major routes of transportation through this subwatershed include Hanover Road (MD 30). Commercial and industrial activities are concentrated around these roads.

Figure 5-3d: Little Morgan Run Subwatershed Land Use and Description

LITTLE MORGAN RUN SUBWATERSHED

Total Area= 8.6 square miles

1997 Land Use	Total Acres	% Watershed
Commercial	35.3	0.6
Cropland	1,764.1	32.0
Forest	1,712.7	31.0
Industrial	110.2	2.0
Low Density Residential	1,041.3	18.9
Medium Density Residential	199.7	3.6
Pasture	655.9	11.9
Total	5,519.2	100.0



The Little Morgan Run subwatershed is mainly composed of cropland (32%), forested areas (31%) and rural, low-density residential areas (19%). The remaining areas of Little Morgan Run consist of pasture land and light industrial areas.

Baltimore City has one water quality monitoring station on Little Morgan Run.

There are no municipalities within the Little Morgan Run subwatershed.

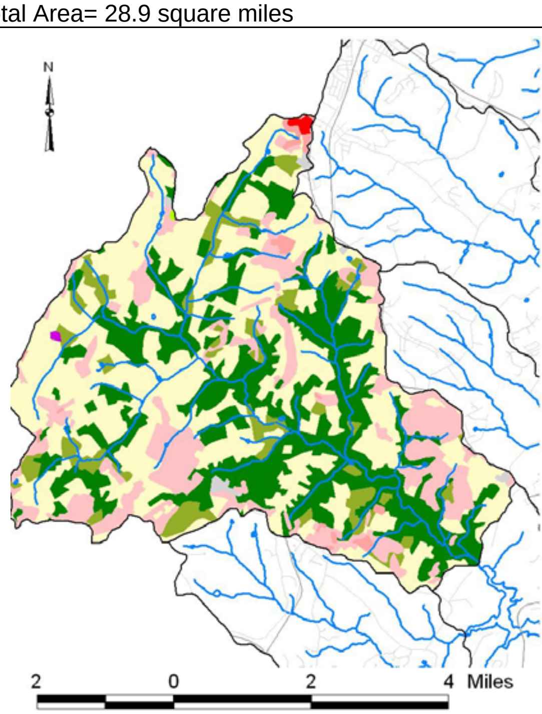
The major route of transportation through this subwatershed is Liberty Road (MD 26). Commercial and light industrial activities are concentrated around MD 26.

Figure 5-3e: Morgan Run Subwatershed Land Use and Description

MORGAN RUN SUBWATERSHED

Total Area= 28.9 square miles

1997 Land Use	Total Acres	% Watershed
Commercial	93.8	0.5
Concentrated Agriculture	11.0	0.1
Cropland	8,577.7	46.2
Extractive	1.4	0.01
Forest	5,363.9	28.9
High Density Residential	34.5	0.2
Low Density Residential	3,014.8	16.3
Medium Density Residential	172.3	0.9
Open Urban Land	5.0	0.03
Pasture	1,275.8	6.9
Total	18,530.2	100.0



The Morgan Run subwatershed is the third largest subwatershed within the Liberty Reservoir watershed. This subwatershed is composed of Cropland (46%), forested areas (29%) and rural low-density residential areas (16%). Public sewer services are not provided within this relatively undeveloped subwatershed.

Baltimore City has one water quality monitoring station on Morgan Run. The USGS maintains a gaging station on Morgan Run. The Department of Natural Resources stocks Morgan Run with trout on a yearly basis.

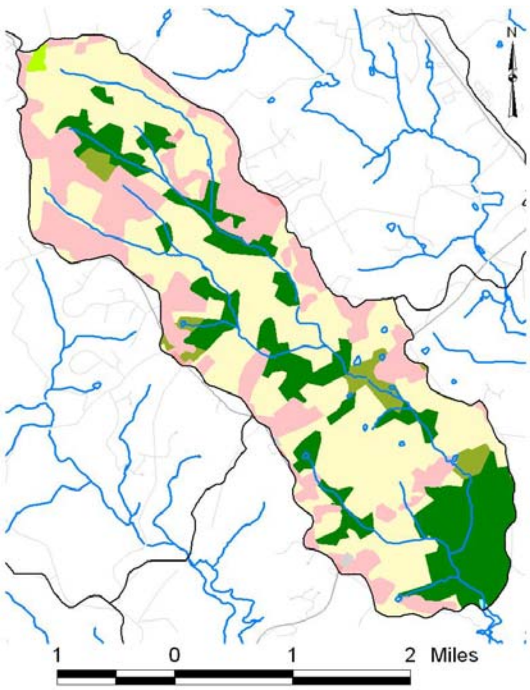
There are no municipalities within the Morgan Run subwatershed.

Major routes of transportation through this subwatershed include MD 97, Ridge Road (MD 27), and Sykesville Road (MD 32).

Figure 5-3f: Middle Run Subwatershed Land Use and Description

MIDDLE RUN SUBWATERSHED

Total Area= 8.4 square miles



1997 Land Use	Total Acres	% Watershed
Commercial	9.1	0.2
Cropland	2,703.3	50.0
Forest	1,160.6	21.5
Low Density Residential	1,322.1	24.5
Medium Density Residential	14.9	0.3
Open Urban Land	15.4	0.3
Pasture	170.4	3.1
Water	3.2	0.1
Total	5,399.0	100.00

The Middle Run Subwatershed is approximately 5,399 acres and is mainly cropland (50%), forested areas (21%) and rural, low-density residential areas (24%). Middle Run, a relatively undeveloped subwatershed, is not provided with public sewer services.

Baltimore City has one water quality monitoring station on Middle Run.

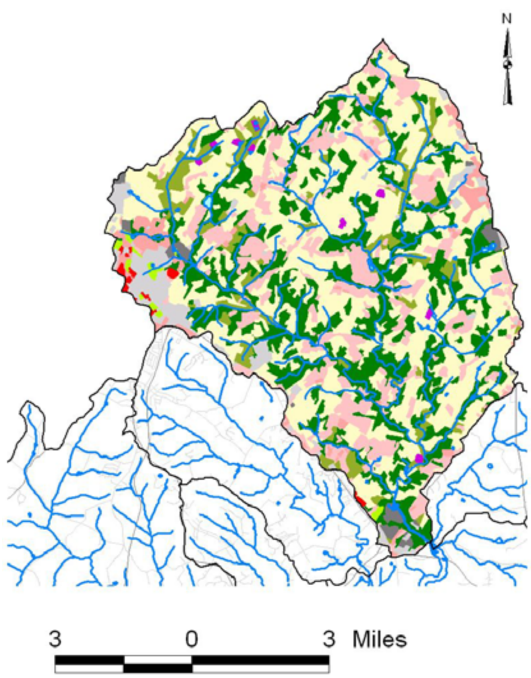
There are no municipalities within the Middle Run subwatershed.

Major routes of transportation through this subwatershed include Sykesville Road (MD 32) and Gamber Road (MD 91).

Figure 5-3g: North Branch Subwatershed Land Use and Description

NORTH BRANCH SUBWATERSHED

Total Area= 41.6 square miles



1997 Land Use	Total Acres	% Watershed
Commercial	1,590.2	4.4
Concentrated Agriculture	124.4	0.3
Cropland	16,140.2	44.3
Forest	9,067.4	24.9
High Density Residential	143.4	0.4
Industrial	419.6	1.1
Low Density Residential	5,379.7	14.8
Medium Density Residential	1,033.7	2.8
Open Urban Land	175.3	0.5
Pasture	2,293.8	6.3
Water	64.7	0.2
Total	36,432.4	100.0

The second largest subwatershed, the North Branch is mainly composed of cropland (44%), forested areas (24%) and rural low-density residential areas (15%). This subwatershed has the highest percentage of commercial areas within the Liberty Reservoir watershed at 6 percent. Commercial and industrial activities are concentrated Westminster, Hampstead, and MD 140.

Baltimore City has one water quality monitoring station on the North Branch. The USGS maintains a gaging station on the North Branch.

Municipalities within the subwatershed include portions of Westminster and Hampstead.

Major routes of transportation through this subwatershed include Baltimore Boulevard (MD 140), Hampstead-Mexico Road (MD 482), and Manchester Road (MD 27).

Ten sinkholes are reportedly located within the North Branch subwatershed. The greatest concentration of sinkholes are located in the Westminster area.

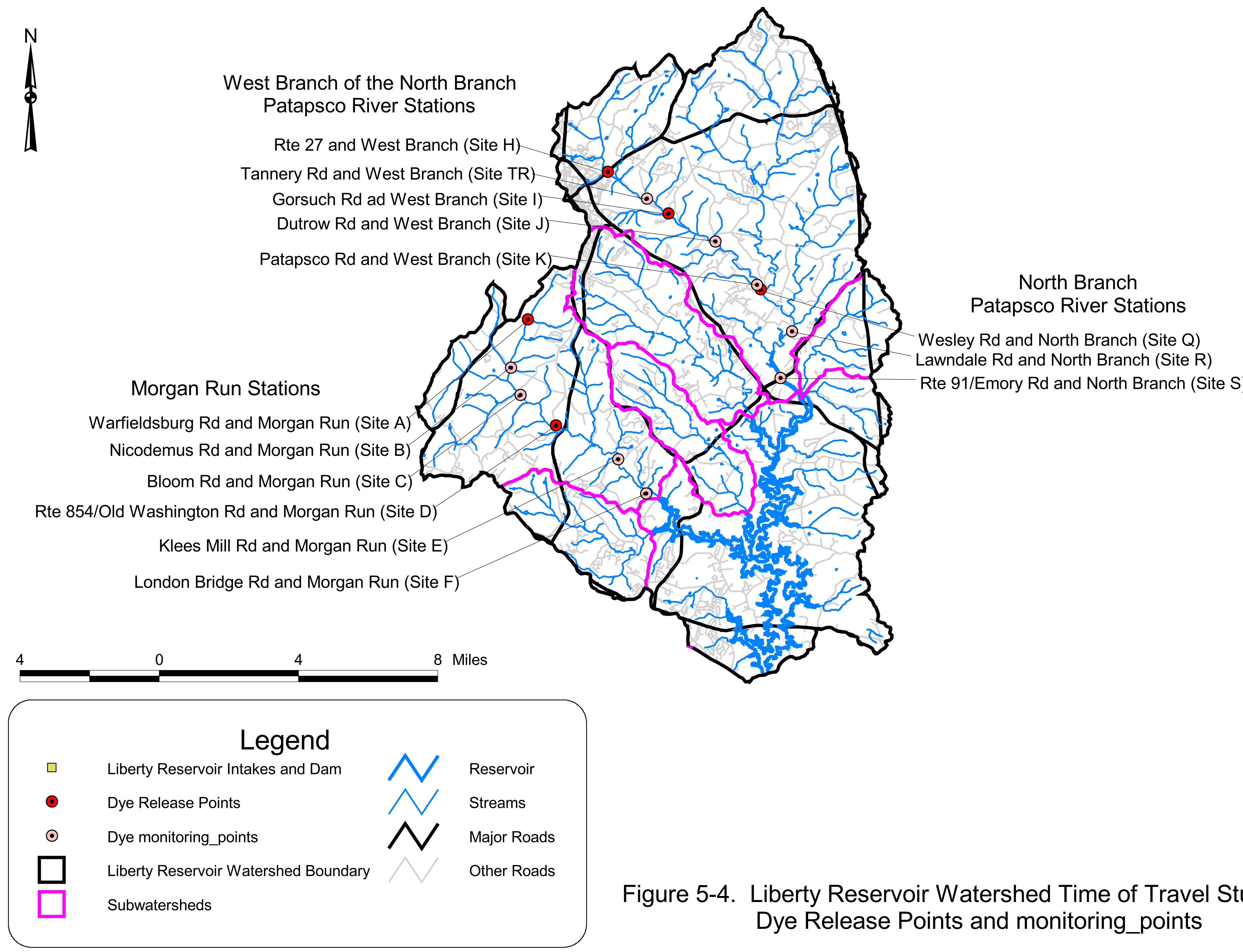


Figure 5-4. Liberty Reservoir Watershed Time of Travel Study
Dye Release Points and monitoring_points

Figure 5-5: Dye Concentrations on N. Branch Patapsco Low Flow At Stations R and S

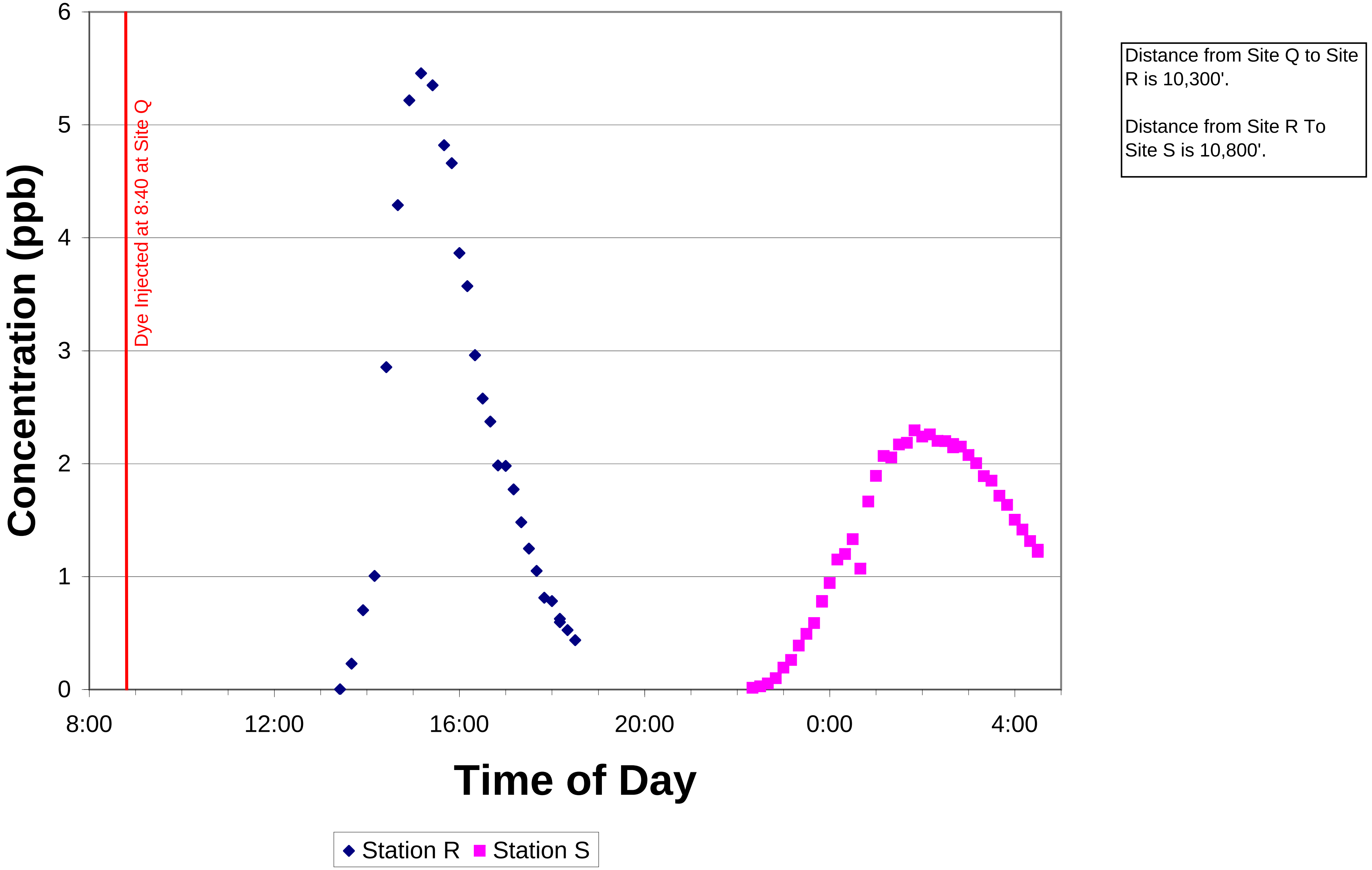
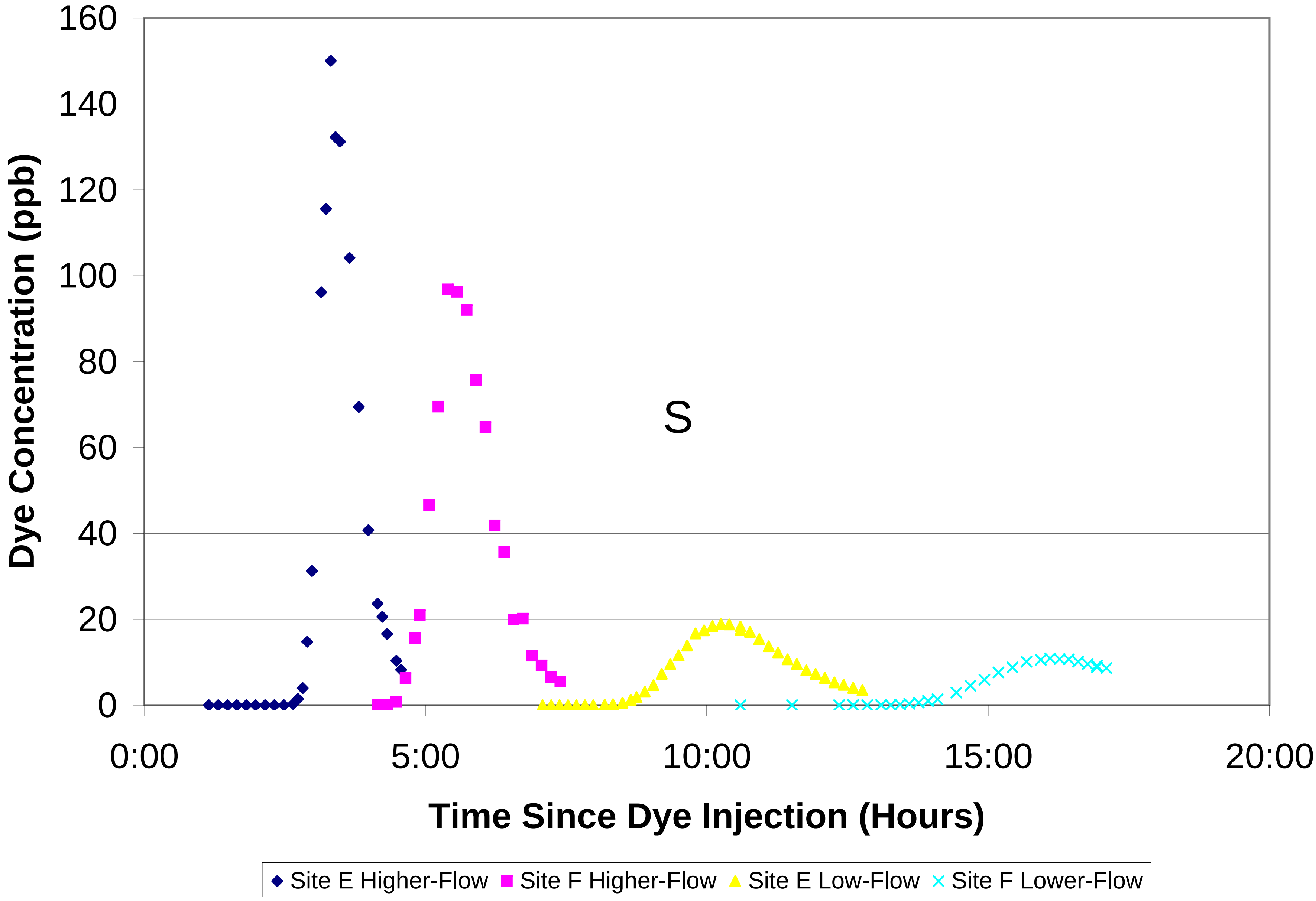
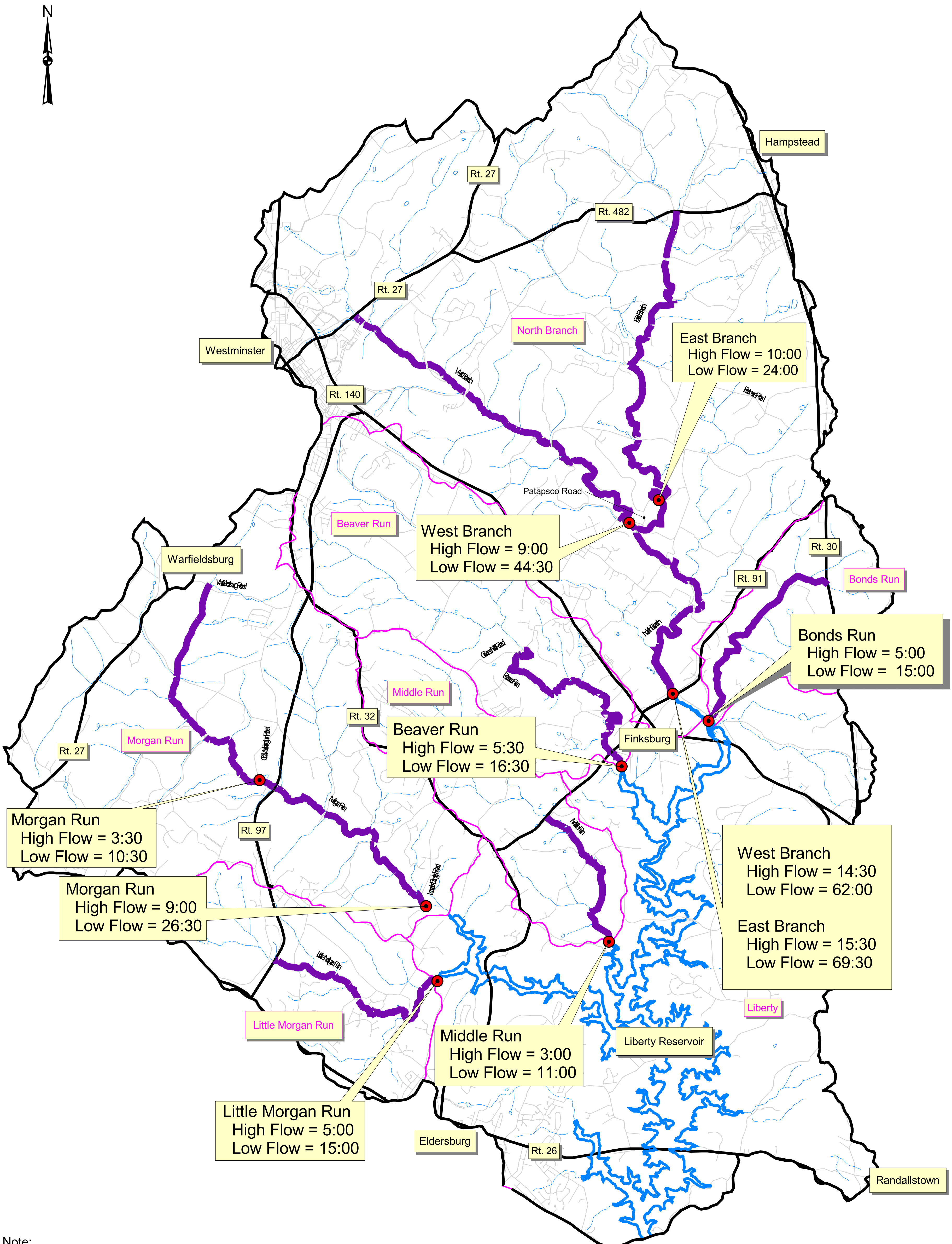


Figure 5-6: Morgan Run TOT Comparison





Note:
1) All times are in the format HOURS:MINUTES.
2) All times are from the furthest up stream extent of the TOT Reach.

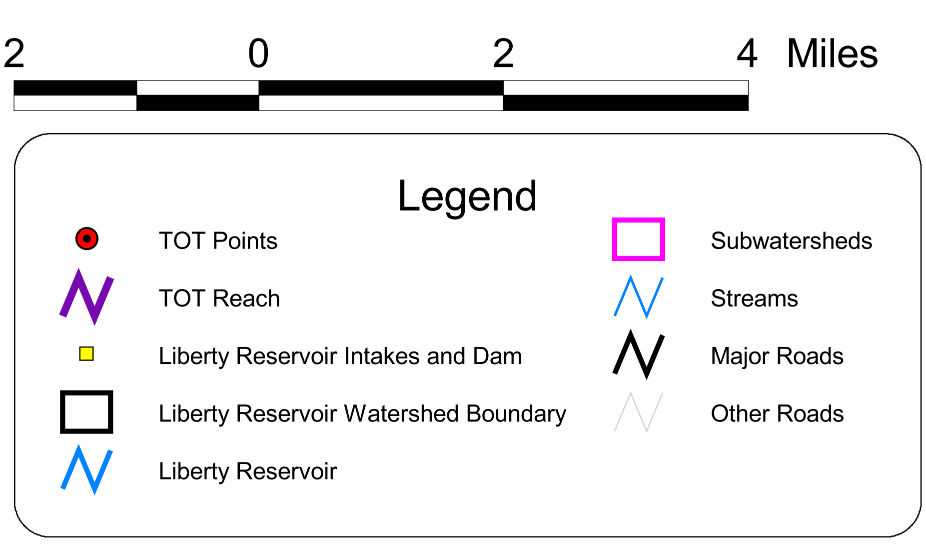


Figure 5-7. Estimated Time of Travel
Liberty Reservoir Source Water Assessment

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6.0 POTENTIAL SOURCES OF CONTAMINATION

6.1 Point and Nonpoint Sources Data

The identification and mapping of potential contaminant point sources within the subwatersheds of Liberty Reservoir was completed as part of this source water assessment. MDE provided the databases and geographic information system (GIS) coverages used for the identification of these potential sources (Table 6-1). These databases and coverages were used to create maps to depict the distribution of the various categories of potential contaminant sources in the watershed (Figures 6-1 through 6-5).

The number of potential contaminant sources within each of the seven subwatersheds was summarized by potential contaminant source type (Table 6-2). The results of this table are discussed in the following paragraphs in this section.

6.2 Description of Potential Contaminant Sources in the Liberty Reservoir Watershed and its Subwatersheds

6.2.1 Overview

The majority of the potential contaminant sources summarized in Table 6-2 are located in the North Branch subwatershed (57%) and the Liberty subwatershed (23%). These two subwatersheds also have the highest combined commercial and industrial land use area within the Liberty Reservoir watershed: North Branch at 2.38 square miles (mi^2) and Liberty at 1.63 mi^2 compared to 1.14 mi^2 for the remainder of the Liberty Reservoir watershed. Within these two subwatersheds, there are identifiable areas of concern with higher commercial and industrial land uses and consequently the highest concentrations of potential contaminant sources: Westminster; Hampstead; Finksburg; and the Route 140 corridor. The other five subwatersheds in the Liberty Reservoir watershed (Beaver Run, Bonds Run, Little Morgan Run, Middle Run, and Morgan Run) are primarily composed of undeveloped land, agricultural land, and rural low-density residential areas.

Transportation facilities, including highways, a railroad, and petroleum and gas pipelines, are potential sources of contamination to the reservoir. Both Route 26 and Route 140 are used heavily for commercial traffic through the Liberty Reservoir watershed. Both routes pose potential spill danger to the reservoir because they cross portions of the reservoir body as well as major tributaries. The eastern Route 26 Bridge is of particular concern because it crosses the main body of the reservoir approximately 3,300 feet upstream of the City of Baltimore's raw water intake structure. These routes have many industrial and commercial facilities located adjacent to them. The Route 140 corridor is more commercialized and industrialized than the Route 26 corridor (Figure 5-1). Numerous hazardous waste generators and automotive businesses are located along Route 140.

The Maryland Midland railway is also a potential contaminant source. The railway runs immediately adjacent to the North Branch Patapsco River and West Branch. The tracks run through portions of the Liberty and North Branch subwatersheds. Because of the proximity of the railway to the river, the river is vulnerable to any spill.

Colonial Pipeline Company (Colonial) owns and operates two pipelines and a facility near Finksburg (Figure 6-3). The Colonial Greensboro-Linden pipeline transports refined petroleum products: gasoline, heating oil, diesel fuel, aviation fuels, and military fuels. Approximately 95 million gallons of these products are transported to eastern states via the pipeline each day. This pipeline originates near Houston, Texas. The Finksburg delivery facility is not active and has been closed for a number of years. Colonial has no plans to reactivate it. The Pipeline leading to this facility is also inactive. The active pipeline crosses the channels of Little Morgan Run, Morgan Run, Middle Run, Beaver Run, and the North Branch Patapsco River just upstream of Finksburg. Due to the proximity of the pipelines to the reservoir and the multiple tributary crossings, potential leaks and spills from these pipelines are a concern.

Typically, tributaries in areas of heavier agricultural use are more susceptible to agricultural non point source pollution problems (i.e. nutrient and sediment loading, pesticides). Additionally, these areas are typically characterized by the predominance of septic tanks for sanitary treatment, which can also potentially contaminate ground and surface water.

The Carroll County Health Department (CCHD) maintains information concerning septic systems in the Liberty Reservoir watershed. CCHD reports that there are currently no identified failing systems in the county because failing systems are repaired when they are observed to be failing. However, CCHD has identified four septic system areas of concern within the watershed. These areas of concern are communities that have septic system problems, small lots, and limited soil capabilities for septic systems. Figure 6-6 provides the location of these four areas of concern:

- Snydersburg, E.D. #8;
- Carrollton, Carrollton Road near Dutrow Road;
- Cedarhurst, Cedarhurst Road adjacent to the North Branch Patapsco River; and
- Patapsco, Patapsco Road near Ridge Road.

The Baltimore County Department of Environmental and Protection and Resource Management (DEPRM) lists 1,905 septic systems (1,722 residential and 183 agricultural residences) in the Baltimore County portion of the Liberty Reservoir Watershed. No problem areas have been identified in this area of the watershed, however, this is based on assessments by residents.

6.2.2 North Branch Patapsco River Subwatershed

The North Branch subwatershed has the highest percentage of commercial and industrial land use within the Liberty Reservoir watershed (6%). These commercial and industrial activities are primarily concentrated near Westminster, and secondarily along the Route 140 corridor and near Hampstead. In addition, 44 percent of the watershed is agricultural, which typically contribute non-point source pollution to tributaries.

Major sources of potential contamination include leaking underground storage tank open cases (18), hazardous waste generators (46), automotive businesses (65), and sludge application facilities (10).

All four of the CCHD septic system areas of concern are located within this subwatershed (Figure 6-6).

Northern Landfill is located at about 2 miles east of the former Cranberry Mall at 1400 Baltimore Boulevard in Westminster. The Carroll County Department of Enterprise and Recreation Services owns and operates the landfill for use by county residents and county-based business. This municipal landfill is approximately 13 years old, and has a total acreage of 220 acres, of which approximately 30 acres are currently being used.

There are several major transportation routes for commercial traffic within the subwatershed on which spills could occur. Route 140 is the major traffic artery to Westminster. Routes 27 and 482 provide a link between Westminster and Route 30 near Hampstead. However, the major transportation concern within this subwatershed is the Maryland Midland Railway, which runs immediately adjacent to the West Branch from Finksburg to Westminster. The river is vulnerable to any spill along the railway.

6.2.3 Liberty Subwatershed

The Liberty subwatershed is mainly undeveloped except for the areas surrounding Finksburg and Eldersburg (Figure 5-1). Major land uses consist of agriculture and low-density residential. Non-point contamination concerns include agricultural fields and septic systems.

Although small in area, Finksburg is highly industrialized and commercialized (Figure 5-1). One of the industries in the area is the Congoleum Corporation (Congoleum). The Congoleum plant maintains three industrial national pollutant discharge elimination system (NPDES) permits with a major status to discharge to the North Branch Patapsco River. The major status indicates that the volume of wastewater discharged is high, or that the sensitivity of the receiving waters is high. The Colonial Greensboro-Linden pipeline (Figure 6-3) is used to transport approximately 95 million gallons of refined petroleum products (gasoline, heating oil, diesel fuel, aviation fuels, and military fuels) to eastern states each day. This pipeline crosses the North Branch Patapsco River in the northern portion of the Liberty subwatershed, and travels southwest through the Beaver Run, Middle Run, Morgan Run, and Little Morgan Run subwatersheds. The former Colonial pipeline Finksburg Delivery Facility for refined petroleum products is inactive with no plans to reactivate it or the pipeline leading to it.

The Eldersburg area has less industrial and commercial land use than the Finksburg area. However, the proximity of Eldersburg to the main body of the reservoir, primarily the raw water intakes, makes it an area of concern.

Major commercial transportation routes include:

- Route 140, the major highway between Baltimore and Westminster that has a bridge over the northern end of Liberty Reservoir;

- Route 26, that has two bridges over Liberty Reservoir; one of which is within one mile of the City of Baltimore water intake; and

- Route 32 in the Eldersburg area.

The Maryland Midland Railway runs adjacent to the North Branch Patapsco River in the Finksburg area. The river is vulnerable to any spill along the railway.

6.2.4 Little Morgan Run Subwatershed

This watershed is mostly composed of pasture land, cropland, forest, and low-density residential land uses. Therefore, agricultural fields and septic systems are potential sources of non-point pollution. Limited areas of commercial development are located along Route 26.

Virtually no potential sources of contamination were uncovered during the database search (Table 6-2). One leaking underground storage tank open case and one superfund site are located in the subwatershed.

Commercial transportation routes within the Little Morgan run watershed include Route 26 along the southern subwatershed boundary and Route 97. Route 97 carries commercial traffic to and from Westminster and crosses Little Morgan Run near the headwaters.

6.2.5 Morgan Run Subwatershed

Major land uses within the Morgan Run subwatershed include cropland, forest, and low-density residential. Agricultural fields and septic systems are potential sources of non-point pollution. Much of the land surrounding Morgan Run in the middle portion of the subwatershed is parkland owned by the State of Maryland (Morgan Run Natural Environmental Area).

The database search revealed very few potential sources of contamination (Table 6-2). Two leaking underground storage tank open cases were identified.

Commercial transportation routes include Route 27 in the western headwater portion of the subwatershed, and Route 97. Both of these roads carry traffic to Westminster.

6.2.6 Middle Run Subwatershed

This subwatershed is composed mainly of cropland, forest, and low-density residential land uses. Potential sources of non-point pollution include agricultural fields and septic systems.

Very few potential sources of contamination were identified by the databases (Table 6-2). Three hazardous waste generators, three sludge application sites, and one automotive business were identified.

Route 91 is the only major commercial route that traverses the subwatershed. This route carries commercial traffic to and from Finksburg and links with Route 30.

6.2.7 Beaver Run Subwatershed

This subwatershed is composed mainly of cropland, forest, and low-density residential land uses (Table 6-3). Potential sources of non-point pollution include agricultural fields and septic systems.

Several potential sources of contamination were identified by the databases (Table 6-2). Six hazardous waste generators, four leaking underground storage tank open cases, and six automotive businesses were identified.

Routes 91 and 97 are the only major commercial routes that traverse the subwatershed. The Route 91 crossing is approximately 1,500 feet upstream of the reservoir. The TOT extrapolation in Section 5.4.3 (Table 5-4) indicates that a potential spill at this crossing during low-flow conditions would enter the reservoir within one hour of the incident. Thus, due to its proximity to the reservoir, this crossing is of concern.

6.2.8 Bonds Run Subwatershed

The Bonds Run subwatershed is the least developed in the Liberty Reservoir watershed (Table 6-3). It is mainly composed of cropland and forest. A potential source of non-point pollution is agricultural fields. A small amount of commercial land is present along Route 30 south of Hampstead.

The database search revealed several potential sources of contamination (Table 6-2). Four superfund sites, four hazardous waste generators, three leaking underground storage tank open cases, and five automotive businesses are clustered around Route 30.

Route 30 is the only major commercial route within this subwatershed. It skirts the eastern portion of the subwatershed boundary. Any potential spills would likely occur along this route.

6.3 Land Use Planning Concerns

The 1990 and 1997 land uses for the Liberty Reservoir watershed were summarized by subwatershed to identify changes in land use that could potentially affect the water quality of the reservoir or its tributaries (Table 6-3, Figure 6-7). The land use change percentages were determined using GIS by deriving the acreage of each land use type within each subwatershed for the years 1990 and 1997. The acreages for the 1990 and 1997 overlays were then compared to determine the percent change.

Two trends emerge from this analysis. Commercial and industrial land uses have increased surrounding Westminster, Hampstead, and Eldersburg, and conversion of agricultural land to residential land is ongoing in some subwatersheds. The highlighted cells in Table 6-3 illustrate these trends.

Commercial and industrial land use has increased from 1990 to 1997 surrounding Westminster, Hampstead, and Eldersburg (Figure 6-7). The increase in commercial and industrial land use surrounding Westminster has occurred in close proximity to the headwaters of the West Branch. The Hampstead area has also experienced increased growth in the headwaters of the East Branch along Route 482 and Route 30. Commercial and industrial land has also increased along Route 26 and Route 32 in Eldersburg.

Conversion of agricultural land to residential land is ongoing (Table 6-3). All subwatersheds except Bonds Run experienced a decrease in agricultural land (cropland and pasture) and an increase in residential land (low and medium-density residential) to varying degrees. The Beaver Run subwatershed experienced the greatest magnitude of this conversion in the Liberty Reservoir watershed. The amount of cropland decreased by approximately 7 percent from 1990 to 1997, while low-density residential land increased by nearly 7 percent. Similarly, agricultural land in the Middle Run and Little Morgan Run subwatersheds decreased by approximately 6 and 5 percent respectively, while residential land increased by approximately the same amount. Conversion of agricultural to residential land is occurring to a lesser extent in the North Branch, Morgan Run, and Liberty subwatersheds. The Bonds Run subwatershed does not appear to be developing.

The Reservoir Watershed Management Agreement, first signed in 1984, has been a powerful instrument to protect and improve the water quality of Liberty Reservoir, thereby protecting the drinking water for nearly 2 million people in the Baltimore metropolitan region. In recent years, Carroll County's Commissioners, as part of an effort to attract industry, have threatened to withdraw from the Reservoir Watershed Management Agreement. The Commissioners contended that the agreement unduly limited Carroll County's ability to develop according to the Commission's vision. The threat to withdraw and permit development in a manner inconsistent with the agreement raised serious concerns about the ongoing integrity of the water system. These concerns were shared by both the citizens of Carroll County and Baltimore City, as well as the other signatories of the Watershed Protection Committee. During the 2002 election cycle, new Commissioners were elected, based in part on their publicly stated intent to sign the Reservoir Watershed Management Agreement. Since their election, the new commissioners have restated their intent to continue to be an active member of the Watershed Protection Committee. This recommitment to working to protect and improve the water quality of Liberty Reservoir will undoubtedly benefit all of the interested parties.

Table 6-1: Potential Contaminant Databases and Land Use Coverages

Database	File Name (minus extension)	Type	Source Data	Shape Files Created By	Maintained By
Above Ground Storage Tanks (ASTs)	abgs-tanks.	vector/point	MDE	MDE	MDE
Agricultural NPDES	agriculture-npdes.	vector/point	MDE	MDE	MDE
Automotive Businesses	auto-business.	vector/point	CC	MDE	CC
Bulk Pesticide Dealers	bulk-pesticide-dealrs.	vector/point	MDA	MDE	MDE
CERCLA Sites	cercla sites.	vector/point	MDE	MDE	MDE
Hazardous Waste Generators	hazgens.	vector/point	MDE	MDE	MDE
Industrial NPDES	industrial-npdes.	vector/point	MDE	MDE	MDE
Junkyards	junkyards.	vector/point	CC	MDE	MDE
Landfills	landfill.	vector/point	MDE	MDE	MDE
Leaking Underground Storage Tank (LUST) Sites	lust-sites.	vector/point	CC	MDE	CC
Sludge Application Facilities	sludge-application.	vector/point	CC	MDE	CC
1990 Land Use	liberty-1990-lu.	vector/polygon	MDP	MDP	MDP
1997 Land Use	liberty-1997-lu.	vector/polygon	MDP	MDP	MDP

Abbreviations: MDE- Maryland Department of the Environment; CC- Carroll County; MDA - Maryland Department of Agriculture; BMC - Baltimore Metropolitan Council; MDP - Maryland Department of Planning

Table 6-2: Potential Contaminant Sources

Potential Contaminant Source Type	Subwatershed						
	Beaver Run	Bonds Run	Liberty	Little Morgan Run	Middle Run	Morgan Run	North Branch Patapsco
Hazardous Waste Generators	6	4	30	0	3	2	46
Junkyards	1	0	3	0	0	2	3
Landfills	0	0	0	0	0	0	1
Sludge Application Facilities	1	0		1	3	0	10
CERCLA Sites	1	4	2	1	0	0	3
Aboveground Storage Tanks (ASTs)	0	0	6	0	0	0	4
Leaking Underground Storage Tanks (LUST)	4	3	6	1	0	2	18
Industrial NPDES	0	1	6	0	0	1	5
Agricultural NPDES	0	1	0	0	0	0	0
Bulk Pesticide Dealers	0	0	1	0	0	0	4
Automotive Businesses	6	5	11	0	1	0	65

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act
NPDES: National Pollutant Discharge Elimination System

Table 6-3: Liberty Reservoir Land Use Change 1990-1997

Subwatershed	Beaver Run Land Use (%)			Bonds Run Land Use (%)			Liberty Land Use (%)			Little Morgan Run Land Use (%)		
Land Use Type	**1990**	**1997**	**% Change (+/-)**	**1990**	**1997**	**% Change (+/-)**	**1990**	**1997**	**% Change (+/-)**	**1990**	**1997**	**% Change (+/-)**
Barren Land	0.02	0.00	-0.02	0.00	0.00	0.00	0.09	0.19	0.10	0.75	0.00	-0.75
Commercial	2.30	3.44	**1.15**	1.25	1.62	0.37	1.57	2.17	0.60	0.40	0.64	0.24
Concentrated Agriculture	0.24	0.21	-0.04	0.32	0.32	0.00	0.20	0.21	0.01	0.00	0.00	0.00
Cropland	45.49	38.39	**-7.10**	61.95	55.79	-6.16	24.24	22.01	**-2.23**	37.39	31.96	**-5.43**
Extractive	0.18	0.13	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forest	26.38	27.09	0.71	18.39	27.57	9.18	44.00	41.91	-2.09	33.31	31.03	-2.27
High Density Residential	0.40	0.05	-0.36	0.00	0.00	0.00	0.29	0.24	-0.05	0.00	0.00	0.00
Industrial	0.00	0.12	0.12	1.55	1.80	0.24	0.46	0.82	0.36	0.68	2.00	1.32
Low Density Residential	13.80	20.55	**6.75**	10.16	7.72	-2.44	12.11	15.03	**2.92**	14.17	18.87	**4.69**
Medium Density Residential	4.20	5.46	**1.26**	0.00	1.06	1.06	2.17	2.83	0.67	0.49	3.62	**3.13**
Open Urban Land	0.22	0.45	0.23	0.08	0.09	0.00	0.54	0.80	0.26	0.35	0.00	-0.35
Pasture	6.66	4.00	**-2.65**	5.63	3.65	-1.98	5.12	4.35	**-0.77**	12.46	11.88	**-0.58**
Water	0.00	0.00	0.00	0.67	0.39	-0.27	9.15	9.44	0.29	0.00	0.00	0.00
Wetlands	0.13	0.11	-0.01	0.00	0.00	0.00	0.07	0.00	-0.07	0.00	0.00	0.00

Subwatershed	Middle Run Land Use (%)			Morgan Run Land Use (%)			North Branch Land Use (%)		
Land Use Type	**1990**	**1997**	**% Change (+/-)**	**1990**	**1997**	**% Change (+/-)**	**1990**	**1997**	**% Change (+/-)**
Barren Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial	0.00	0.17	0.17	0.37	0.51	0.14	3.89	5.16	**1.27**
Concentrated Agriculture	0.00	0.00	0.00	0.06	0.06	0.00	0.34	0.35	0.01
Cropland	55.78	50.07	**-5.71**	47.95	46.18	**-1.77**	47.64	43.73	**-3.91**
Extractive	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Forest	21.62	21.50	-0.13	30.70	28.95	-1.76	23.97	24.13	0.15
High Density Residential	0.09	0.00	-0.09	0.12	0.19	0.07	0.03	0.46	0.43
Industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.57	0.01
Low Density Residential	18.78	24.49	**5.71**	13.63	16.27	**2.64**	12.31	14.80	**2.50**
Medium Density Residential	0.00	0.28	0.28	0.05	0.93	0.88	1.30	3.25	**1.95**
Open Urban Land	0.00	0.29	0.29	0.05	0.03	-0.03	0.63	0.53	-0.10
Pasture	3.71	3.16	**-0.55**	7.07	6.88	-0.19	9.08	6.86	**-2.21**
Water	0.03	0.06	0.03	0.00	0.00	0.00	0.22	0.16	-0.06
Wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	-0.05

Note: Bold cells are indicative of the land use trends discussed in the text in Section 6.3.

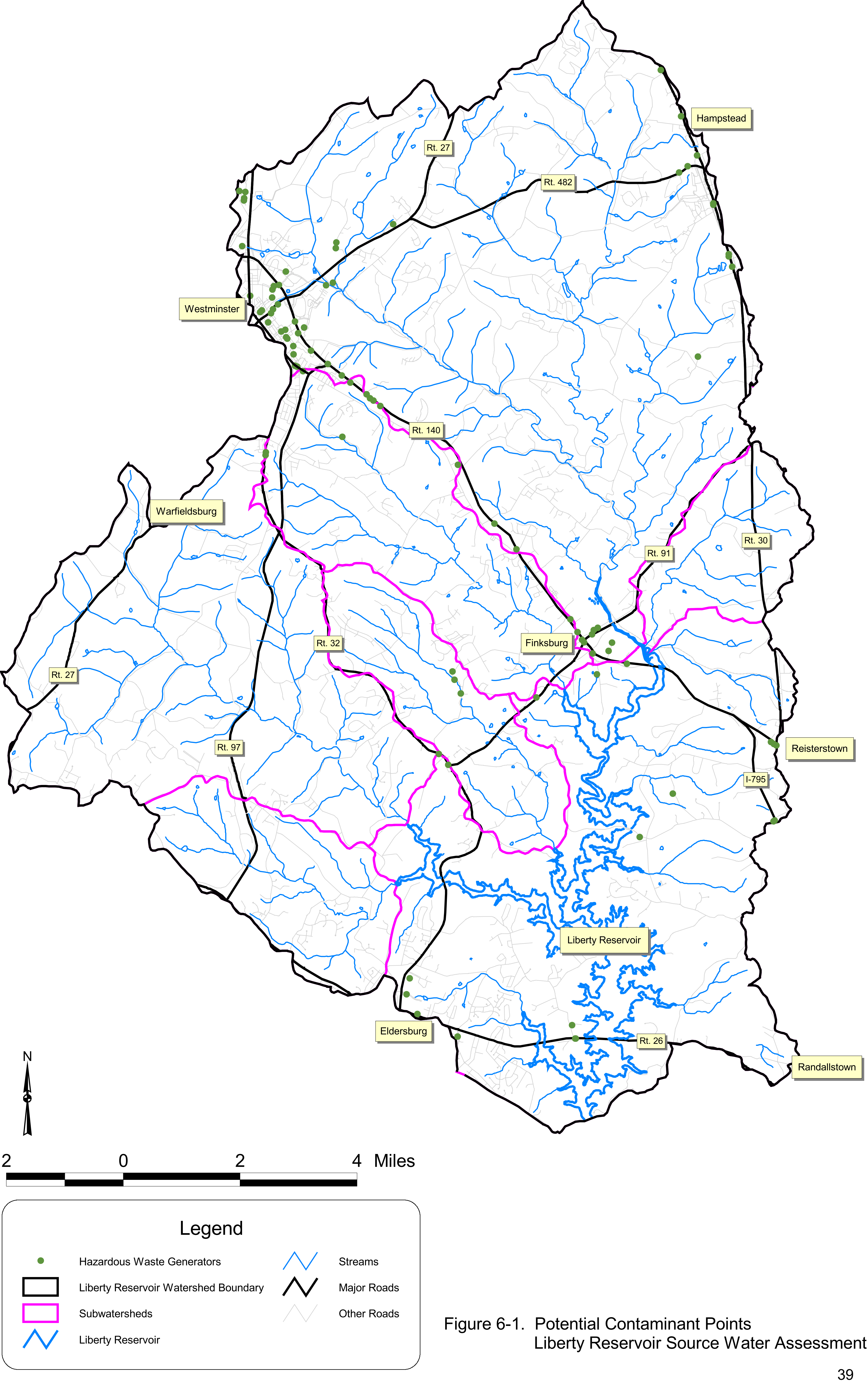


Figure 6-1. Potential Contaminant Points
Liberty Reservoir Source Water Assessment

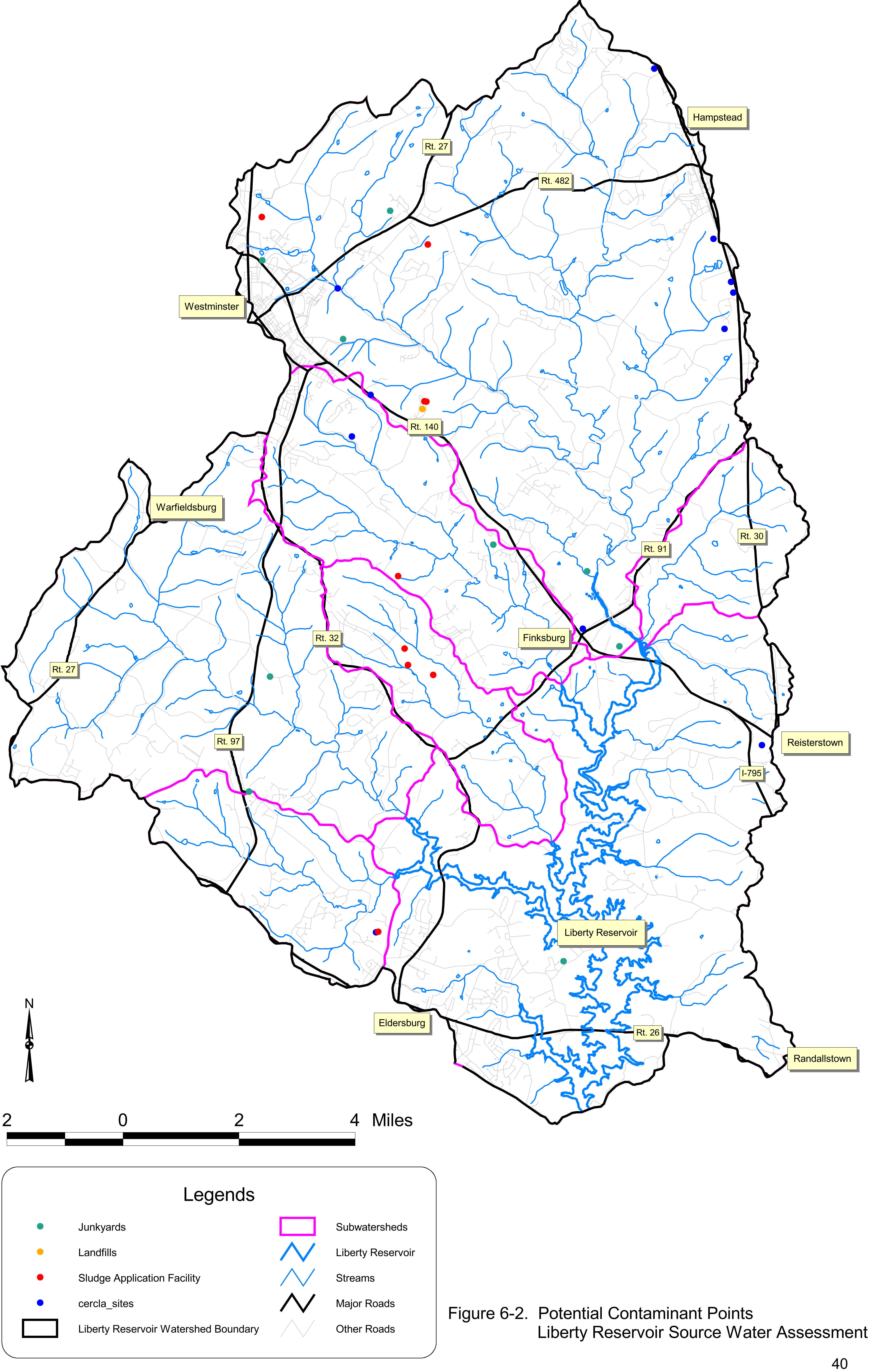


Figure 6-2. Potential Contaminant Points
Liberty Reservoir Source Water Assessment

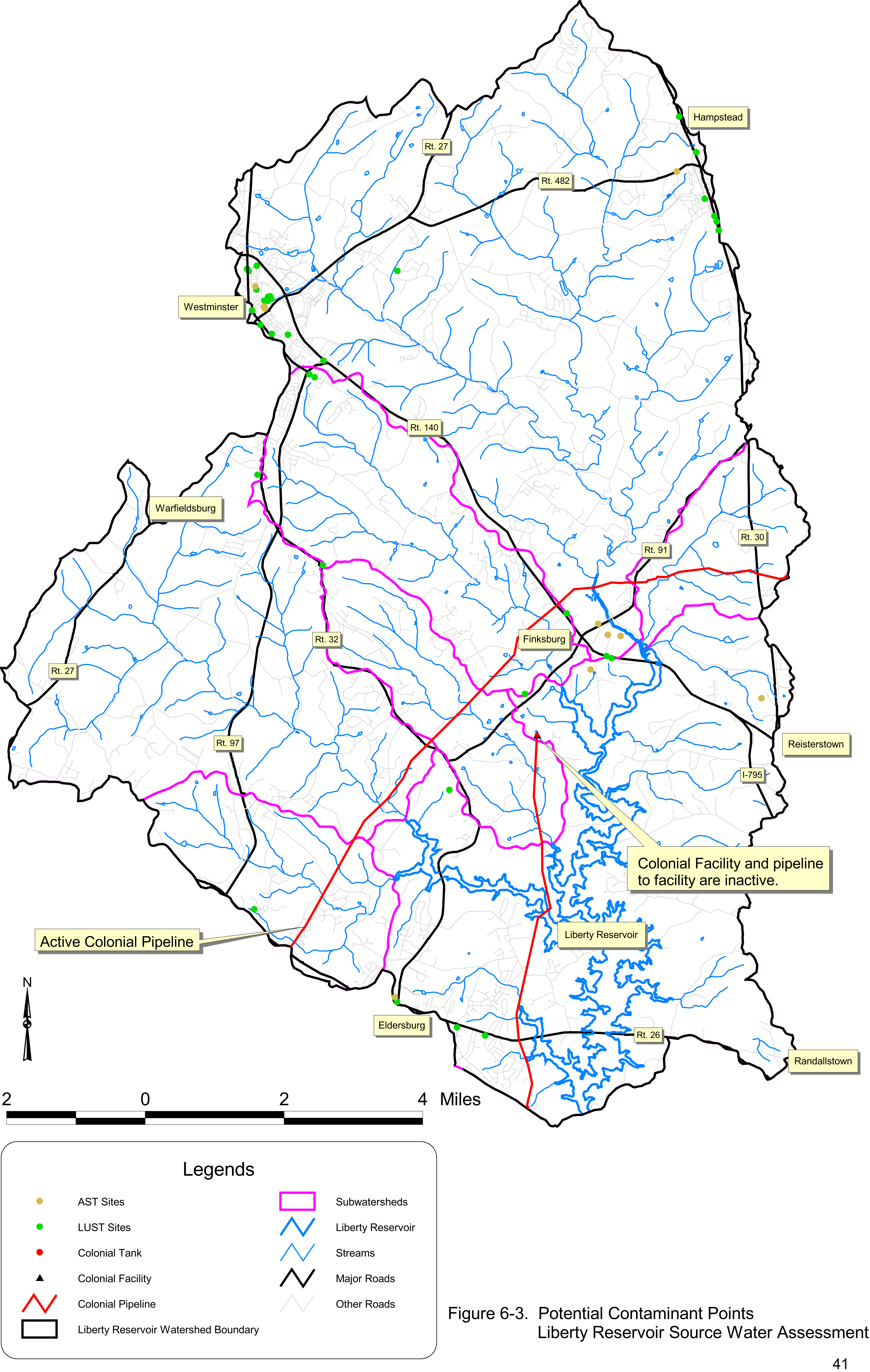


Figure 6-3. Potential Contaminant Points
Liberty Reservoir Source Water Assessment

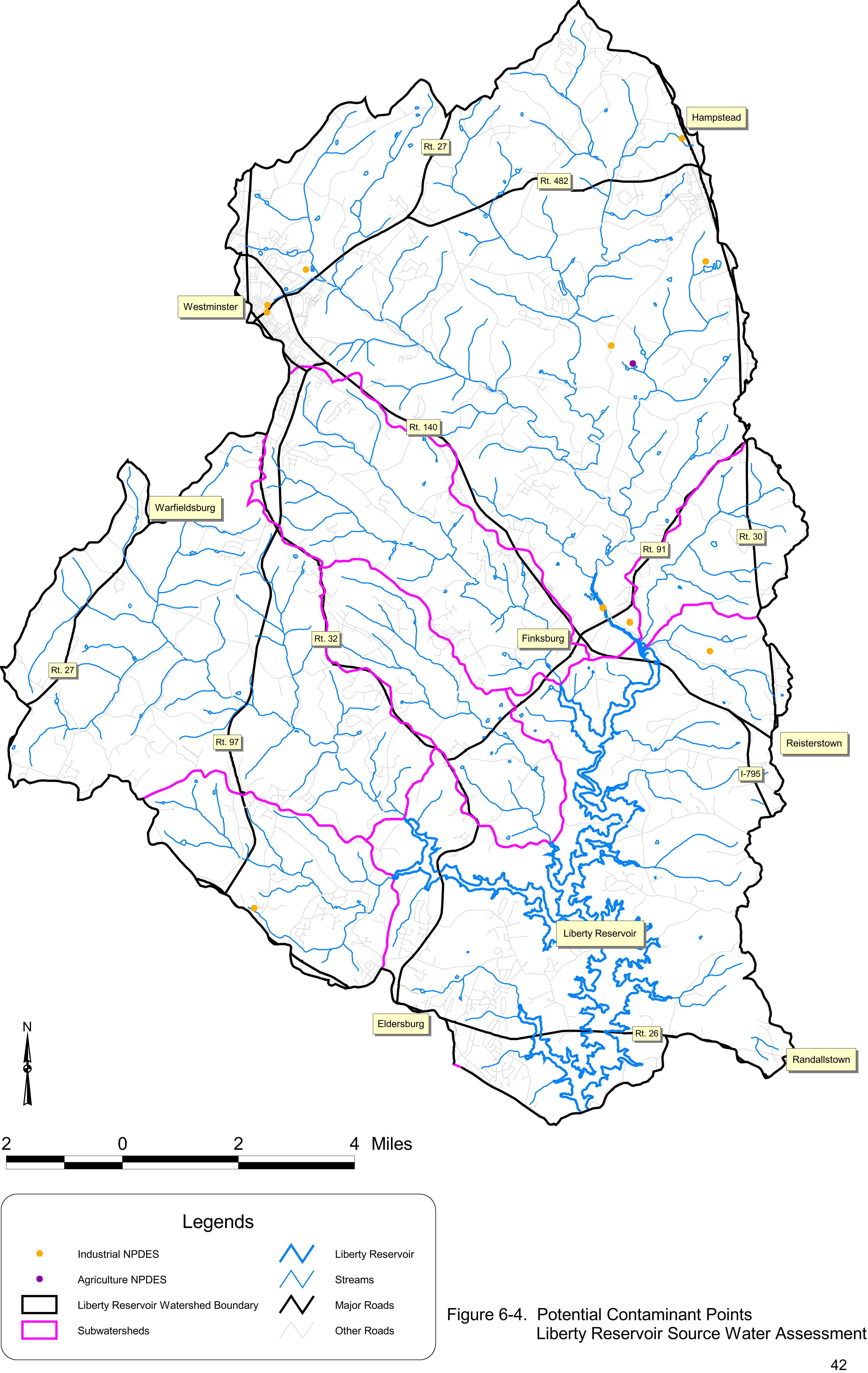


Figure 6-4. Potential Contaminant Points
Liberty Reservoir Source Water Assessment

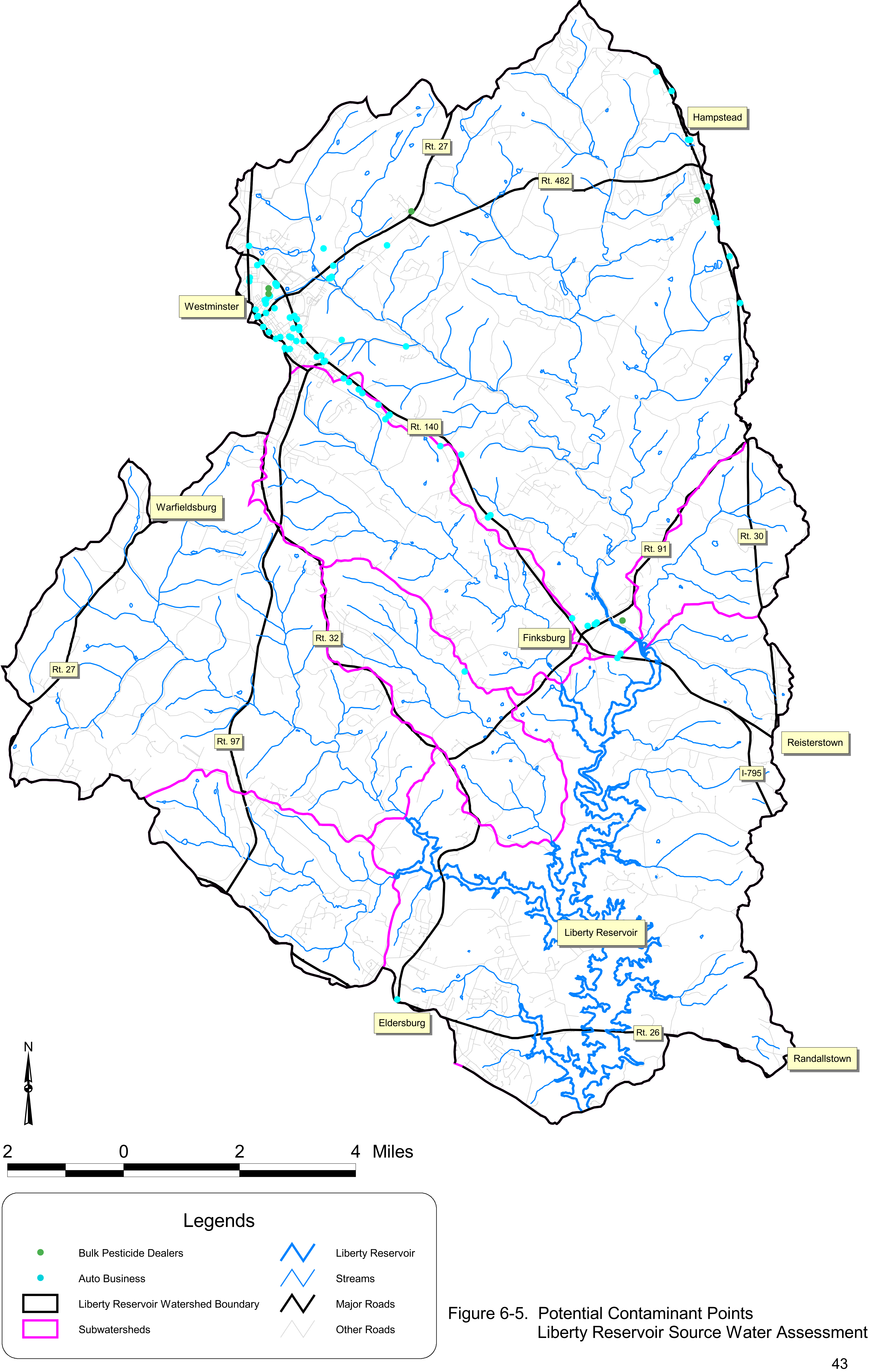
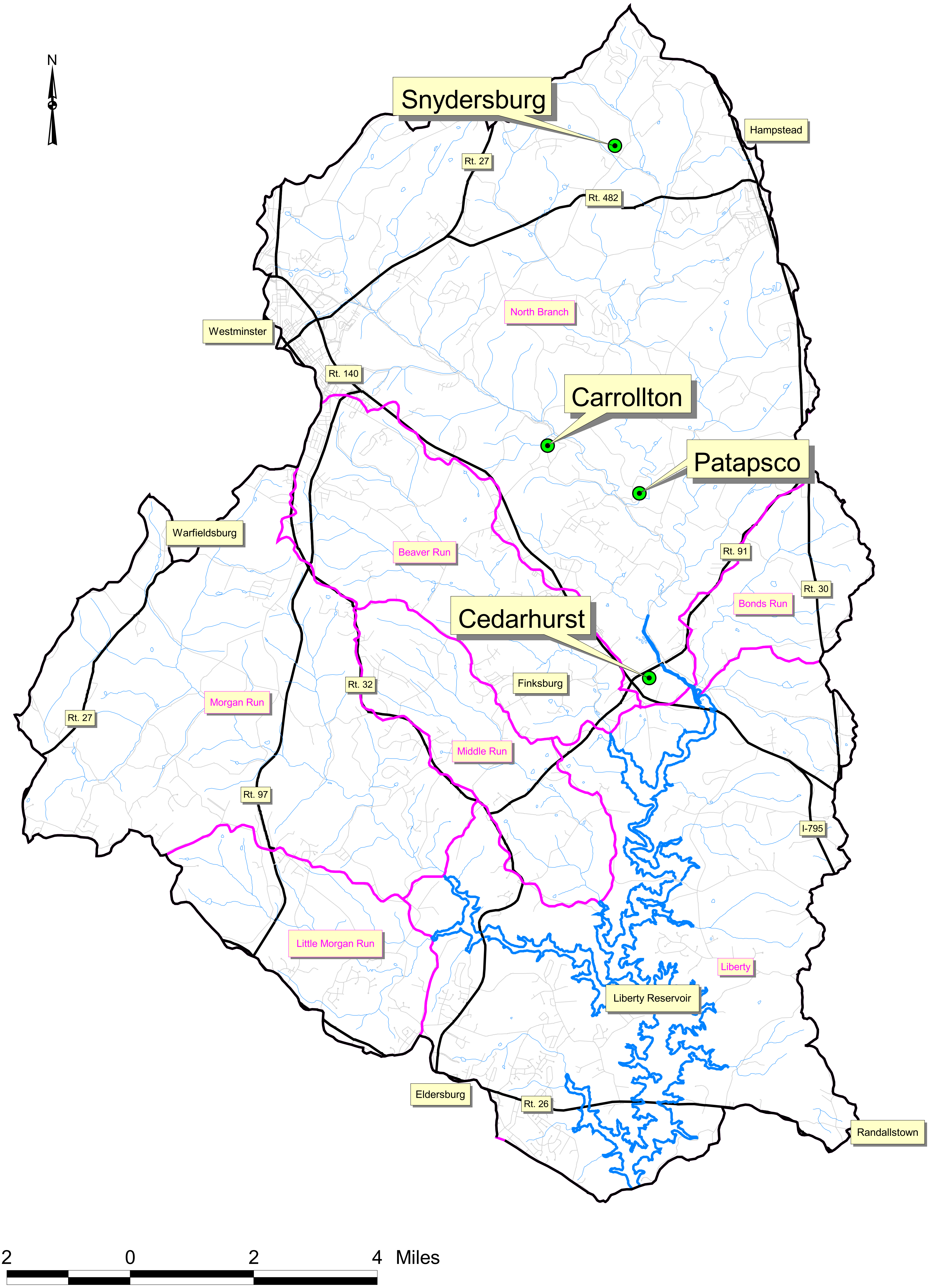


Figure 6-5. Potential Contaminant Points
Liberty Reservoir Source Water Assessment



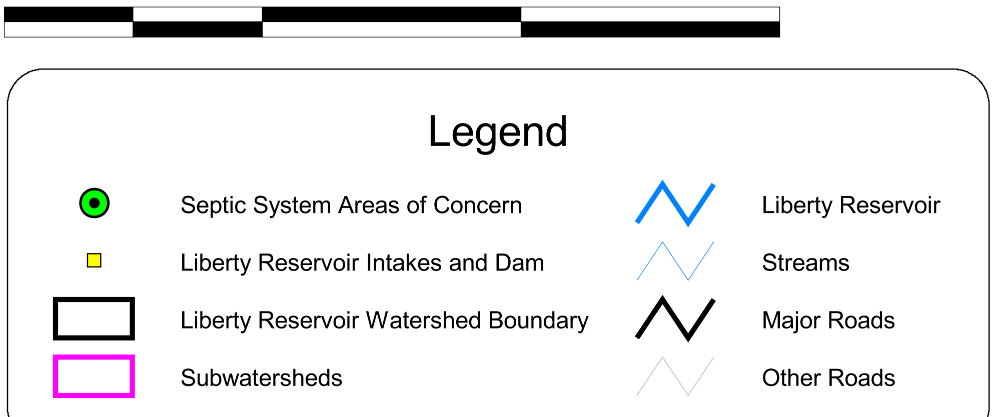
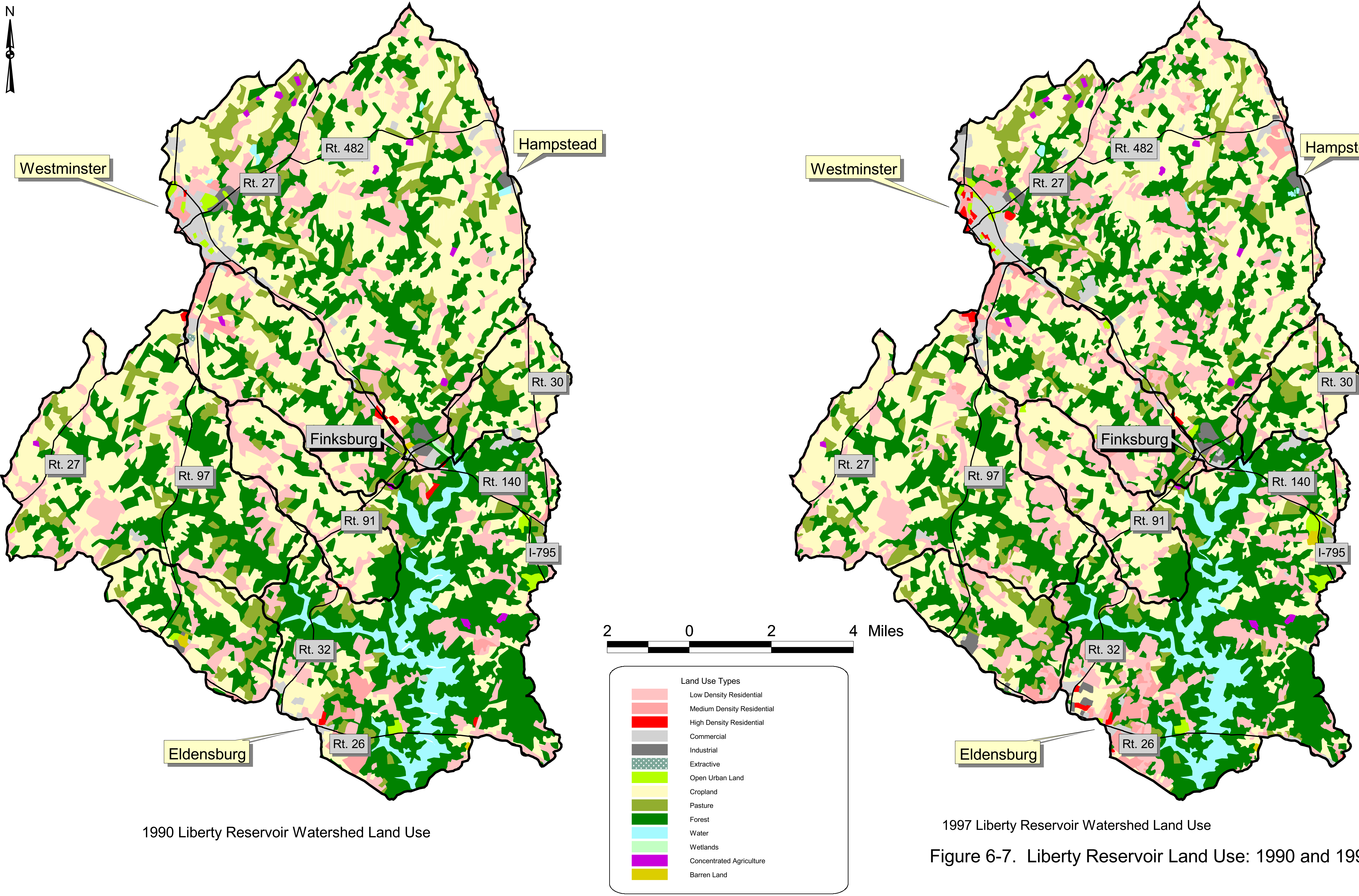


Figure 6-6. Septic System Areas of Concern
Liberty Reservoir Source Water Assessment



1990 Liberty Reservoir Watershed Land Use

1997 Liberty Reservoir Watershed Land Use

Figure 6-7. Liberty Reservoir Land Use: 1990 and 1997

7.0 REVIEW OF WATER QUALITY DATA

The City of Baltimore maintains an extensive water quality monitoring program for Liberty Reservoir. Routine sampling is performed at the following locations in an effort to monitor and improve the water quality conditions of the Liberty Reservoir water supply:

- Six tributaries to Liberty Reservoir;
- Four in-Reservoir monitoring locations; and
- Ashburton Water Treatment Plant raw and treated water.

Additional sources of water quality data reviewed were the MDE TMDL data and MDE historical data from EPA's STORET database system.

7.1 <u>Ashburton Treatment Plant Water Quality Monitoring</u>

The City of Baltimore analyzes raw and treated water at the Ashburton Water Treatment plant (Table 7-1). MDE periodically analyzes samples of the treated water (Table 7-1). Raw water samples are collected at the plant prior to treatment; treated water samples are collected after the water has passed through the treatment plant. Summaries of these data are provided in Tables 7-2a, 7-2b, 7-2c, and 7-2d, and are discussed in the following sections.

7.1.1 Volatile Organic Compounds

The City of Baltimore analyzes the treated water for the 21 regulated volatile organic compounds (VOCs) (i.e., those for which a maximum contaminant level [MCL] has been established) and approximately 32 additional VOCs. MDE has conducted annual sampling for VOCs since 1988.

In the last five years (1997 through 2001), no VOCs have been detected in the City of Baltimore samples. However, MDE sampling has detected three VOCs (bromodichloromethane, chloroform, and dibromochloroform), all of which are trihalomethanes (THMs), in the past five years. Table 7-2b provides the results for all MDE VOC detections since 1988. Therefore, with the exception of THMs, VOCs are not currently considered to be a concern. THMs are discussed in greater detail in the disinfectant by-products section below.

7.1.2 Synthetic Organic Compounds

The City of Baltimore analyzes the treated water for synthetic organic compounds (SOCs). MDE has conducted annual sampling of the treated water for SOCs since 1994. MDE also collected a sample of the raw water on July 17, 2000.

In the last five years (1997 through 2001), no SOCs have been detected in the City of Baltimore treated water samples, however, four SOCs [2,4-D; dalapon; di(2-ethylhexyl)adipate; and di(2-ethylhexyl)phthalate] were detected in the MDE treated water samples (Table 7-2b). None of these SOCs exceeded 50 percent of the MCL. Only di(2-ethylhexyl)phthalate was detected in MDE's July 17, 2000, raw water sample; it exceeded 50 percent of the MCL (3.9 µg/L compared to the MCL of 6 µg/L). The source of the di(2-ethylhexyl)phthalate is not known, however, di(2-ethylhexyl)phthalate is a common laboratory contaminant, and contamination by protective gloves often worn by sampling personnel is also common for this compound. Dalapon and 2,4-D are pesticides that were detected only at very low concentrations. Pesticides are likely to be present in spring runoff, which is the most likely source for these compounds.

These data indicate that semi-volatile organic compounds (SVOCs) are not currently a concern for the Liberty Reservoir source water.

7.1.3 Metals

The City of Baltimore analyzes the treated water for metals (aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, copper, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, sodium, thallium, and zinc), and MDE has conducted annual sampling for metals since 1993.

Metals have not been detected at concentrations exceeding 50 percent of the MCL in any of the City of Baltimore samples analyzed during the last four years (1998 through 2001) or in any of the MDE samples (1993 through 2001).

These data indicate that metals are not currently a concern for the Liberty Reservoir source water.

7.1.4 Other Inorganics / Physical

This category includes nitrate/nitrite, fluoride, cyanide, asbestos, and turbidity. Cyanide and asbestos are not analyzed by the City of Baltimore due to a MDE statewide waiver for these compounds.

Neither nitrate/nitrite nor fluoride exceeded 50 percent of the MCL during the last five years (1997 through 2001). Since 1993, MDE has analyzed samples annually for nitrate/nitrite and fluoride; neither nitrate/nitrite nor fluoride exceeded 50 percent of the MCL during this period.

EPA describes turbidity as a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms may be present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites, and some bacteria.

Turbidity is measured in the raw water at the Ashburton Plant on a daily basis. The monthly summary statistics for each month during the period 1996 through 2001 is presented in Table 7-2c. For the period 1996 through 2001 the average turbidity measured was 1.4 nephelometric turbidity units (NTU), the minimum turbidity measured was 0.37 NTU, and the maximum turbidity measured was 11.5 NTU.

As of January 1, 2002, the maximum allowable level for turbidity for the Ashburton Treatment Plant is 1.0 NTU, and 95 percent of the time it is required to be less than 0.3 NTU; previously the maximum value was 5 NTU and 95 percent of the time less than 0.5 NTU. Therefore, the average turbidity of the raw, untreated water exceeds the current maximum allowable level. Although the turbidity of the raw water is low, filtration is required to achieve the maximum allowable level.

Therefore, of the inorganics / physical parameters, only turbidity is a current concern. Turbidity is discussed further in the susceptibility analysis section (Section 8) and the recommendations section (Section 9).

7.1.5 Protozoa, Viruses, and Total/Fecal Coliform

Cryptosporidium and *Giardia lamblia* are protozoans that can cause gastrointestinal illnesses in humans. These protozoans are analyzed monthly in the Ashburton Treatment Plant treated water by EPA Method 1623; neither has been detected during the past five years during the City's monthly sampling program (1997 through 2001).

The City of Baltimore collected monthly *Cryptosporidium* and *Giardia lamblia* samples from July 1997 through December 1998 (18 monthly samples) for EPA's Information Collection Rule (ICR). In April 1998, 8 empty *Giardia lamblia* cysts per 100 liters were identified, and in September 1998, 14 amorphous *Cryptosporidium* oocysts per 100 liters were identified. Empty cysts and amorphous oocysts are generally considered to be nonviable, however, the results do indicate that *Cryptosporidium* and *Giardia lamblia* are present in the Liberty Reservoir watershed. Sampling conducted for the SWA identified low concentrations of these pathogens in tributaries to the reservoir. The presence of these pathogens in the watershed is to be expected because they are present in most natural waters.

Total coliform and fecal coliform monitoring tests are performed on the raw water at Ashburton on a daily basis. A summary of the monthly average, median, maximum, and minimum concentrations for total and fecal coliform concentrations during the period 1996 through 2001 are presented in Table 7-2c.

Overall, these data indicate that Liberty Reservoir has a relatively high quality relating to bacterial concentrations. Some of the high concentration entries might be associated with storm events. However, no attempt was made in this study to correlate the data with storm events.

The Ashburton Treatment Plant is not required to analyze for viruses.

7.1.6 Radionuclides

Radionuclides in the treated water are analyzed every four years. The levels detected have been within MDE requirements, therefore, radionuclides are not currently considered to be a concern.

7.1.7 Disinfection Byproducts and Disinfection Byproduct Precursors

The City of Baltimore has been monitoring disinfection byproducts (DBPs) in Ashburton Treatment Plant treated water to monitor compliance with the Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) (Table 7-2d). The DBPs are total trihalomethanes (TTHMs) and haloacetic acids (HAA). In addition, disinfection byproduct precursors (DBPPs) have been monitored in the raw and treated Ashburton Treatment Plant water; total organic carbon has been used as a surrogate for DBPPs (Table 7-2d).

All of the reported TTHMs and HAA analyses at the Ashburton Treatment Plant effluent in the past five years were less than the MCLs set by EPA. However, the concentrations of these compounds increases within the distribution system. A third quarter average TTHM concentration from remote sampling points within the distribution system was 76 :g/L (City of Baltimore, 1998).

7.2 Watershed Water Quality Monitoring

The City of Baltimore regularly monitors water quality in tributaries discharging into the reservoir as well as the water quality within the reservoir itself. A description of the monitoring is provided in the following sections.

7.2.1 City of Baltimore Water Quality Monitoring Program for Tributaries Stations

Tributary sampling is conducted by the City of Baltimore. The sampling program is designed to collect data to:

- Estimate loads entering the reservoir;
- Look for changes over time; and
- Look for seasonal cycles.

Six City of Baltimore tributary monitoring stations are located within the Liberty Reservoir watershed (Figure 7-1):

- Beaver Run (Station BEA0016) (near USGS gaging station) (baseline and storm);
- Morgan Run (Station MOR0040) (near USGS gaging station) (baseline and storm);
- North Branch Patapsco River (Station NPA0165) (near USGS gaging station) (baseline and storm);
- Little Morgan Run (Station LMR0015) (not gaged) (baseline only);
- Middle Run (Station MDE0026) (not gaged) (baseline only); and
- Bonds Run (Station UZP0002) (not gaged) (baseline only).

From the years 1981 to 1993, water samples were collected on a monthly basis from the six tributary monitoring stations during non-storm and storm events; sampling during storm events was specifically targeted to collect data representative of storm events that result in high tributary discharges. For the period from 1994 to 2001, sample collection did not specifically target storm events, therefore, data for the higher discharge periods are incomplete. Targeted storm event sampling was recently reinitiated.

7.2.1.1 Tributary Sampling Design

The following sampling activities are conducted during dry weather monitoring:

- Samples are collected by staff from the Reservoir Natural Resources Section;

- Low-density polyethylene bottles are used to collect a grab sample from the stream flow;

- A Hydrolab Surveyor III portable water quality meter is immersed in the stream to measure the water temperature, pH, conductivity and dissolved oxygen;

- A portable thermometer is used to measure air temperature;

- The proper weather code for the day samples are collected and for the prior day is recorded;

- The stream height according to the station's gage is recorded for USGS gaged tributaries; at the other tributary stations, measurements were sometimes collected by City personnel using a Pygmy flow meter at the time a sample was collected; and

- Samples are delivered to the Water Quality Lab at Ashburton on ice within a few hours of the time of collection.

The following sampling activities are conducted during wet weather monitoring:

- Samples are collected by staff from the Water Quality Management Section and/or the Reservoir Natural Resources Section;

- The field team assembles several ISCO 2700 automated samplers prior to the storm with the sampler base filled with ice. The sampler is programmed to collect a one-liter sample each hour beginning after a set time has elapsed or when an ISCO 1640 actuator set above the surface of the stream becomes immersed;

- Discharge was obtained from USGS for the three tributary stations continuously monitored by the USGS; at the other tributary stations, measurements were sometimes collected by City personnel using a Pygmy flow meter at the time a sample was collected;

- Samples are delivered to the Water Quality Management Section on ice within 24 hours of the time they were taken. Samples are chosen for analysis based on where on the storm hydrograph they were taken. These samples are prepared for transfer to the proper lab for analysis; and

- Infrequently, samples are collected manually when there is insufficient time for sampler assembly.

7.2.1.2 Tributary Sampling Analytical Parameters for Dry Weather Monitoring

Table 7-1 provides a summary of the parameters measured and analyzed for the tributary monitoring program. The following parameters are measured in the field with portable instruments during the dry weather monitoring:

- Air temperature in degrees Celsius;
- Water temperature in degrees Celsius;
- Conductivity in μmhos/cm;
- Dissolved oxygen in mg/L; and
- pH.

The following parameters are measured in the Water Quality Lab at Ashburton for dry weather monitoring events:

- Alkalinity in mg/L;
- Chlorides in mg/L;
- Ammonia-nitrogen in mg/L;
- Nitrite-nitrogen in mg/L (no longer analyzed);
- Nitrate-nitrogen in mg/L;

- Nitrite-plus-nitrate-nitrogen in mg/L (no longer analyzed);
- Dissolved phosphorus in mg/L (no longer routinely analyzed);
- Total phosphorus in mg/L;
- Dissolved solids in mg/L;
- Suspended solids in mg/L; and
- Turbidity in NTU.

The following parameters are calculated by personnel in the Water Quality Lab at Ashburton:

- Dissolved oxygen percent saturation; and
- Total solids in mg/L.

The following parameters are sometimes measured by the Water Quality Management Office personnel in their lab:

- Suspended solids in mg/L;
- Chlorophyll-a in µg/L; and
- Conductivity in µmhos/cm.

7.2.1.3 Tributary Sampling Analytical Parameters for Wet Weather Monitoring

The following parameters are measured by personnel in the Water Quality Management lab for wet weather monitoring events:

- Conductivity in µmhos/cm; and
- Suspended solids in mg/L.

The following parameters are measured by personnel from the Water Quality Lab at Ashburton on only those samples indicated by the Water Quality Management section:

- Ammonia-nitrogen in mg/L;
- Nitrite-nitrogen in mg/L (no longer analyzed);
- Nitrate-nitrogen in mg/L;
- Nitrite-plus-nitrate-nitrogen in mg/L (no longer analyzed);
- Dissolved phosphorus in mg/L; and
- Total phosphorus in mg/L.

7.2.2 City of Baltimore Water Quality Monitoring Program for In-Reservoir Monitoring Stations

Water quality samples have been collected on a monthly schedule from Liberty Reservoir since 1981. Readings are used by Water Facilities personnel to check for signs of algae blooms or other problems that may result in water treatment difficulties. The data are entered by Water Quality Management Section personnel into a database for long-term trend analyses. The four in-reservoir monitoring stations are as follows (Figure 7-1)

- Station NPA0042 is located at the Liberty Gatehouse and is sampled monthly from November through April and twice monthly from May through October. The maximum depth sampled is approximately 105 feet;

- Station NPA0059 is located mid-channel at the eastern Liberty Road Bridge (MD Route 26). This station is only accessible by boat and is sampled monthly in April and November and twice monthly from May through October. The maximum depth is approximately 120 feet;

- Station NPA0067 is located at the end of the Freedom District Water Treatment Plant intake pipe. This station is only accessible by boat and is sampled monthly in April and November and twice monthly from May through October. The maximum depth at the intake is approximately 95 feet; and

- Station NPA0105 is located mid-channel at the Nicodemus Road bridge and is sampled monthly from November through April and twice monthly from May through October. The maximum depth is approximately 60 feet.

7.2.2.1 In-Reservoir Sampling Design

The sampling program has evolved over the years. The following sampling pattern has been established over the past several years for all stations within Liberty Reservoir:

- Readings are taken using the Hydrolab Surveyor III at five foot intervals starting from the surface until a depth of 60 feet; thereafter, readings are taken every ten feet until the bottom is reached (readings from the bottom are not entered into the database);

- A sample is collected every ten feet starting from the surface until a depth of 50 feet for chlorophyll-a analysis; and

- Samples for chemical and algal analyses are collected at station NPA0042 at the surface, 10 feet below, at elevation 365 (to correspond with the 55-foot deep intakes), and at elevation 320 (to correspond with the 100-foot deep intakes); for stations NPA0059 and NPA0067 at the surface, 10 feet below, 20 feet below, 40 feet below, and 80 feet below; and for station NPA0105 at the surface, 10 feet below, 20 feet below, and 40 feet below.

7.2.2.2 In-Reservoir Sampling Method

The sampling method for collection of in-reservoir samples is as follows. The depths at which samples will be collected are chosen, and the sample bottles are labeled before the team arrives at the station. Staff of the Reservoir Natural Resources Section either take a boat or position themselves on a bridge or cat-walk at the sampling station. They radio personnel at the Water Facilities Telemetry group to ask for the current water surface elevation for the reservoir at the dam. A code for that day's and the prior day's weather is chosen from the weather index. A thermometer is set in an appropriate position to measure the air temperature. The Secchi disk is lowered on a graduated cable into the water until it can no longer be seen and the length of cable is recorded. The Hydrolab is lowered to the proper depth using its depth sensor's read-out. Between the surface and 60 feet below, readings for water temperature, dissolved oxygen, pH, and conductivity are taken every five feet; thereafter they are taken every ten feet until the bottom is reached. A Kemmerer sampling bottle on a graduated cable is lowered to the appropriate depth to retrieve a sample. This is repeated until all the samples for that station are taken. Samples are delivered on ice within a few hours to the Water Quality Lab at Ashburton.

7.2.2.3 In-Reservoir Sampling Parameters

In the field, the following parameters are measured using portable meters:

- Sample depth in feet;
- Air temperature in degrees Celsius;
- Secchi disk depth in feet;
- Water temperature in degrees Celsius;
- Dissolved oxygen in mg/L;
- pH;
- Conductivity in µmhos/cm; and
- Chlorophyll-a is measured by the lab personnel of the Water Quality Management Office.

The samples collected at Liberty Reservoir are analyzed at the Water Quality Lab at Ashburton. The personnel at this lab calculate percent saturation of dissolved oxygen for all the samples submitted based on the field measurement of dissolved oxygen at the same depth the sample was taken. All of the parameters mentioned below are analyzed for each of the samples from station NPA0042. The following pattern generally holds for the other three stations whenever they are sampled:

- The following parameters are measured for all samples submitted: dissolved solids in mg/L; ammonia-nitrogen in mg/L; nitrite-plus-nitrate-nitrogen in mg/L (no longer analyzed); nitrate-nitrogen in mg/L; total phosphorus in mg/L; and turbidity in NTU;

- The following parameters are measured for only samples from the surface at each station: chlorides in mg/L; alkalinity in mg/L; hardness in mg/L; manganese in mg/L; and iron in mg/L; and

- The total algae count (number per 100 ml) is measured only for samples from the surface and 10 feet below surface at each station.

7.2.3 Review of Data from the City of Baltimore's Tributary Monitoring Program

The City of Baltimore Comprehensive Plan (City of Baltimore, 1998) reported a summary of the comprehensive reservoir water quality assessment. The results of dry weather flow tributary monitoring for the period 1981 through 1994 revealed that most stations exhibited increasing levels over time for nitrate-nitrogen, dissolved solids, chlorides, and conductivity, with the remainder exhibiting no trend (Table 7-3). However, except for Beaver Run, the tributaries exhibited decreasing total phosphorus (TP) levels, which was consistent with decreasing phosphorus levels observed within the reservoir. The assessment also indicated that TP loads were dominated by stormwater runoff loads.

7.2.3.1 Nitrogen and Phosphorus – Tributary Loads and Trends

The nutrients nitrogen and phosphorus are an identified concern to water quality in Liberty Reservoir. Table 7-4 was created using data collected from 1981 through 1993. Table 7-4 clearly indicates that a large proportion of both dissolved phosphorus and total phosphorus enter the reservoir during storm events. Total phosphorus concentrations measured during storm sampling events are generally an order of magnitude greater than the total phosphorus concentrations measured during dry weather sampling events, and dissolved phosphorus concentrations tend to be more than four times higher during storm sampling events than during dry weather sampling events. During dry weather, the dissolved phosphorus comprised approximately 80 percent of the total phosphorus, however during storm events dissolved phosphorus comprised only from 5 to 35 percent of total phosphorus. Dissolved phosphorus tends to be a more readily available nutrient source for plant growth than phosphorus that is bound in particulate matter (i.e., that portion of total phosphorus that is not dissolved).

In contrast to phosphorus, the nitrate/nitrite-N concentrations tended to be lower during storm events than during conditions. The growth of plants and algae in Liberty Reservoir is known to be highly limited by the amount of the nutrient phosphorus that is available. The tributary data indicate that total and dissolved phosphorus inputs are very low relative to nitrate/nitrite-N.

These data confirm the continued phosphorus limited status of waters tributary to Liberty Reservoir, and indicate that stormwater runoff is a primary source of phosphorus to Liberty Reservoir. Therefore, good stormwater management practices are critical to maintain or improve the water quality in the reservoir.

7.2.3.2 Total Dissolved Solids, Chloride, and Conductivity – Trends

Total dissolved solids (TDS), chloride, and conductivity are water quality parameters that are useful as surrogates for unmonitored contaminants, and are general indicators of overall water quality. The chemicals measured as TDS frequently originate from the same sources as chemicals that are not desirable in a drinking water supply. It is not feasible to measure all undesirable chemical compounds that may potentially be entering surface waters, therefore, these parameters are used as indicators of whether unwanted compounds may be present, or if changes in water quality have occurred. Increases in the levels of these parameters may indicate unwanted chemicals are entering the surface water.

TDS is a measure of any minerals, salts, metals, cations and anions dissolved in water. These are inorganic salts (primarily calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some dissolved organic compounds. Examples of sources of TDS in surface waters include natural sources as well as human sources such as industrial wastewater, domestic sewage, urban run-off, stormwater, agricultural runoff, salts for road de-icing. Conductivity measures the extent to which water can transmit an electrical current. Generally, the more TDS in water the higher the conductivity, therefore, conductivity is a measure of TDS. Chlorides are one group of compounds measured in the TDS analysis. Chlorides in surface water come from sources such as chlorides dissolved from rocks, road salting, agricultural runoff, industrial wastewater, and domestic wastewater.

As stated above, the results of dry weather flow tributary monitoring for the period 1981 through 1994 revealed that most stations exhibited increasing levels over time for dissolved solids, chlorides, and conductivity, with the remainder exhibiting no trend (Table 7-3). An increasing trend in these parameters is an early warning that changes are occurring. These changes may or may not be detrimental or a significant concern. The trend may indicate undesirable compounds, that have not yet detected, may be slowly increasing in concentration in the tributaries.

7.2.4 Review of Data from the City of Baltimore's In-Reservoir Monitoring Program

7.2.4.1 City of Baltimore Comprehensive Reservoir Water Quality Assessment

The City of Baltimore's Comprehensive Plan (City of Baltimore, 1998) summarized the results of a comprehensive reservoir water quality assessment that involved over 20,000 samples analyzed for multiple water quality parameters (City of Baltimore, 1996). The following summary is from the Comprehensive Plan.

Nutrient conditions and algal growth in the reservoirs, water quality trends from the last decade, and water quality data from the hypolimnion were all presented in this report. Parameters investigated beginning in 1981 included total phosphorus, total algal counts, Secchi disk depth, chlorophyll-a, ammonia, nitrate-nitrogen, conductivity, manganese, iron, dissolved oxygen, color, turbidity, and pH.

Epilimnetic and hypolimnetic water quality data from the reservoir sampling stations are summarized in Table 7-5. The results of the comprehensive reservoir water quality assessment reported several key findings which are summarized as follows:

- Water quality improved longitudinally along the reservoir with poorer water quality observed at the upper sampling stations;
- Reductions in total phosphorus have been occurring in the epilimnion since the early 1980's but appeared to be leveling off. Total phosphorus levels in the hypolimnion were still declining. However, for some years, Liberty Reservoir exhibited higher total phosphorus concentrations in the hypoliminion implying phosphorus releases from the anoxic sediments;
- Total algal counts declined substantially during this period while chlorophyll-a levels remained at low concentrations;
- Water clarity had been improving at Liberty Reservoir based on historical Secchi disk measurements; and
- Late summer and fall hypolimnetic dissolved oxygen measurements taken at Liberty Reservoir showed substantial improvement between 1986 and 1993, however a gradual increase in dissolved solids (as indicated by specific conductance) has been observed.

In addition, the reservoir trophic classification was assessed in the assessment report using Carlson's TSI model that produces a numeric trophic rating criteria from measured TP, chlorophyll-a, and Secchi disk depths levels. A description of the meaning of values calculated by this model is provided in Table 7-6. Using growing season data for TP and chlorophyll-a, it was determined that the percent of samples classified as eutrophic (TSI > 50) at the four in-reservoir sampling stations was estimated to be 4, 5, 8, and 35 percent based on TP and 6, 9, 13, and 34 percent based on chlorophyll-a. The higher eutrophic state reflects water quality conditions at the upper sampling station. Depending on which water quality parameter is utilized, the TSI for Liberty Reservoir predominantly falls between 30 and 50, except at the upper sampling station.

7.2.4.2 Data for 1981 – 1997: City of Baltimore Comprehensive Plan Water Quality Evaluation

Seasonal reservoir water quality trends for the period 1981 through 1997 were described in Section 4.5 of the Comprehensive Plan for Water Facilities (City of Baltimore, 1998); Section 4.5 of the Plan is provided in Appendix A. For the Comprehensive Report, water quality trending data were developed for Liberty Reservoir using turbidity, color, total algae count, chlorophyll-a, dissolved oxygen and manganese data to complete a seasonal trend analysis. The seasonal trends described in Appendix A, and below, are for the combined data of Stations NPA0042 and NPA0059 and are from the Comprehensive Report:

Turbidity: Turbidity reaches its greatest value at multiple depths in November and December at the end of thermal stratification. Turnover begins in December and turbidity at all depths increases because the layers of the reservoir are once again permitted to mix. Then turbidity values drop through April while the reservoir is homogeneous and algae growth minimal. When surface waters warm in late spring and thermal stratification has started, turbidity levels drop to their lowest values and remain low through August until deeper water quality conditions decline.

Color: The seasonal trend of color is similar to that of turbidity but is not as clearly defined. This could be a result of the low color values.

Total Algae Count and Chlorophyll-a: Both the Total Algae Count and the chlorophyll-a average monthly analytical results reveal comparable seasonal trends due to the peak algae growing season. Higher total algae counts occur predominantly during August through October in the upper 30 feet of the reservoir. Chlorophyll-a concentrations increase during these months as well, with peak concentrations occurring in waters of 20 to 30 feet. Increased algae growth is observed during March through May as well.

Dissolved Oxygen: Homogeneous waters from January through April produce an evenly distributed oxygen filled reservoir. In May, when thermal stratification begins, dissolved oxygen levels start declining in lower layers. By September and October, rapid reduction of dissolved oxygen has occurred as shallow as 30 feet due to excess decaying algae depleting available oxygen. Normal conditions resume when turnover occurs in December and dissolved oxygen levels rise at all depths of the reservoir.

Manganese: Manganese concentrations increase in the hypolimnion beginning in August. This is consistent with the anoxic conditions that develop in the deeper waters. Manganese concentrations in the surface waters peak in December as turnover occurs.

7.2.4.3 Data for 1994 – 2001: Source Water Assessment Water Quality Evaluation

Turbidity

Turbidity was measured at Station NPA0042 near the intake in 427 samples during the period 1994 through 2001. Turbidity exceeded 1.0 NTU in 287 of these samples. The higher turbidity measurements tended to be for samples collected at the deeper sampling locations; 18 of the 20 samples that exceeded 4 NTU were collected from a depth of 80 feet or more. Ten of the twenty turbidity readings exceeding 4 NTU occurred in November and January; the remainder were in samples collected from September through March. The middle gates (elevation 365) are at 55 feet below the crest elevation of the reservoir.

Dissolved Oxygen, Chlorophyll-a, Manganese, Total Algae Count, and Total Phosphorus, Nitrate/Nitrite

For this Liberty Reservoir SWA, the data for dissolved oxygen, chlorophyll-a, manganese (Station NPA0042 only), total algae count, total phosphorus and nitrate/nitrite-nitrogen for the years 1994 through 2001 were compiled and graphed for the four in-reservoir stations: Station NPA0042 (Figures 7-2a through 7-2f), Station NPA0059 (Figures 7-3a through 7-3e), Station NPA0067 (Figures 7-4a through 7-4e), and Station NPA0105 (Figures 7-5a through 7-5e).

The seasonal trends for dissolved oxygen, chlorophyll-a, manganese (Station NPA0042 only), and total algae count for 1994 through 2001 data are similar to those described above (also see Appendix A) in the Comprehensive Plan for Water Facilities (City of Baltimore, 1998). The trend for improved water quality as one moves from the upper stations (Stations NPA0067 and NPA0105) to the lower stations (Stations NPA0042 and NPA0059) is evident, as it was during comprehensive reservoir water quality assessment utilizing data through 1997.

The growth of algae in Liberty Reservoir is limited by the amount of the nutrient phosphorus that is available, whereas nitrate-nitrogen is present in excess of algal growth requirements. Station NPA0105 illustrates the relationships between the nutrients phosphorus and nitrogen, and algal growths (represented by chlorophyll-a and the total algae count) (Figures 7-5b through 7-5e).

Chlorophyll-a and total algae count data indicate there are two peak periods of algae growth, one in the spring (February, March, and April) and one in late summer/early fall (August, September, and October) (Figures 7-5b and 7-5c). During the first growth period, total phosphorus is slowly depleted in the upper 30 feet, which is the region of the highest algal growth during February, March, and April (Figure 7-5d), whereas the available nitrate-nitrogen remains high (Figure 7-5e). Only a portion of total phosphorus is typically utilizable by algae. For instance, phosphorus bound in particulate material is not directly available to algae. Therefore, when total phosphorus concentrations are low, there may be very little or no phosphorus available to support additional algal growth; the supply of phosphorus is limiting the ability of more algae to grow. There is then a decrease in algae during May and June, followed by the second algal bloom in August through approximately October. The total phosphorus concentrations remain low during this period, and a reduction in the nitrate/nitrite-N concentration is also evident, although the supply of nitrogen remains in excess of that needed to support algal growth.

The spring bloom is in response to the complete mixing of the reservoir during the winter months thereby making nutrients available for algal growth. As the reservoir stratifies, phosphorus in the epilimnion is depleted. As the water becomes warmer, growth conditions (e.g., temperature and low phosphorus concentrations) not favorable for the types of algae present in the spring bloom result in a die off of the algae. The recycling of the nutrients through decomposition of the algae results in favorable growth conditions for the algae observed in the late summer/early fall bloom.

The composition of the two algal peaks is different, as is typical for lakes. The spring peak has a much lower total algae count but higher chlorophyll-a concentrations than the late summer peak. The spring bloom is typically dominated by diatoms (*Asterionella*, *Fragilaria, Coscinodiscus*, and *Cyclotella*), and the green alga *Planktosphaeria*. The blue-green alga *Oscillatoria* is often present in January through March. Depending on the year, the diatoms *Asterionella* and *Fragilaria* are either dominant throughout the spring bloom, or the centric diatoms *Coscinodiscus* and *Cyclotella* become dominant at the end of the bloom in May. In contrast, the late summer/fall bloom is typically dominated by blue-green algae (*Anabaena*, *Anacystis*, and *Microcystis*) and the green alga *Planktosphaeria*.

The City of Baltimore also analyzes the raw water at the treatment plant for algal composition. Generally, the algae present in the raw water appear to reflect the in-reservoir algal composition. However, at times during the late fall and early winter (about October through December), the predominant alga in the raw water is *Dinobryon*. *Dinobryon*, although present at low levels in the reservoir, has not been observed in as high levels in the reservoir as in the raw water; this is likely a sampling artifact with the colonies being missed when samples are collected in the reservoir. Typically, *Dinobryon* grows well in water containing low phosphorus concentrations.

Therefore, the reduction in chlorophyll-a and total algae counts since the early 1980s are likely attributable to the reduction in nutrient concentrations, particularly phosphorus. This is an important factor to be utilized in managing the water quality of the reservoir, that is, if phosphorus loading to the reservoir increases, algal growth will also, resulting in deteriorated water quality.

7.2.5 Review of Protozoa Data from the City of Baltimore's Source Water Assessment

Since September 1995, the City of Baltimore has collected and analyzed raw water from Ashburton on a monthly basis and no *Giardia lamblia* or *Cryptosporidium* has been observed. There were no historical data on *Giardia lamblia* or *Cryptosporidium* from tributary waters of the Liberty Reservoir. Therefore, as part of this source water assessment study, samples were collected from tributaries during September and October 2001 in the hours immediately following significant rain events (Table 7-7). The samples were collected from surface water in tributaries at various locations within the Liberty Reservoir watershed. EPA Method 1623 was used for the sample analyses.

The low concentrations of both *Giardia lamblia* and *Cryptosporidium* measured are consistent with the common occurrence of these protozoa in the surface water sources throughout the U.S. and the overall relatively high water quality of the Liberty Reservoir. It is important to note that the analytical method cannot distinguish between viable and dead organisms. Natural attenuation can explain the fact that although *Giardia lamblia* or *Cryptosporidium* exist in the source water of Liberty Reservoir. Although these pathogens have not been identified in a viable state in the raw water at the treatment plant, *Cryptosporidium* can remain viable in natural waters for up to 18 months. The time of travel study conducted during the SWA indicates that water from even the tributaries farthest from the intake may take less than a month to travel to the intake. Therefore, the source water must be considered susceptible to these organisms. High turbidity and elevated bacteria concentrations can be an indicator for the presence of these pathogens. Sources of contamination include human and animal waste, including birds. Although the reservoir may assist in the removal of pathogens, complete removal cannot be expected. Water filtration does not always provide a 100 percent effective barrier, especially against the smaller *Cryptosporidium* oocysts. The new National Primary Drinking Water Regulations published by EPA in January 2002 address filtration issues and is an effort to reduce risks posed by *Giardia lamblia* and *Cryptosporidium*. These regulations are now a final rule.

7.2.6 Review of Data from MDE's TMDL Sampling Program

Liberty Reservoir is in the headwaters of the Patapsco River. Under the TMDL program, Liberty Reservoir was identified as being impaired due to nutrients (e.g., phosphorus and nitrogen), suspended sediments, chromium, and lead. Chromium and lead impairment were included as a result of chromium and lead measured in Longquarter Branch, an urban stream located in the City of Westminster. Therefore, chromium and lead are considered to have resulted in a localized impairment that does not affect the reservoir watershed as a whole. MDE conducted water quality sampling in the Liberty Reservoir watershed as part of the Patapsco/Back Rivers TMDL project from October 1999 through September 2000. Sampling was conducted in seven tributaries and nine in-reservoir stations. The three gaged tributaries (Beaver Run, Morgan Run, and the North Branch Patapsco River) were sampled during the months of January through February; the four ungaged tributaries (Little Morgan Run, Middle Run, Snowden Run, and Bonds Run) were sampled during the months of March through September. The nine in-reservoir stations were sampled during the months of March through September, except for June.

Samples were analyzed in the field for temperature, dissolved oxygen, conductivity, pH, Secchi disk depth, and salinity, and the discharge of the tributaries was gaged. Samples submitted to a laboratory were analyzed for full nitrogen series, phosphorus series, and organic carbon series; silicate; total suspended solids, chlorophyll-a, and biochemical oxygen demand.

Prior to the TMDL study, there were no data for dissolved organic carbon (DOC) or total organic carbon (TOC) for tributaries other than the North Branch Patapsco River; data for the reservoir were also unavailable. Table 7-8 summarizes the tributary data, and Table 7-9 summarizes the in-reservoir station data. The reservoir stations are listed in order starting with the lowermost station (closest to the dam) and then moving north to the uppermost station. Only very general conclusions should be made from the data summaries in these tables due to the number of samples and time periods when they were collected. However, dissolved and total organic carbon concentrations in tributaries clearly increased at higher discharges at each tributary station, and in-reservoir concentrations were highest (maximum, median, and mean) at the uppermost station and appeared to decrease progressively as one travels toward the lowermost station. This suggests that algae may be a significant contributing factor to total organic carbon and dissolved organic carbon concentrations in the reservoir. It also appears that, under lower discharge conditions in the tributaries, the concentration of organic carbon in the tributaries is less than in the reservoir. When tributary discharges increased, such as would happen after a rain storm, the organic carbon concentrations in the tributaries were greater than in the reservoir.

7.2.7 Review of Maryland Department of Natural Resources Data

The Maryland Department of Natural Resources collected monthly samples from Station NPA0165 (North Branch Patapsco River) from April 1980 through December 1995. Although the parameters analyzed varied somewhat over the years, generally the following were analyzed: turbidity, conductivity, dissolved oxygen, pH, total alkalinity, total nitrogen, total organic nitrogen, dissolved ammonia, un-ionized ammonia, total or dissolved nitrite-nitrogen, total or dissolved nitrate-nitrogen, total nitrogen, total Kjeldahl nitrogen, orthophosphate-phosphorus, total phosphorus, total coliform, fecal coliform, and total organic carbon. These data were downloaded from EPA's STORET database system.

7.2.8 Maryland Geological Survey Bathymetric and Sedimentation Mapping of Liberty Reservoir

The current bathymetry of Liberty Reservoir is not known. However, in 2001 the Maryland Geological Survey (MGS) collected the field data required for bathymetric mapping of the reservoir. These data have not yet been compiled into a bathymetric map. In addition, the (MGS) will be collecting data to determine the amount of sedimentation that has occurred since the reservoir was constructed. The rate of sedimentation in the reservoir is a concern due to the potential loss of water storage capacity, and water quality problems associated with sediment loads. These data are important for evaluating the potential impact of land uses on the reservoir, and should be carefully considered during zoning planning.

TABLE 7-1: Routine Water Quality Monitoring Parameters for In-Field Testing and Laboratory Analysis

Parameter	Liberty In-Reservoir (City of Baltimore)	Liberty Tributaries (City of Baltimore)	Ashburton Water Treatment Plant (City of Baltimore)	Ashburton Water Treatment Plant (MDE)
Chlorophyll-a	X			
Total Phosphorus	X	X		
Total Algal Count	X		R,T	
Algae Taxonomic Identification	X		R	
Total Suspended Solids		X		
Nitrate-Nitrogen	X[1]	X[1]	T	
Nitrite	X[1]	X[1]		
Nitrite/nitrate – Nitrogen	X[1]	X[1]		
Ammonia-Nitrogen	X	X		
Secchi Disk	X			
Conductivity	X	X	X	
Dissolved Solids	X	X		
Manganese	X		R,T	
Iron	X		R,T	
Dissolved Oxygen	X	X	R,T	
Color	X		R,T	
Turbidity	X		R,T	
pH	X	X	R,T	
Temperature	X	X	T	
Heterotrophic Plate Count (HPC)				
Total and Fecal Coliform			R	
Chlorine Residual			T	
Hardness			R,T	
Alkalinity	X	X	R,T	
Total Organic Nitrogen (TON)			T	
Trihalomethanes (THM)			R,T	
Halo Acetic Acid (HAA)			R,T	
Cryptosporidium and Giardia			R	
Fluoride			T	T
Total Organic Carbon (TOC)			R,T	
Chlorides	X	X	T	
Total Solids		X	T	
Phosphate-phosphorus			T	
Silica			T	
Sulfates			T	T
Aluminum			T	
Calcium			T	
Magnesium			T	
Potassium			T	
Sodium			T	T
Arsenic			T	T
Radionuclides				T
Synthetic Organic Compounds (SOCs)			T	T
Volatile Organic Compounds (VOCs)			T	T
Inorganic Compounds			T	T

Note: 1. Nitrate-N is now analyzed rather than Nitrite/Nitrate-N.
R = Ashburton Treatment Plant raw water.
T = Ashburton Treatment Plant treated water.

Table 7-2a: Summary of Ashburton Treatment Plant Treated Water Analytical Results for the Years 1997 Through 2001

Parameter	Maximum Contaminant Level (MCL)	Exceeds 50% MCL	Comments
Volatile Organic Compounds (VOCs)	Varies	No	No VOCs were detected.
Synthetic Organic Compounds (SOCs)	Varies	No	No SOCs were detected.
Metals	Varies	No	Data were for the years 1998 through 2001
Nitrate/Nitrite	Nitrate: 10 mg/L; Nitrite: 1 mg/L	No	Maximum Nitrate 1997-2001: 3.26 mg/L Maximum Nitrite 1997-2001: 0.03 mg/L
Fluoride	4 mg/L	Yes	The maximum value (mg/L) observed during any month 1997-2001 exceeded 50% of MCL during 3 months: 5/98 2.01; 11/98 3.34; and 6/1999 3.58
Cyanide	0.2 mg/L	Not Analyzed	MDE statewide waiver for cyanide.
Asbestos	7 million fibers/L	Not Analyzed	MDE statewide waiver for asbestos.
Radionuclides[1]	Alpha: 15 picocuries/L Beta: 4 millirems/year	Meets MDE Requirements	Gross Alpha 1997 and 2001: <1 pCi/L; Gross Beta 1997 2 pCi/L; 2001 <3 pCi/L and 3 +/-2 pCi/L
Total/Fecal Coliform			Do not analyze treated water.
Protozoa	Based on treatment technology	No	*Cryptosporidium* and *Giardia lamblia* have not been detected in treated water.
Viruses	Based on treatment technology	Not Analyzed	The Ashburton Plant is not required to analyze for viruses.
Trihalomethanes (THMs)	Before 01/01/2002: 0.1 mg/L As of 01/01/2002: 0.080 mg/L	Not in Treated Water at Plant	Maximum for 1997 through 2001 was 0.040 mg/L
Haloacetic Acids (HAA)	As of 01/01/2002: 0.060 mg/L	Yes	Maximum Values (mg/L): 1997 0.035; 1998 0.046; 1999 0.038; 2000 0.033; 2001 0.034
Turbidity	Before 01/01/2002: 5 NTU As of 01/01/2002: 1.0 NTU	Yes	

[1] Radionuclides are analyzed every four years by MDE. The most recent results are for February and May 2001.

Table 7-2b: MDE Ashburton Treatment Plant Treated Water Detections of Volatile Organic Compounds and Synthetic Organic Compounds

Compound	MCL (µg/L)	Date Sampled	Concentration (µg/L)	Exceeds 50% MCL
Volatile Organic Compounds (VOCs): March 17, 1988 - September 18, 2001				
Bromodichloromethane	80[1]	12/6/1995	7	No
		5/20/1996	9	No
		6/26/1997	6	No
		5/22/2000	6.5	No
		11/30/2001	5.3	No
Chloroform	80[1]	12/6/1995	51	Yes
		5/20/1996	40	No
		6/26/1997	16	No
		5/22/2000	26	No
		11/30/2001	14.2	No
Dibromochloromethane	80[1]	12/6/1995	0.8	No
		6/26/1997	1	No
		5/22/2000	0.6	No
		11/30/2001	0.9	No
1,1,1-Trichloroethane	200	8/1/1990	0.2	No
		10/12/1990	0.2	No
Trichloroethylene	5	12/21/1988	0.1	No
Synthetic Organic Compounds (SOCs): March 16, 1994 - September 18, 2001				
Atrazine	3	6/1/1994	0.2	No
		9/7/1994	0.14	No
		12/19/1994	0.12	No
		3/16/1994	0.16	No
2,4-D	70	5/17/1999	0.26	No
Dalapon	200	8/6/1997	0.42	No
		5/17/1999	5.24	No
		7/17/2000	1.6	No
di(2-ethylhexyl)adipate	400	6/30/1997	1.5	No
		9/7/1999	1.85	No
di(2-ethylhexyl)phthalate	6	6/30/1997	0.73	No
		8/6/1997	2.4	No
		5/17/1999	0.7	No
		7/17/2000	0.7	No
		9/18/2001	1.7	No
Simazine	4	6/1/1994	0.16	No
		9/7/1994	0.03	No
		12/19/1994	0.13	No
		3/16/1994	0.083	No

Table 7-2c: Turbidity, Total Coliform, and Fecal Coliform in Ashburton Treatment Plant Raw Water

Month	Turbidity (NTU) (24-Hour Composites)			Total and Fecal Coliform (MPN # per 100 mL)							
				Total Coliform				Fecal Coliform			
	Avg.	Max.	Min.	Avg.	Med.	Max.	Min.	Avg.	Med.	Max.	Min.
Jan-96	1.01	1.40	0.69	323	93	>2400	<3	5.1	3.6	23	<3
Feb-96	2.21	3.20	1.58	314	93	2400	21	6.9	<3	93	<3
Mar-96	1.77	2.81	1.05	24.4	9.1	150	<3	3.1	<3	3.6	<3
Apr-96	0.91	1.28	0.68	15.3	7.3	43	<3	3.1	<3	3.6	<3
May-96	0.92	2.29	0.54	13.2	7.3	93	<3	3.1	<3	3.6	<3
Jun-96	1.10	3.06	0.74	17.9	9.1	93	<3	4.5	<3	9.1	<3
Jul-96	0.81	1.37	0.56	499	460	>2400	23	6.3	3.6	43	<3
Aug-96	0.65	1.03	0.50	92	43	460	9.1	4.7	<3	23	<3
Sep-96	0.83	1.23	0.60	66	43	460	3.6	6.7	3.6	23	<3
Oct-96	1.14	2.01	0.77	126	43	1100	<3	8.1	3.6	39	<3
Nov-96	1.25	1.51	0.93	144	23/39	>2400	<3	7.4	<3	93	<3
Dec-96	2.22	3.38	1.53	498	240	>2400	3.6	6.7	3.6	23	<3
Jan-97	3.21	9.06	1.31	156	75	1100	7.3	4.2	3	14	<3
Feb-97	2.19	3.00	1.73	155	75/43	1100	9.1	3.2	<3	3.6	<3
Mar-97	1.78	3.47	1.10	48	23	150	3.6	6.6	<3	43	<3
Apr-97	1.66	2.22	1.07	10.9	9.1	43	<3	3.0	<3	3.6	<3
May-97	1.37	3.14	0.70	4.2	3	15	<3	3.0	<3	3.6	<3
Jun-97	1.08	2.42	0.49	5.5	3.6	23	<3	3.1	<3	3.6	<3
Jul-97	0.99	2.15	0.46	12.7	3.6	150	<3	3.7	<3	23	<3
Aug-97	1.12	2.05	0.61	12.8	3.6	93	<3	3.6	<3	9.1	<3
Sep-97	1.25	1.73	0.94	14.3	9.1/15	39	<3	4.5	3/3.6	23	<3
Oct-97	1.23	2.09	0.93	9.1	9.1	23	<3	3.7	<3	14	<3
Nov-97	1.46	2.49	0.92	115	23/21	1100	<3	3.9	<3	9.1	<3
Dec-97	1.97	2.86	1.34	5.3	3.6	15	<3	3.4	<3	9.1	<3
Jan-98	1.48	3.50	0.85	30.6	9.1	210	<3	4.6	<3	15	<3
Feb-98	2.23	7.14	1.26	146	93	460	15	3.5	<3	9.1	<3
Mar-98	2.58	6.29	1.49	57.5	43	240	7.3	3.3	<3	9.1	<3
Apr-98	1.95	4.59	0.94	48.7	9.1	240	<3	3.1	<3	3.6	<3
May-98	1.23	2.99	0.64	14.1	9.1	75	<3	3.1	<3	3.6	<3
Jun-98	1.23	3.03	0.63	102	23	1100	3.6	5.9	<3	43	<3
Jul-98	1.10	2.54	0.64	56	43	240	3.6	3.1	<3	3.6	<3
Aug-98	1.04	2.13	0.54	223	21	>=2400	<3	3.2	<3	3.6	<3
Sep-98	1.32	1.81	0.76	271	43	>=2400	7.3	4.0	<3	23	<3
Oct-98	1.89	4.16	1.14	29	23	93	3.6	7.2	3.6	23	<3
Nov-98	2.09	3.30	1.46	8.3	9.1	23	<3	3.2	<3	3.6	<3
Dec-98	1.90	4.82	1.05	5.2	3.6	15	<3	4.1	<3	15	<3

Table 7-2c: (Continued).

Month	Turbidity (NTU) (24-Hour Composites)			Total and Fecal Coliform (MPN # per 100 mL)							
				Total Coliform				Fecal Coliform			
	Avg.	Max.	Min.	Avg.	Med.	Max.	Min.	Avg.	Med.	Max.	Min.
Jan-99	1.70	3.10	0.98	159	93	1100	<3	5.2	<3	23	<3
Feb-99	1.82	4.21	0.91	61	9.1, 23	460	<3	<3	<3	3.6	<3
Mar-99	1.31	1.83	0.73	5.9	3.6	23	<3	<3	<3	3.6	<3
Apr-99	1.26	2.16	0.73	4.8	<3/3	23	<3	<3.1	<3	3.6	<3
May-99	1.82	3.98	0.95	9.6	3.6	93	<3	3.1	<3	3.6	<3
Jun-99	1.12	2.02	0.55	7.7	3.6	75	<3	4.5	<3	43	<3
Jul-99	1.10	2.67	0.52	6.1	<3	43	<3	4.4	<3	23	<3
Aug-99	1.11	2.13	0.66	11.0	3.6	43	<3	4.2	<3	23	<3
Sep-99	1.78	3.72	0.95	88.4	23	460	7.3	9.2	3.6	43	<3
Oct-99	1.59	2.39	0.66	57.4	43	150	7.3	6.9	3.6	23	<2
Nov-99	1.46	1.96	1.02	20.7	17	79	<1.8	3.7	2.0	13	<1.8
Dec-99	1.37	3.32	0.85	21.6	15.5	84	2.0	2.4	<1.8	6.8	<1.8
Jan-00	2.31	7.04	1.26	10.5	7.8	33	2.0	2.6	2.0	7.8	<1.8
Feb-00	1.02	1.72	0.68	11.0	4.5	170	<1.8	2.0	<1.8	4.5	<1.8
Mar-00	0.88	1.79	0.64	14.2	7.8	79	<1.8	1.8	1.8	2.0	<1.8
Apr-00	1.7.0	11.5	0.62	5.0	4.0	17	<1.8	1.9	<1.8	4.0	<1.8
May-00	1.18	3.01	0.43	5.0	4.5	13	<1.8	<1.8	<1.8	4.5	<1.8
Jun-00	0.99	2.11	0.42	7.3	2.0	48	<1.8	<1.8	<1.8	4.5	<1.8
Jul-00	1.03	2.59	0.37	16.2	9.3	79	<1.8	1.9	2.0	4.5	<1.8
Aug-00	0.84	1.56	0.43	16.4	7.8	70	2.0	<1.8	<1.8	4.5	<1.8
Sep-00	1.01	1.75	0.68	22.7	13	110	2.0	2.3	2.0	17	<1.8
Oct-00	0.95	1.64	0.62	15.0	7.8	70	<1.8	<1.8	<1.8	13	<1.8
Nov-00	1.25	1.94	0.72	10.97	7.8/11	33	<1.8	<1.8	<1.8	6.8	<1.8
Dec-00	1.57	2.13	1.09	10.0	4.0	49	<1.8	<1.8	<1.8	4.5	<1.8
Jan-01	1.00	2.55	0.64	7.2	4.5	23	<1.8	<1.8	1.8	7.8	<1.8
Feb-01	0.82	1.18	0.60	6.7	7.8	22	<1.8	1.8	<1.8	2.0	<1.8
Mar-01	1.16	2.43	0.77	4.5	2.0	33	<1.8	<1.8	<1.8	2.0	<1.8
Apr-01	1.01	1.77	0.72	7.0	4.5	49	<1.8	<1.8	<1.8	2.0	<1.8
May-01	0.74	1.11	0.49	2.2	2.0	7.8	<1.8	<1.8	<1.8	2.0	<1.8
Jun-01	0.90	1.75	0.52	8.1	4.5/6.8	33	<1.8	<1.8	<1.8	7.8	<1.8
Jul-01	0.94	1.85	0.56	8.3	9.3	17	1.8	<1.8	<1.8	4.5	<1.8
Aug-01	0.97	1.69	0.71	5.3	4.0	46	<1.8	<1.8	<1.8	7.8	<1.8
Sep-01	1.24	1.81	0.93	7.3	4.5	33	1.8	1.3	<1.8	17	<1.8
Oct-01	1.25	2.20	0.80	12.8	7.8	79	2.0	<1.8	2.0	4.5	<1.8
Nov-01	2.11	4.68	1.42	8.0	6.8	23	1.8	3.6	2.0	17	<1.8
Dec-01	1.88	2.84	1.15	3.7	2.0	14	<1.8	<1.8	1.8	7.8	<1.8

Table 7-2d: Annual Maximum Concentrations of Organic Compounds in Ashburton Treatment Plant Water

	TOC[1] (mg/L)	TOC (mg/L)	TTHMs (:g/L)	TTHMs[2] (:g/L)	HAA (:g/L)	HAA [3] (:g/L)
Year	Raw Water	Treated Water	Raw Water	Treated Water	Raw Water	Treated Water
1997	2.54	1.69	ND[4]	40.0	ND	35.0
1998	2.0	2.7	ND	27.0	ND	46.0
1999	2.62	1.38	ND	36.0	ND	38.0
2000	3.42	2.30	ND	36.0	ND	33.0
2001	3.10	2.92	ND	19.5	ND	34.0

[1] TOC: Total Organic Carbon
[2] TTHMs: Total Trihalomethanes is the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.
[3] HAA: Haloacetic acids is the sum of the concentrations of mono-, di-, and tri-chloroacetic acids and mono- and di-bromoacetic acids.
[4] ND = Not detected

Table 7-3: Dry Weather Concentration Temporal Trends Observed at Liberty Reservoir Tributary Sampling Stations, 1981-1993 (from City of Baltimore, 1998)

Water Quality Parameter	Tributary					
	Bonds Run	Middle Run	Little Morgan Run	Beaver Run	Morgan Run	North Branch Patapsco River
Alkalinity	Up	Up	Up	None	None	None
Chlorides	Up	Up	Up	None	Up	None
Conductivity	Up	Up	Up	Up	Up	Up
pH	Down	None	None	None	Down	Down
Nitrate-nitrogen	Up	Up	Up	Up	Up	Up
Dissolved Oxygen	None	Up	None	None	None	None
Dissolved Oxygen % Saturation	Up	None	None	None	None	None
Total Phosphorus	Down	Down	Down	None	Down	Down
Dissolved Solids	Up	Up	Up	Up	Up	None
Water Temperature	None	None	None	None	None	None

Table 7-4: Estimated Average Tributary Nutrient Concentrations and Areal Loadings for Gaged Tributaries

Station	Number of Samples Except Dissolved Phosphorus	Number of Samples Dissolved Phosphorus	Average Tributary Discharge (cfs)	Maximum Tributary Discharge (cfs)	Average Nitrate/ Nitrite-N (mg/L)	Average Total Phosphorus (mg/L)	Average Dissolved Phosphorus (mg/L)	Average Areal Total Phosphorus Load (kg/km^2)	Average Areal Dissolved Phosphorus Load (kg/km^2)
Dry Weather Load in Gaged Tributaries 1981 – 1993									
Beaver Run	113	27	12	42	3.70	0.025	0.020	7.2	6.5
Morgan Run	113	30	24	115	3.15	0.021	0.017	6.1	4.8
North Branch	110	27	41	145	3.77	0.045	0.034	15.3	12.0
Wet Weather (Storm) Load in Gaged Tributaries 1981 – 1993									
Beaver Run	173	78	91	1,917	3.15	0.382	0.080	N/A	N/A
Morgan Run	179	80	201	2,985	2.64	0.401	0.097	N/A	N/A
North Branch	167	79	401	6,173	3.22	0.422	0.152	N/A	N/A

Table 7-5: In-Reservoir Water Quality Median Data For 1981 Through 1993

Parameter	Unit	Epilimnion			Hypolimnion
		NPA0042		Upper Stations (NPA0067 and NPA0105)	NPA0042
		Year-Round	Growing Season[1]	Growing Season[1]	Long-Term
Chlorophyll-a	μg/L	3.30	3.30	6.64	2.46
Total Algal Count	#/mL	648	744	1160	307
Total Phosphorus	mg/L	0.012	0.013	0.024	0.016
Nitrate-Nitrogen	mg/L	1.53	1.81	2.04	1.65
Ammonia-Nitrogen	mg/L	0.04	0.03	0.05	0.06
Apparent Color	color units	NA	NA	NA	NA
True Color	color units	4	4	5.5	6
Conductivity	μmhos/cm	153	152	167	158
pH	Std Units	7.50	7.88	7.55	6.78
Iron	mg/L	0.07	0.06	0.09	0.1
Manganese	mg/L	0.02	0.01	0.01	0.14
Dissolved Oxygen	mg/L	8.84	8.81	8.37	6.05
Dissolved Oxygen % Saturation	%	101	105	101	49
Secchi Disk Depth	m	4.27	4.88	2.44	1.6
Turbidity	NTU	1.1	1.0	2.2	2.2

NA: Not Analyzed
[1] The growing season is defined as the period April through September.

Table 7-6: Reservoir Water Quality Changes Related to Carlson Trophic State Index

TSI Rating	Description
TSI < 30	Classical oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes
TSI 30 - 40	Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion in the summer
TSI 40 - 50	Water moderately clear, but increasing probability of anoxia in hypolimnion during the summer. Iron and manganese problems during the summer, Raw water begins to have noticeable odor and THM precursors begin to exceed 100 μg/L
TSI 50 - 60	Lower boundary of classical eutrophy: decreased transparency, anoxic hypolimnion during summer, macrophyte problems, warm water fisheries only. Iron, manganese, taste and odor become problematic
TSI 60 - 70	Blue-green algae dominant during summer, algal scums probable, extensive macrophyte growth.
TSI 70 - 80	Heavy algal blooms possible throughout summer, dense macrophyte beds, but extent limited by light penetration, Reservoir becomes hypertrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

Table 7-7: *Giardia lamblia* and *Cryptosporidium* in Tributaries to Liberty Reservoir

Sampling Date	Station No.	Sub-Watershed	*Giardia lamblia* [1] #/Liter	*Cryptosporidium*[1] #/Liter
9/25/2001	UOL0004	Snowden Run	0.5	0.0
9/25/2001	LMR0015	Little Morgan Run	0.0	0.2
10/15/2001	NPA0165	North Branch Patapsco River	0.6	0.0
10/15/2001	UZP0002	Bonds Run	0.3	0.4
10/15/2001	BEA0016	Beaver Run	0.2	0.5
10/15/2001	MDE0026	Middle Run	0.0	0.0
10/15/2001	MOR0040	Morgan Run	0.4	0.1

[1] Analyses of matrix spiked samples taken on 9/25/01 showed 88.7% recovery rate for *Giardia lamblia* and 18.0% recovery rate for *Cryptosporidium*. Calculations were corrected based on the matrix spiked recovery rates for organisms found in source water.

Table 7-8: Dissolved and Total Organic Carbon Measured in Tributaries During MDE's TMDL Study

Station	Dissolved Organic Carbon (mg/L)				Total Organic Carbon (mg/L)			
	Minimum	Maximum	Median	Mean	Minimum	Maximum	Median	Mean
Beaver Run	1.08	4.74	1.69	1.89	1.29	6.25	1.92	2.30
Little Morgan Run	0.98	1.77	1.41	1.41	1.20	2.16	1.67	1.67
Middle Run	1.34	1.86	1.84	1.76	1.86	3.96	2.29	2.50
Morgan Run	1.00	4.05	1.58	1.75	1.31	5.85	1.96	2.17
North Branch Patapsco	1.29	3.72	2.03	2.17	1.55	4.63	2.49	2.70
Snowden Run	1.44	2.53	1.81	1.92	1.78	3.24	2.23	2.32
Bonds Run	1.01	1.71	1.45	1.43	1.22	2.14	1.79	1.75

Table 7-9: Dissolved and Total Organic Carbon Measured at Reservoir Stations During MDE's TMDL Study

Station	Dissolved Organic Carbon (mg/L)				Total Organic Carbon (mg/L)			
	Minimum	Maximum	Median	Mean	Minimum	Maximum	Median	Mean
NPA0038 (lowermost)	2.11	2.51	2.22	2.25	2.25	2.81	2.44	2.50
NPA0059	2.04	2.54	2.30	2.30	2.22	3.10	2.56	2.59
NPA0071	2.06	2.60	2.19	2.26	2.25	3.22	2.45	2.56
NPA0085	1.97	2.73	2.19	2.23	2.29	3.58	2.47	2.54
NPA0101	1.79	2.79	2.21	2.23	2.33	3.61	2.55	2.69
NPA0116	1.72	2.60	2.27	2.24	2.40	3.58	2.78	2.82
NPA0130	1.64	2.74	2.35	2.30	2.43	4.04	3.05	3.06
NPA0155	1.83	3.20	2.39	2.43	2.49	5.92	3.32	3.54
NPA0164 (uppermost)	2.02	3.51	2.46	2.56	2.56	6.61	3.66	3.89

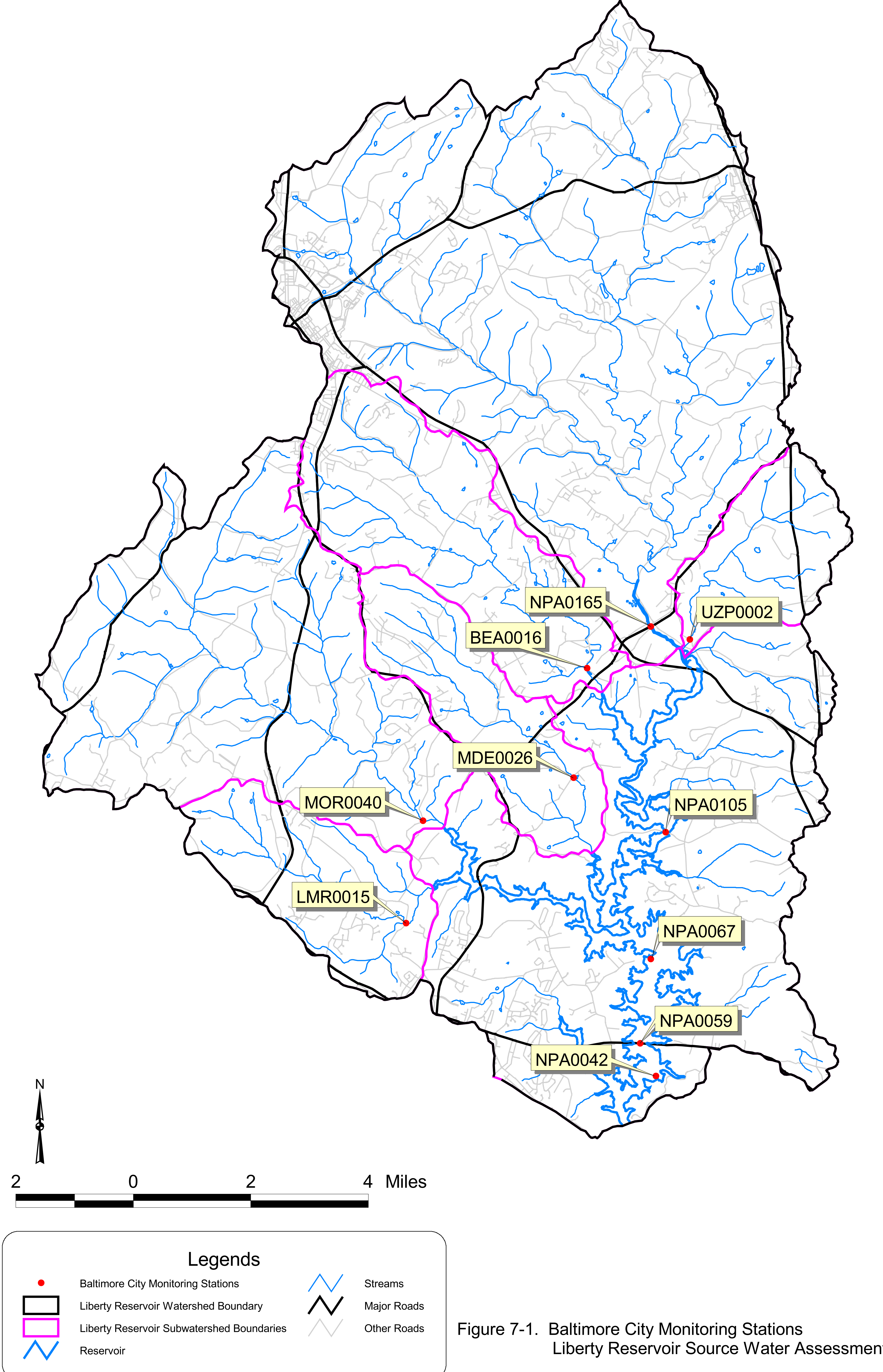


Figure 7-1. Baltimore City Monitoring Stations
Liberty Reservoir Source Water Assessment

Figure 7-2a: Liberty Reservoir Average Monthly Dissolved Oxygen
Monitoring Station NPA0042 (1994 - 2001)

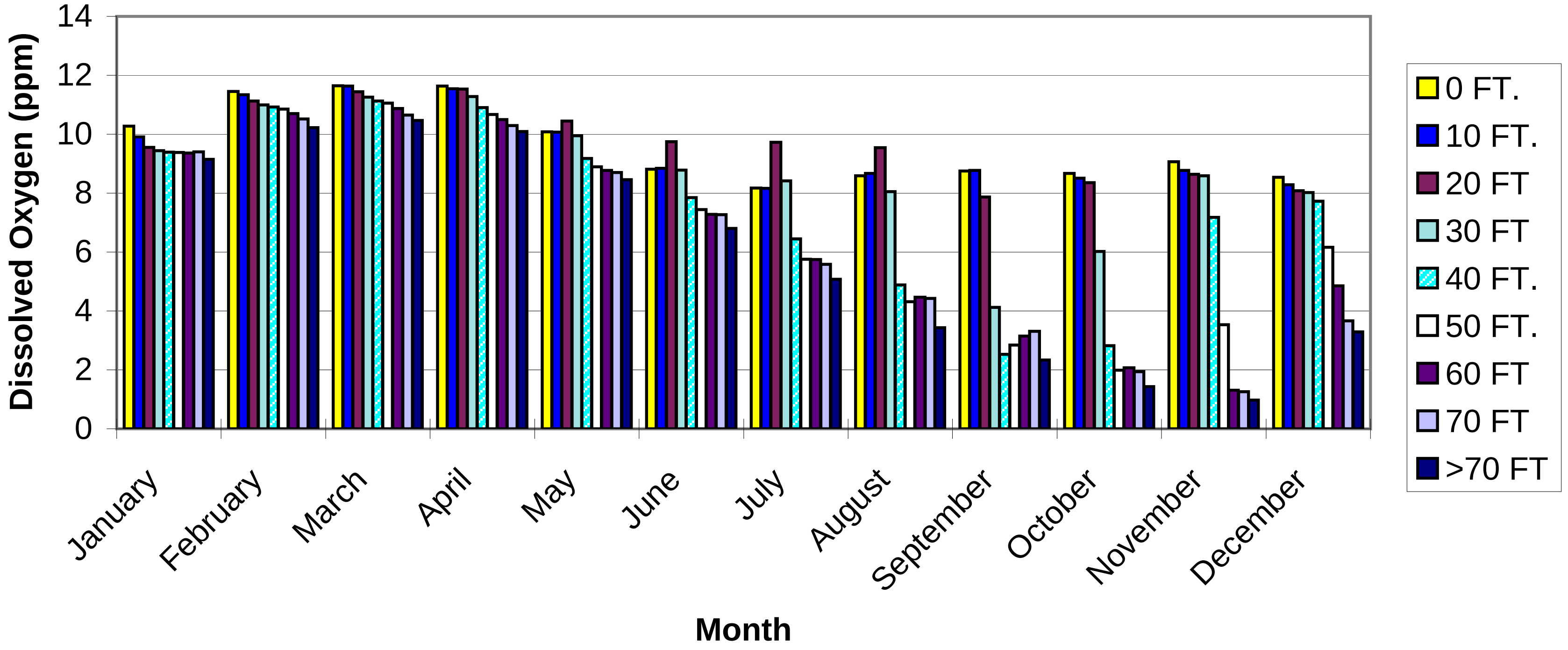


Figure 7-2b: Liberty Reservoir Average Monthly Chlorophyll-a
Monitoring Station NPA0042 (1994 - 2001)

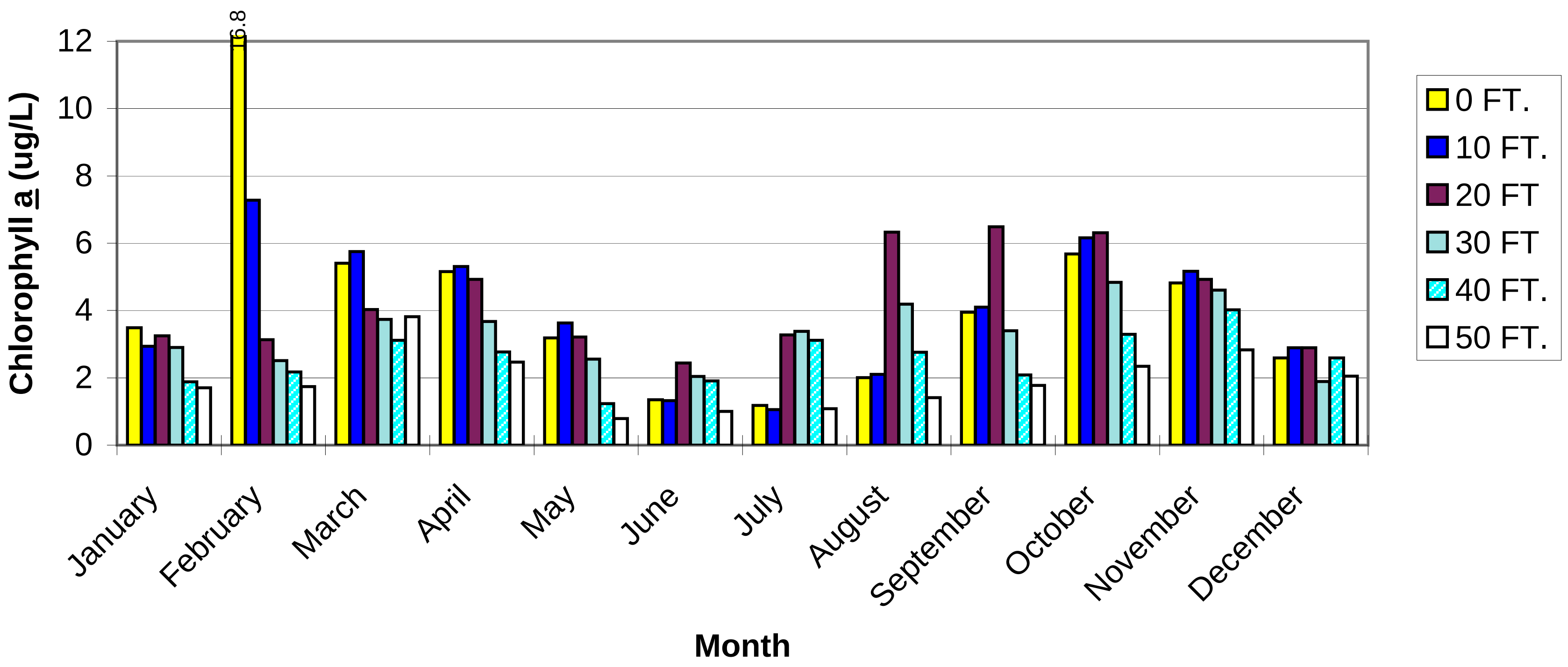


Figure 7-2c: Liberty Reservoir Average Monthly Total Algae Count
Monitoring Station NPA0042 (1994 - 2001)

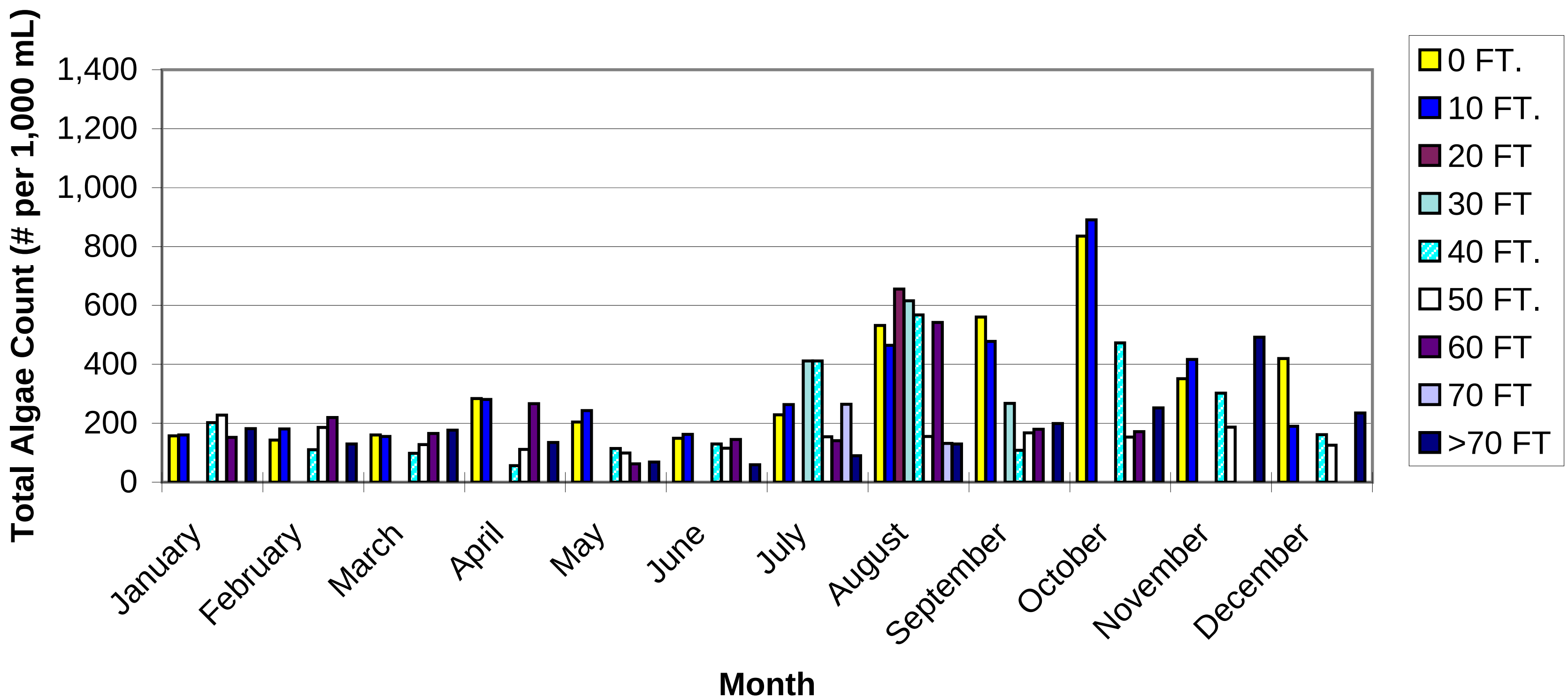


Figure 7-2d: Liberty Reservoir Average Monthly Manganese
Monitoring Station NPA0042 (1994 - 2001)

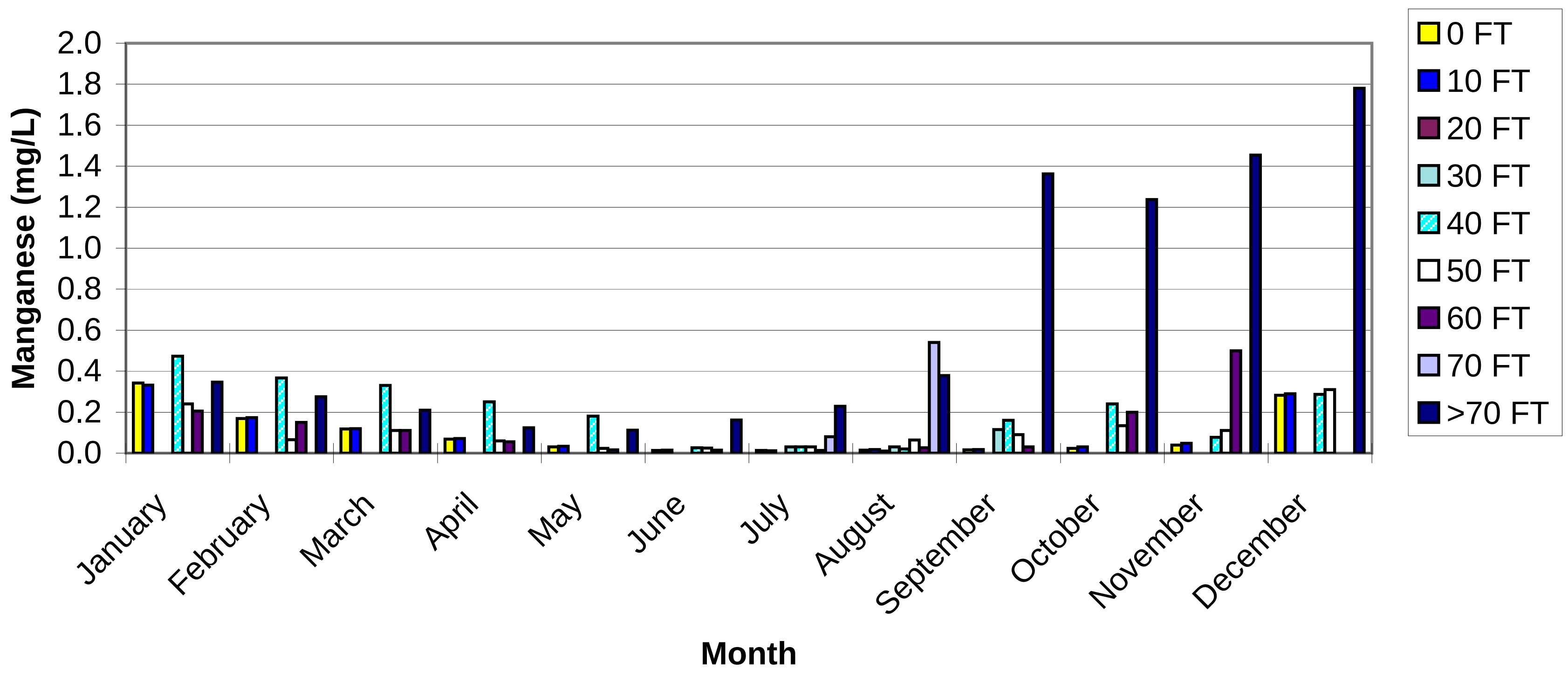


Figure 7-2e: Liberty Reservoir Average Monthly Total Phosphorus
Monitoring Station NPA0042 (1994 - 2001)

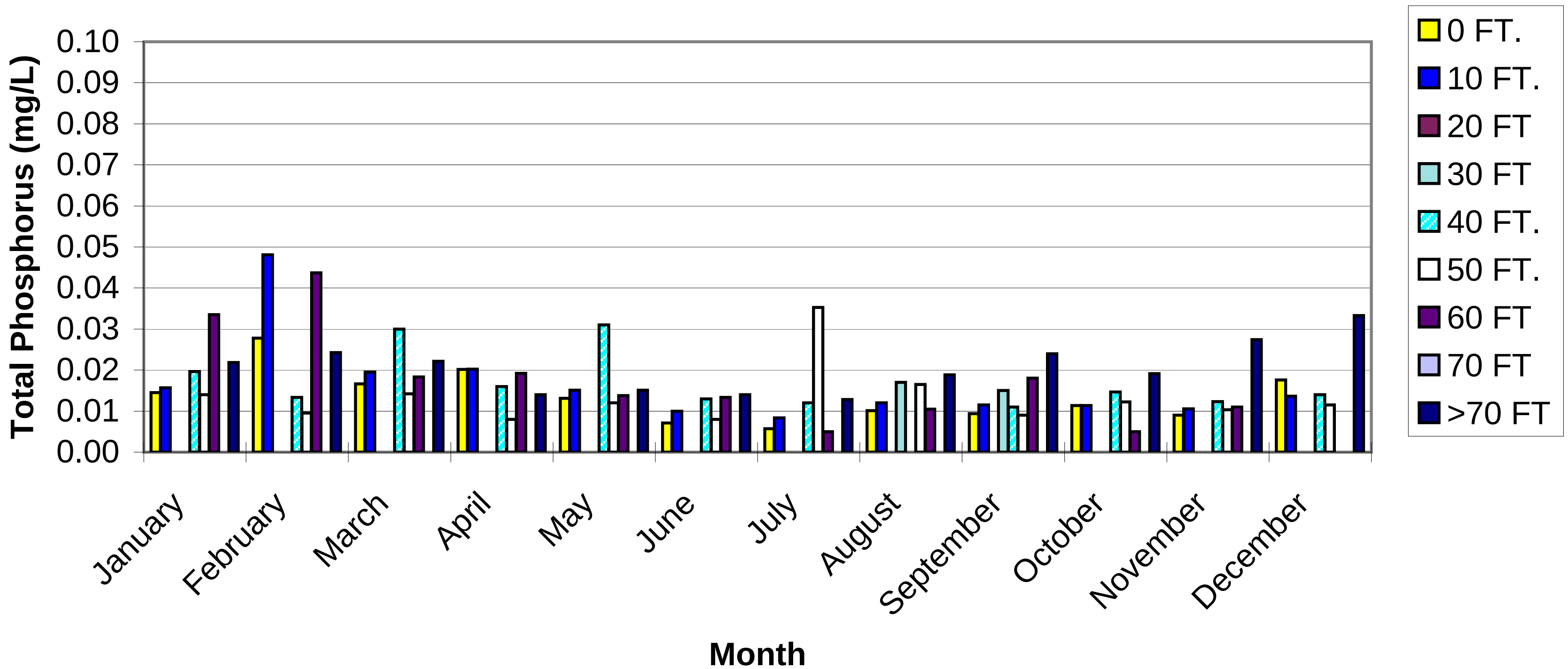


Figure 7-2f: Liberty Reservoir Average Monthly Nitrate/Nitrite-N
Monitoring Station NPA0042 (1994 - 2001)

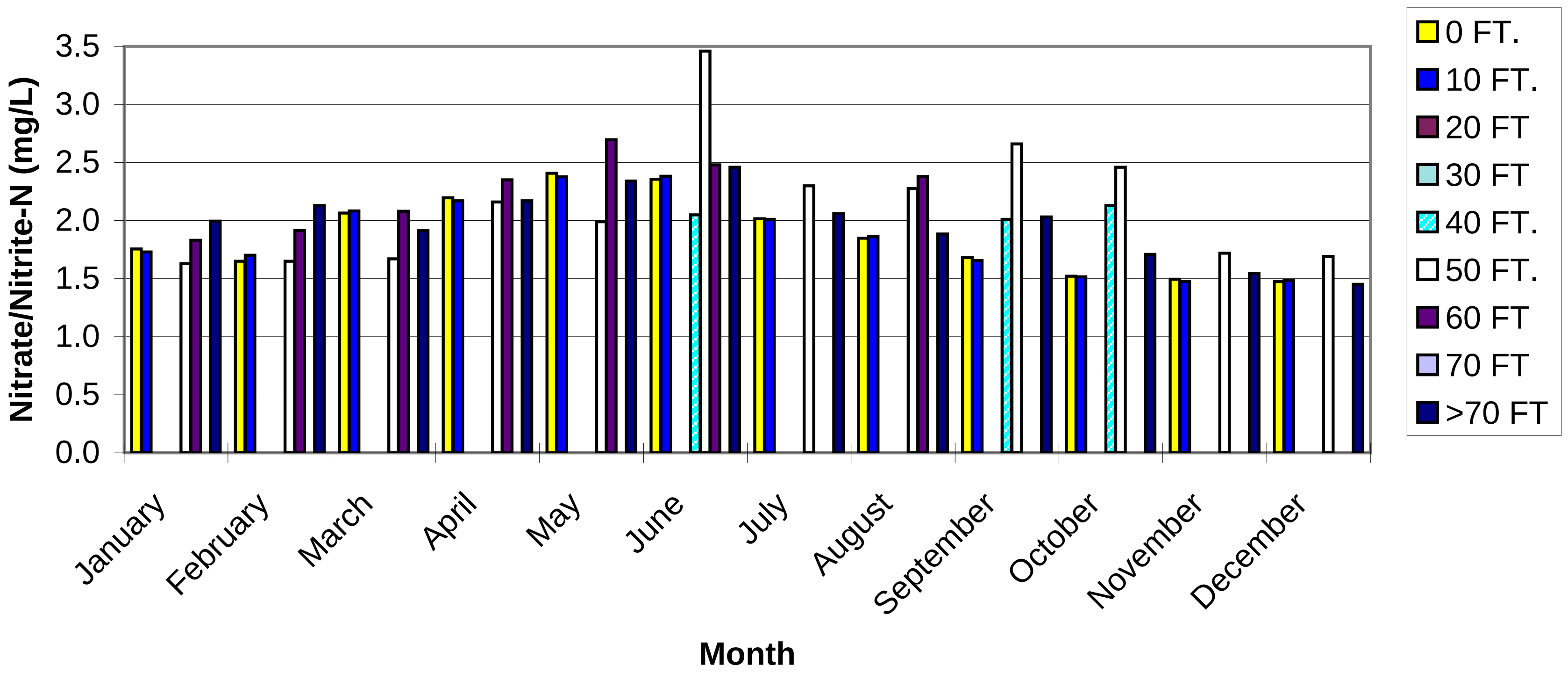


Figure 7-3a: Liberty Reservoir Average Monthly Dissolved Oxygen
Monitoring Station NPA0059 (1994 - 2001)

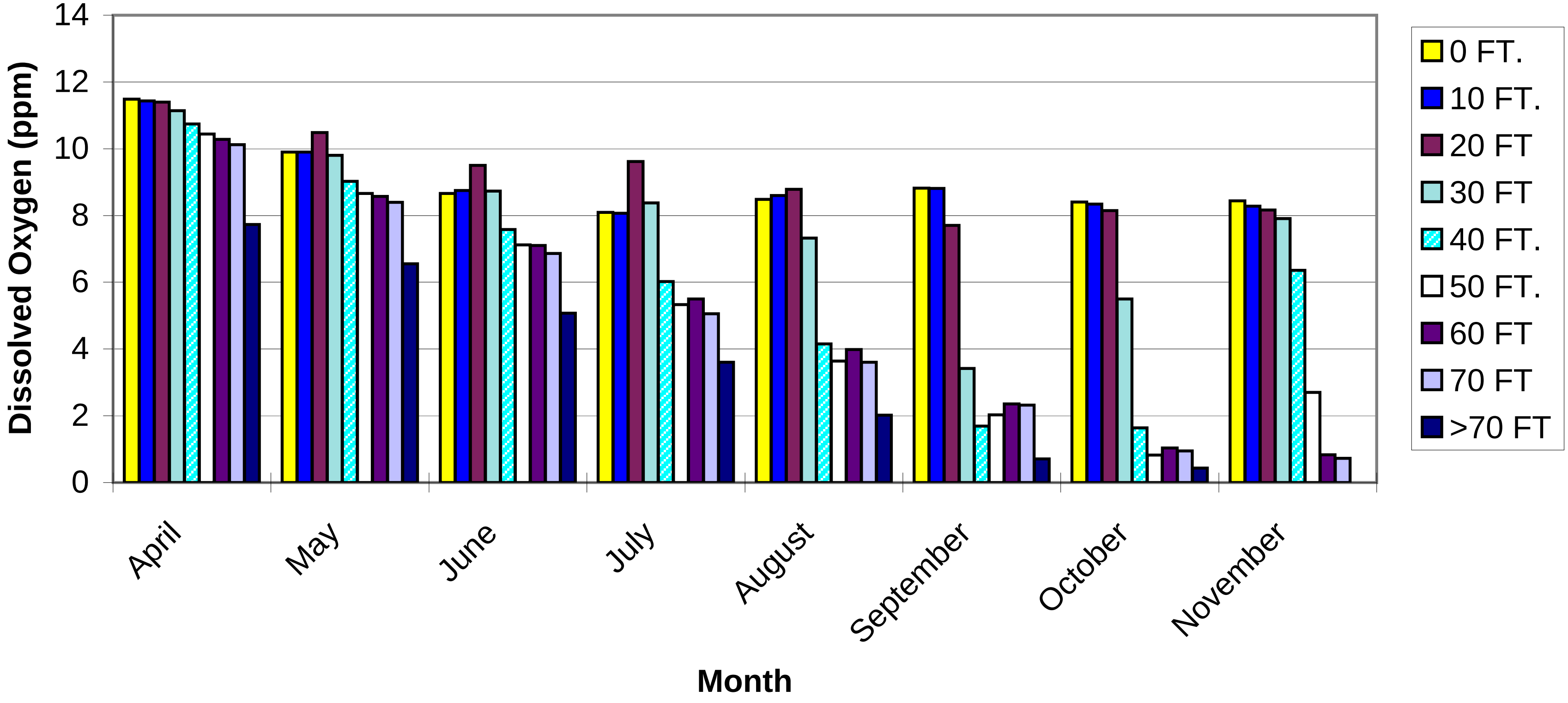


Figure 7-3b: Liberty Reservoir Average Monthly Chlorophyll-a
Monitoring Station NPA0059 (1994 - 2001)

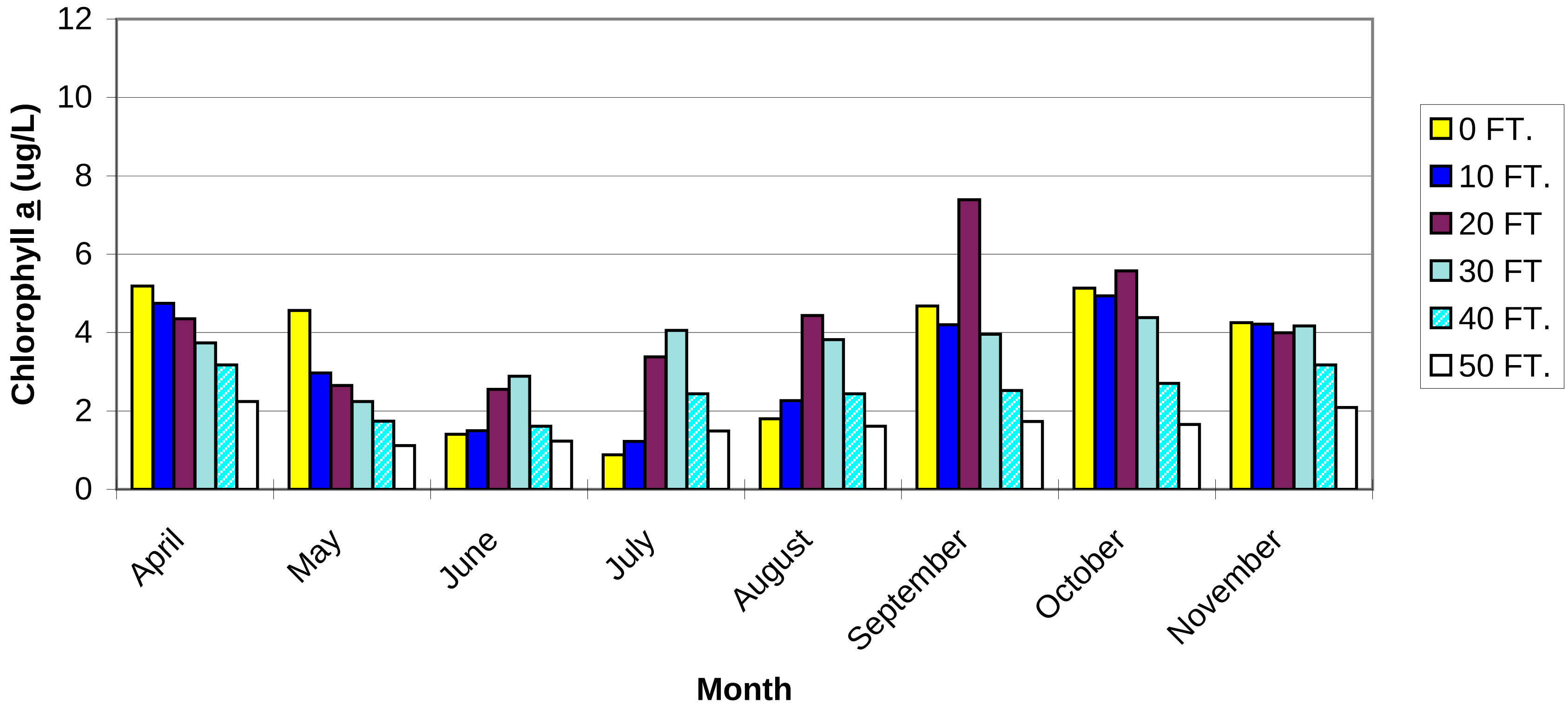


Figure 7-3c: Liberty Reservoir Average Monthly Total Algae Count
Monitoring Station NPA0059 (1994 - 2001)

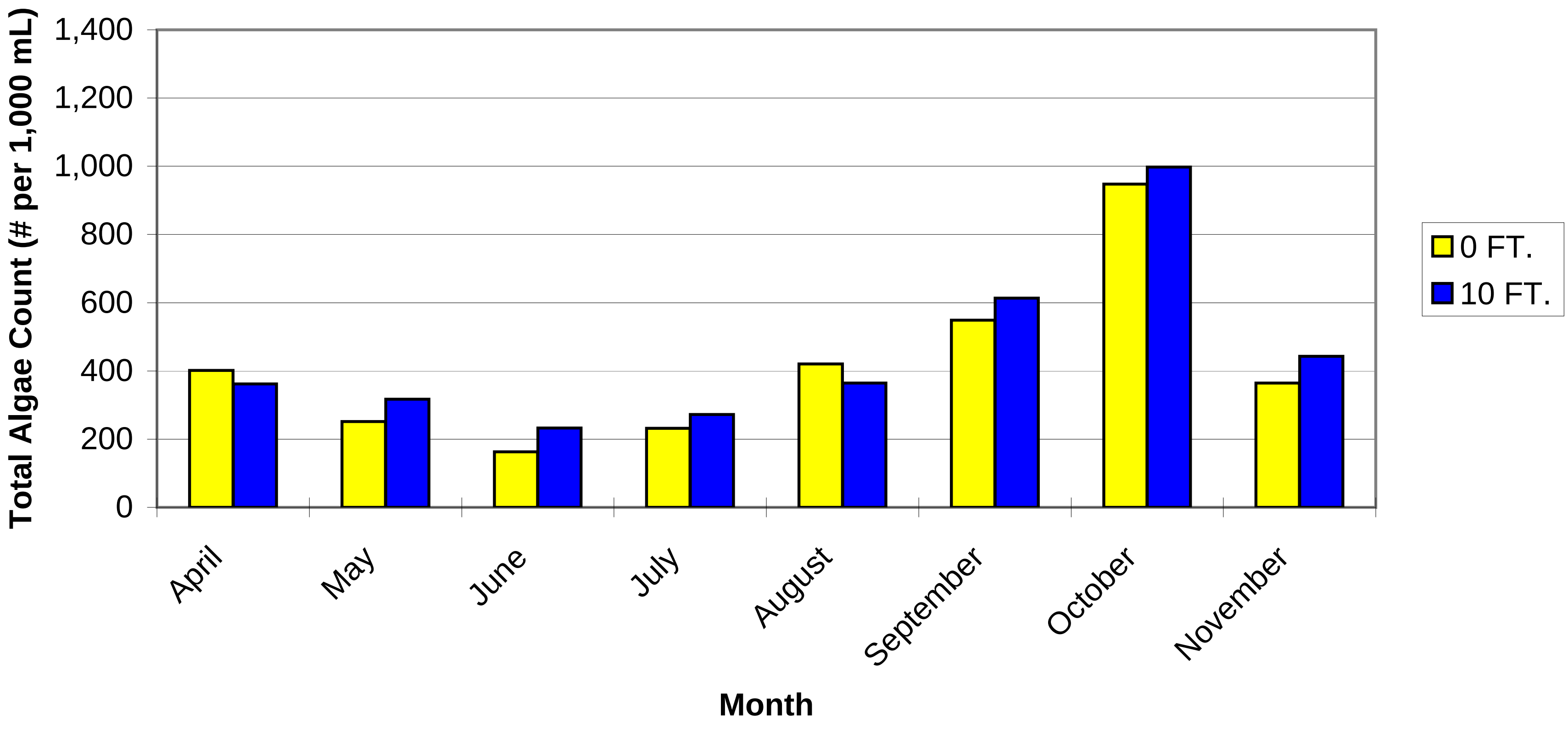


Figure 7-3d: Liberty Reservoir Average Monthly Total Phosphorus
Monitoring Station NPA0059 (1994 - 2001)

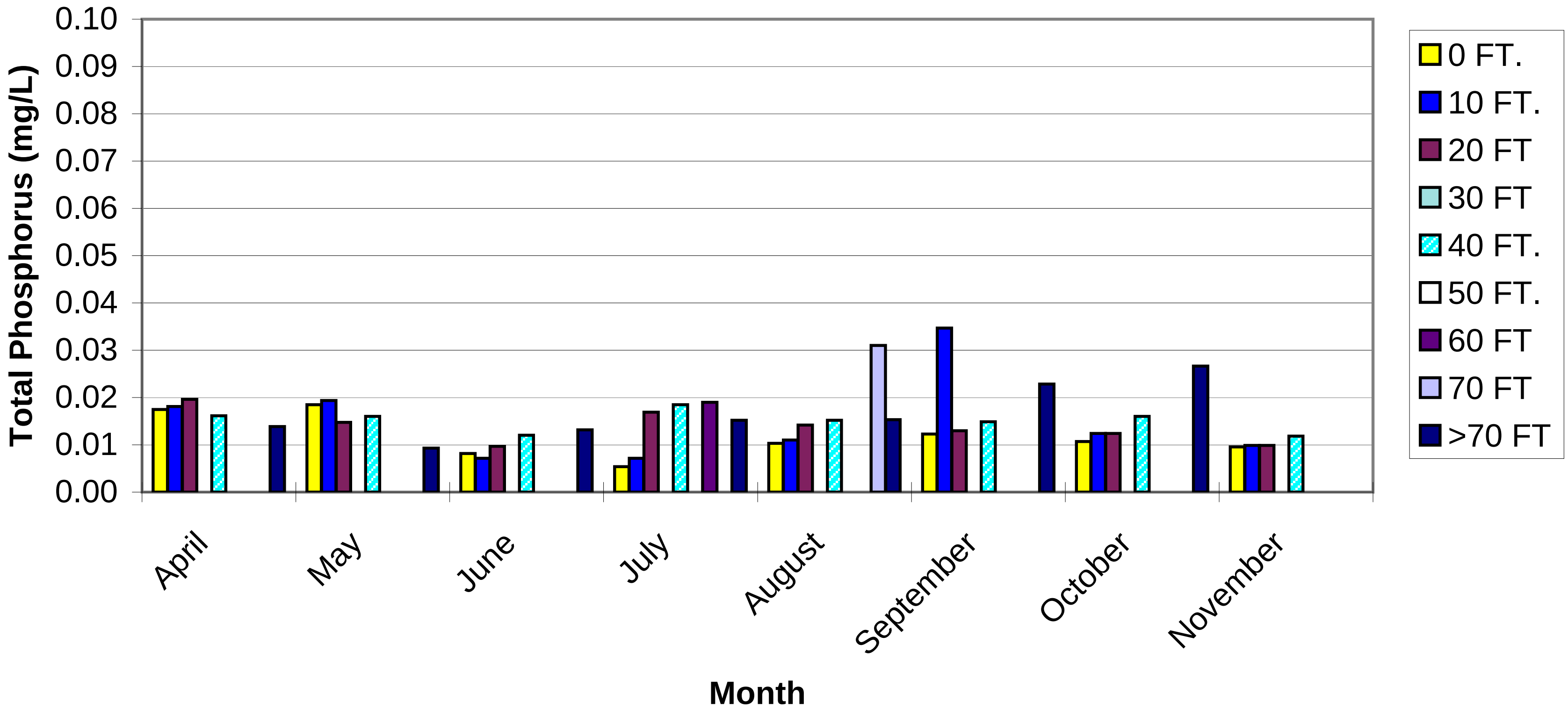


Figure 7-3e: Liberty Reservoir Average Monthly Nitrate/Nitrite-N
Monitoring Station NPA0059 (1994 - 2001)

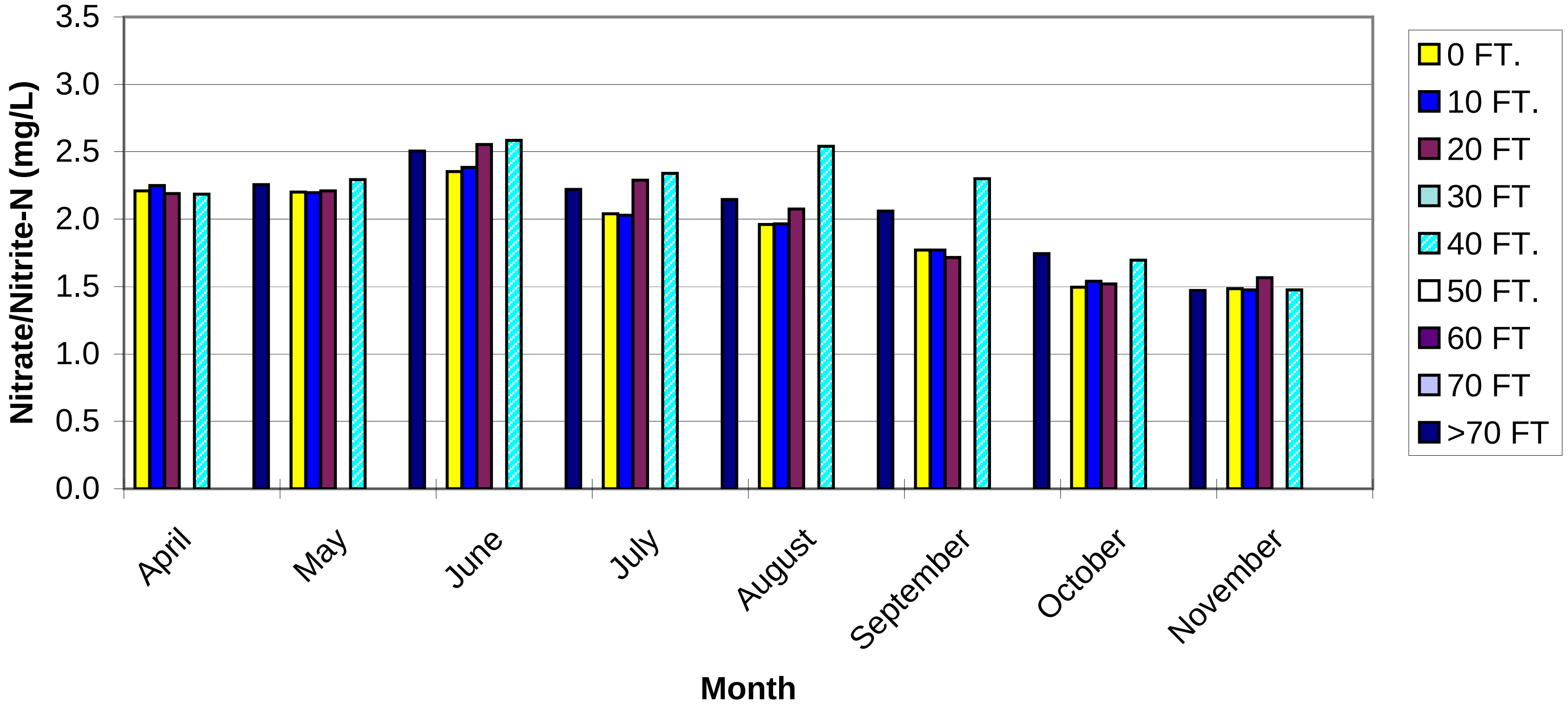


Figure 7-4a: Liberty Reservoir Average Monthly Dissolved Oxygen

Monitoring Station NPA0067 (1994 - 2001)

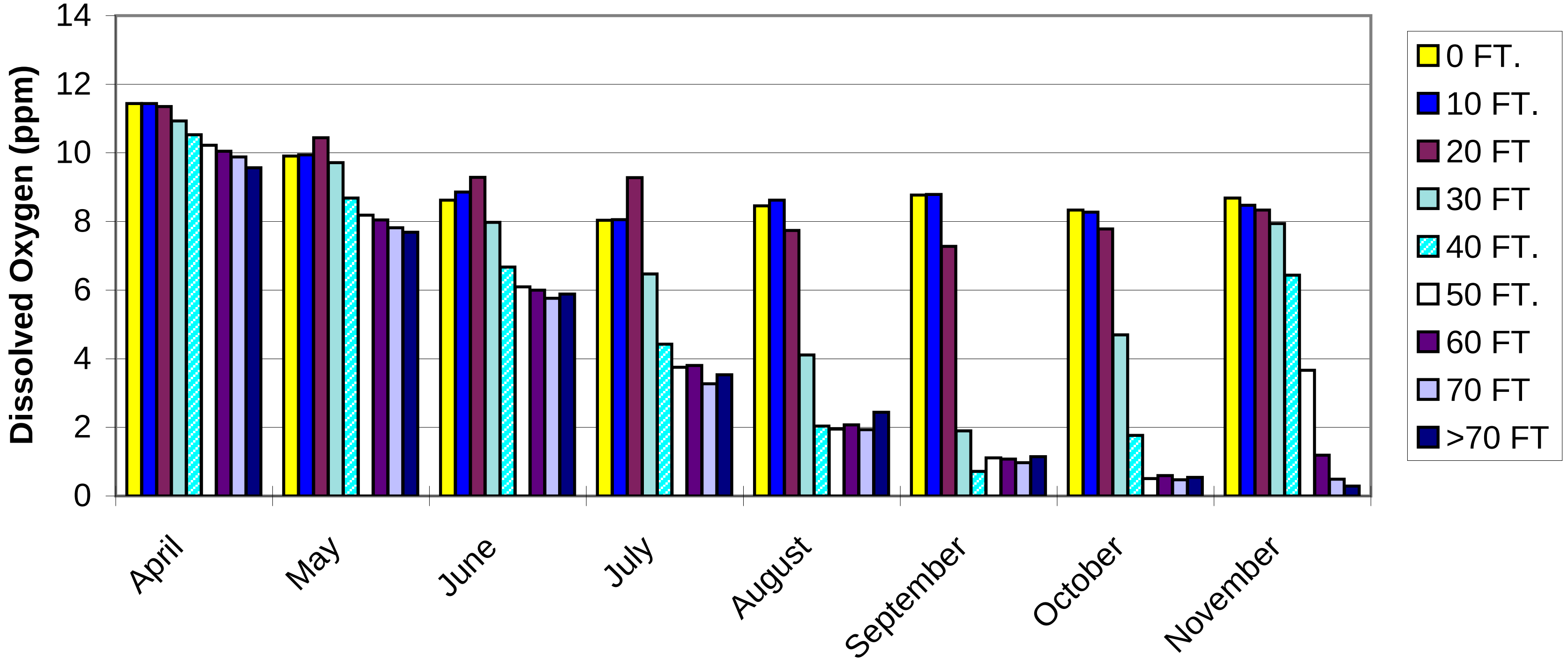


Figure 7-4b: Liberty Reservoir Average Monthly Chlorophyll-a
Monitoring Station NPA0067 (1994 - 2001)

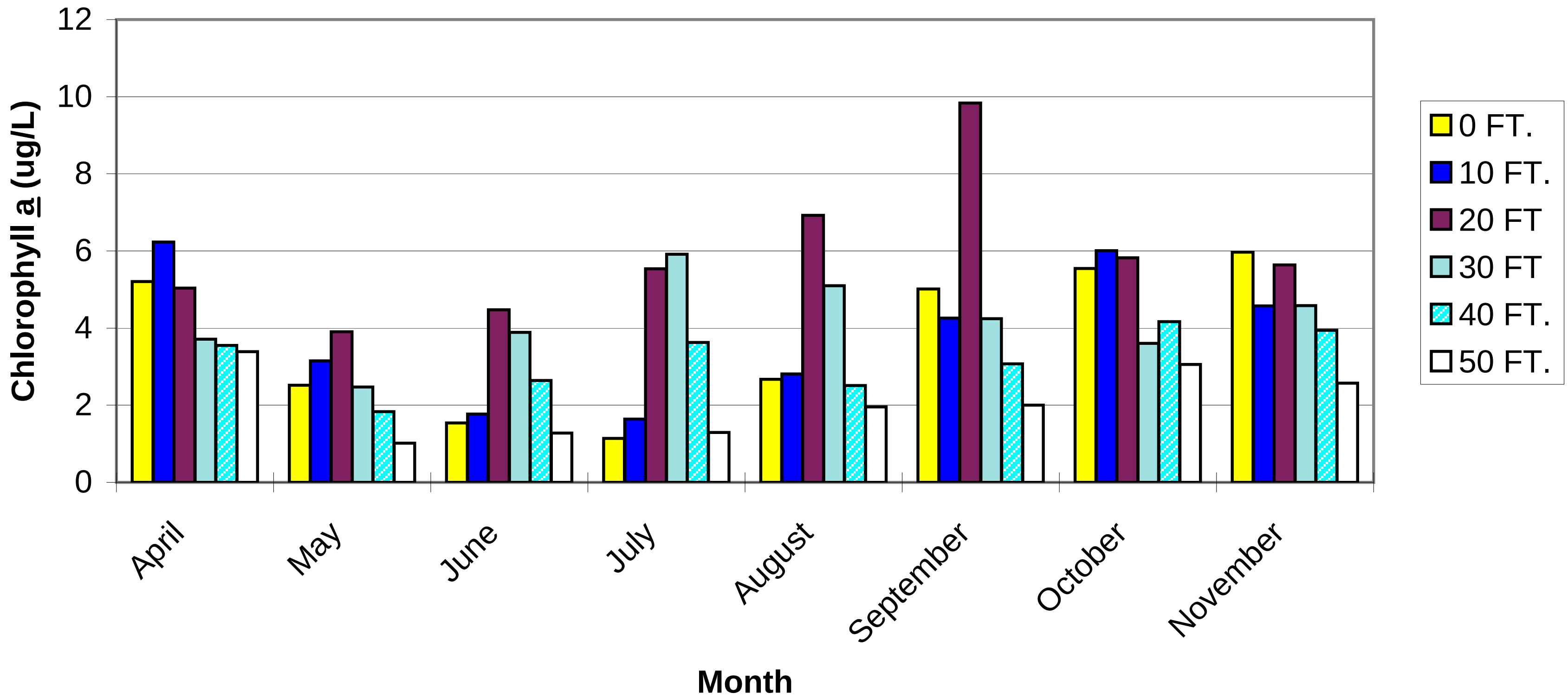


Figure 7-4c: Liberty Reservoir Average Monthly Total Algae Count
Monitoring Station NPA0067 (1994 - 2001)

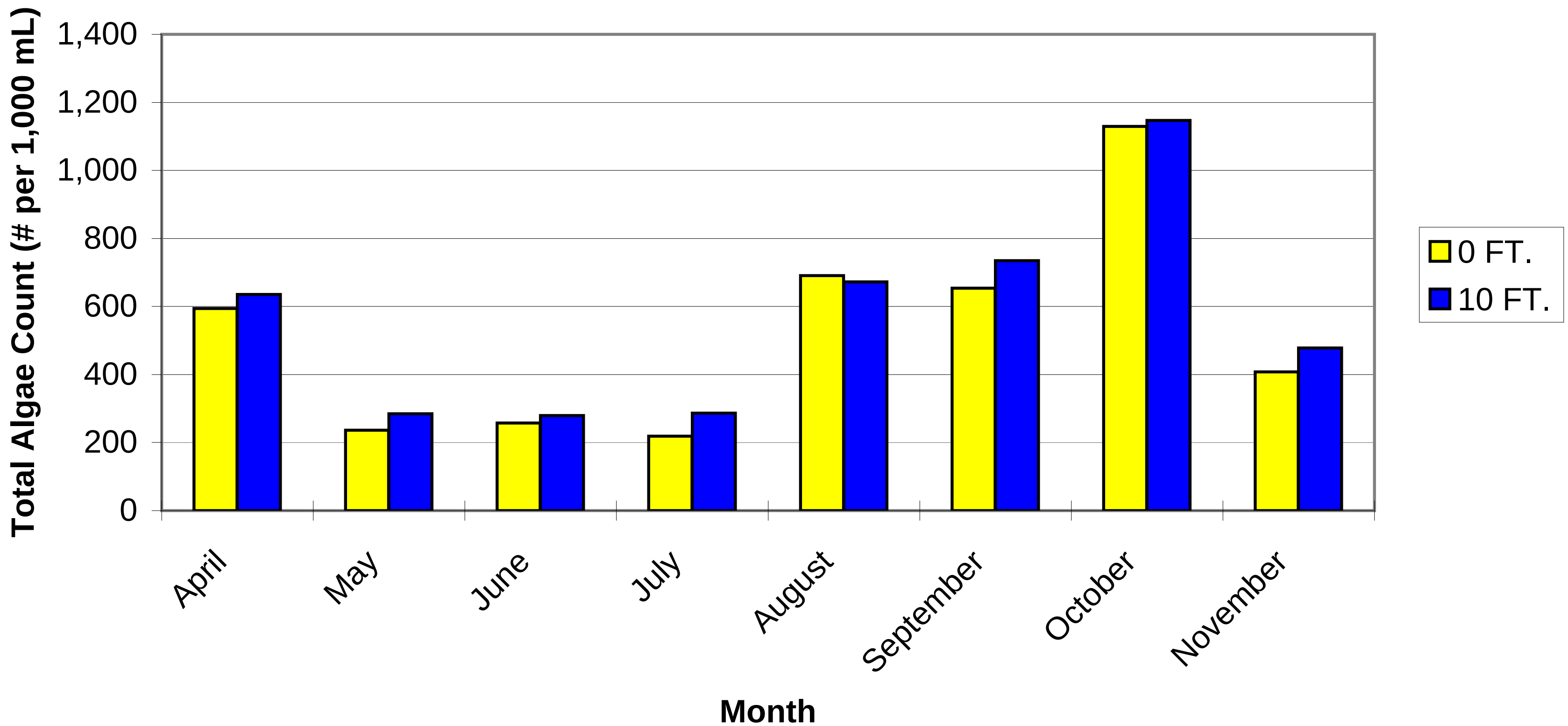


Figure 7-4d: Liberty Reservoir Average Monthly Total Phosphorus
Monitoring Station NPA0067 (1994 - 2001)

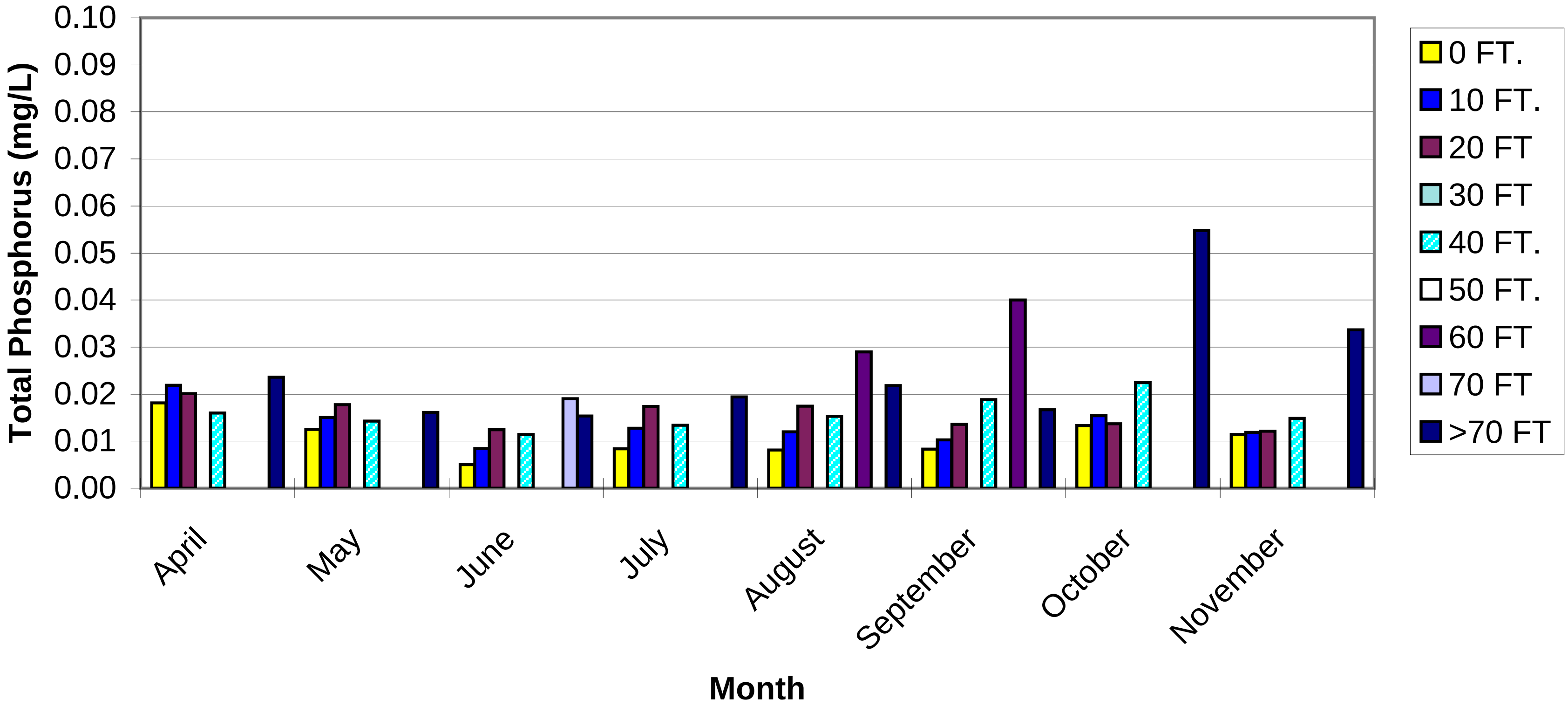


Figure 7-4e: Liberty Reservoir Average Monthly Nitrate/Nitrite-N
Monitoring Station NPA0067 (1994 - 2001)

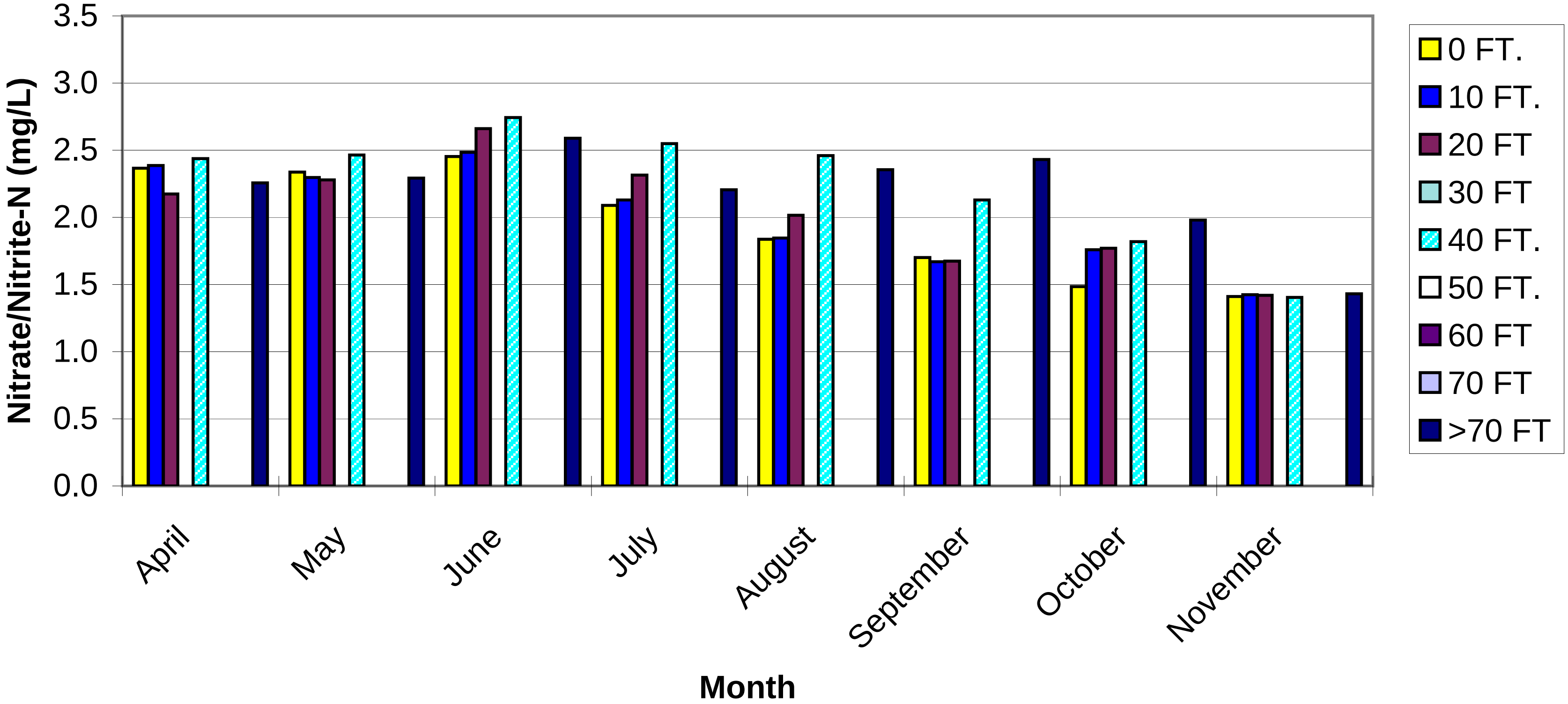


Figure 7-5a: Liberty Reservoir Average Monthly Dissolved Oxygen
Monitoring Station NPA0105 (1994 - 2001)

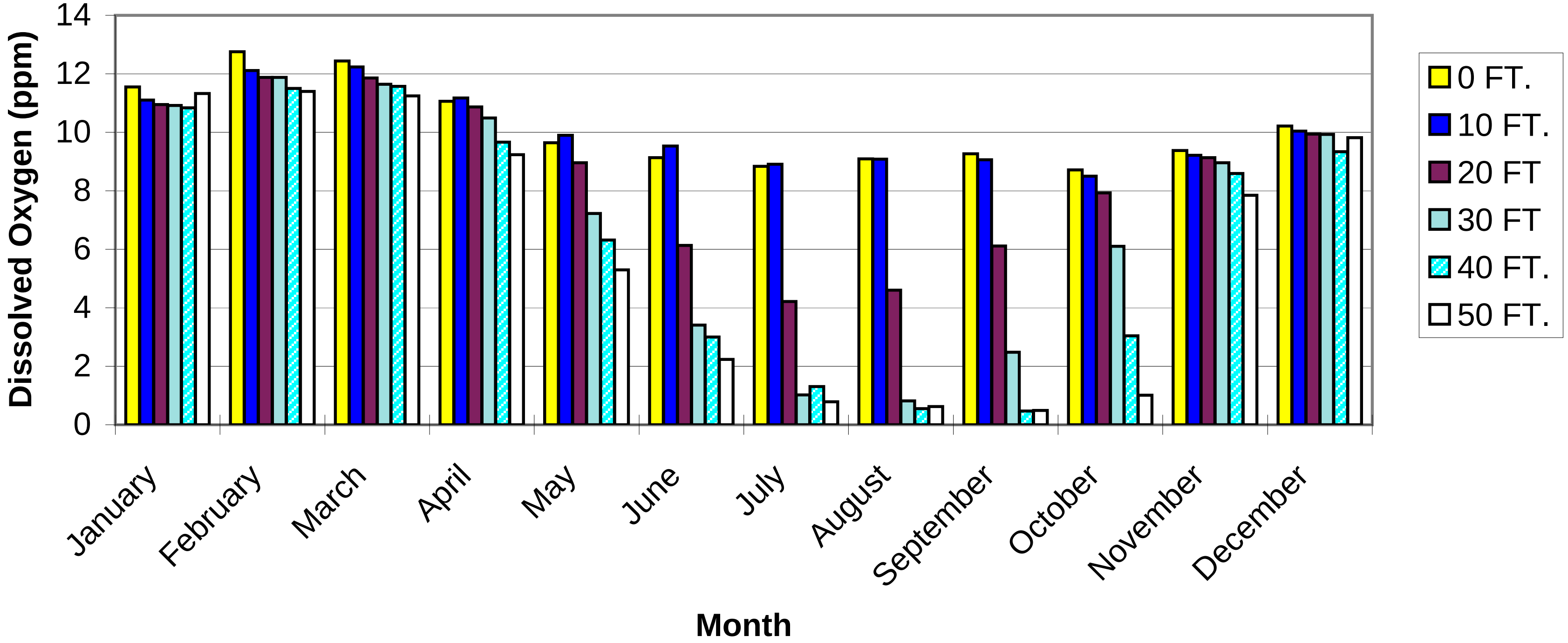


Figure 7-5b: Liberty Reservoir Average Monthly Chlorophyll-a
Monitoring Station NPA0105 (1994 - 2001)

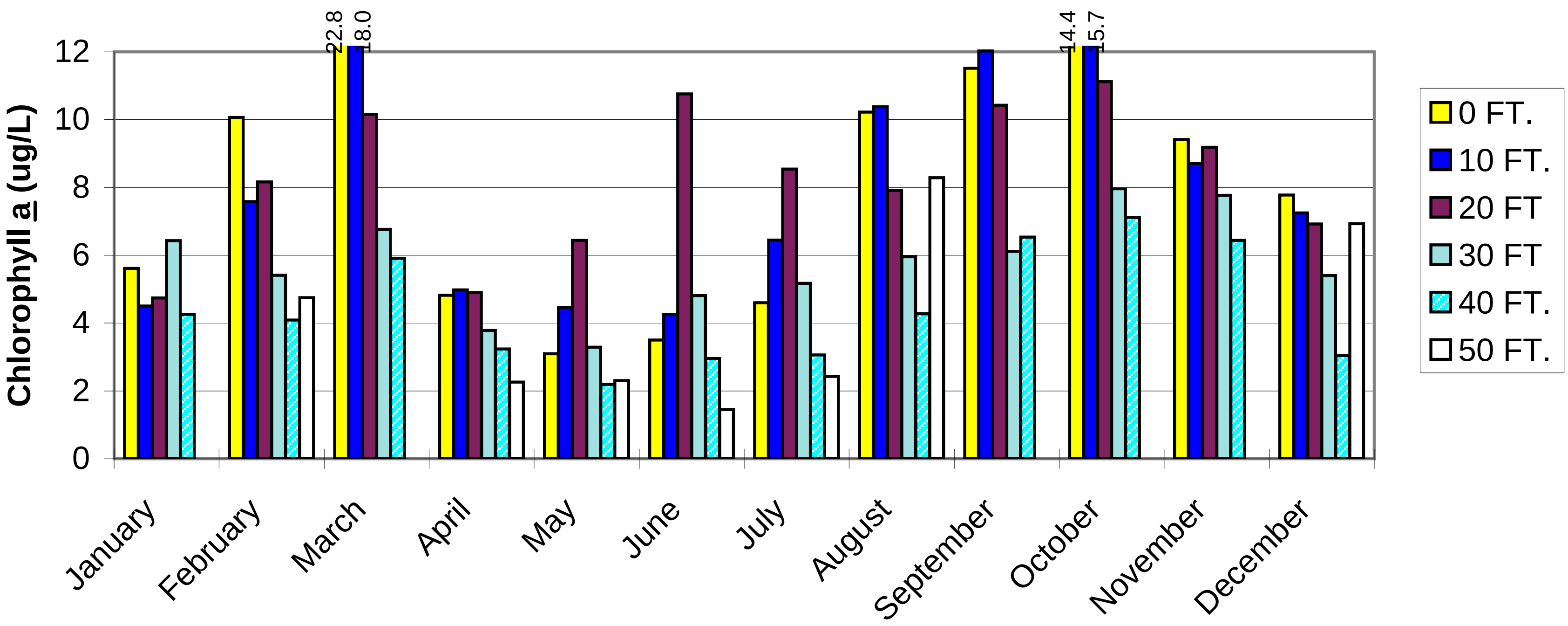
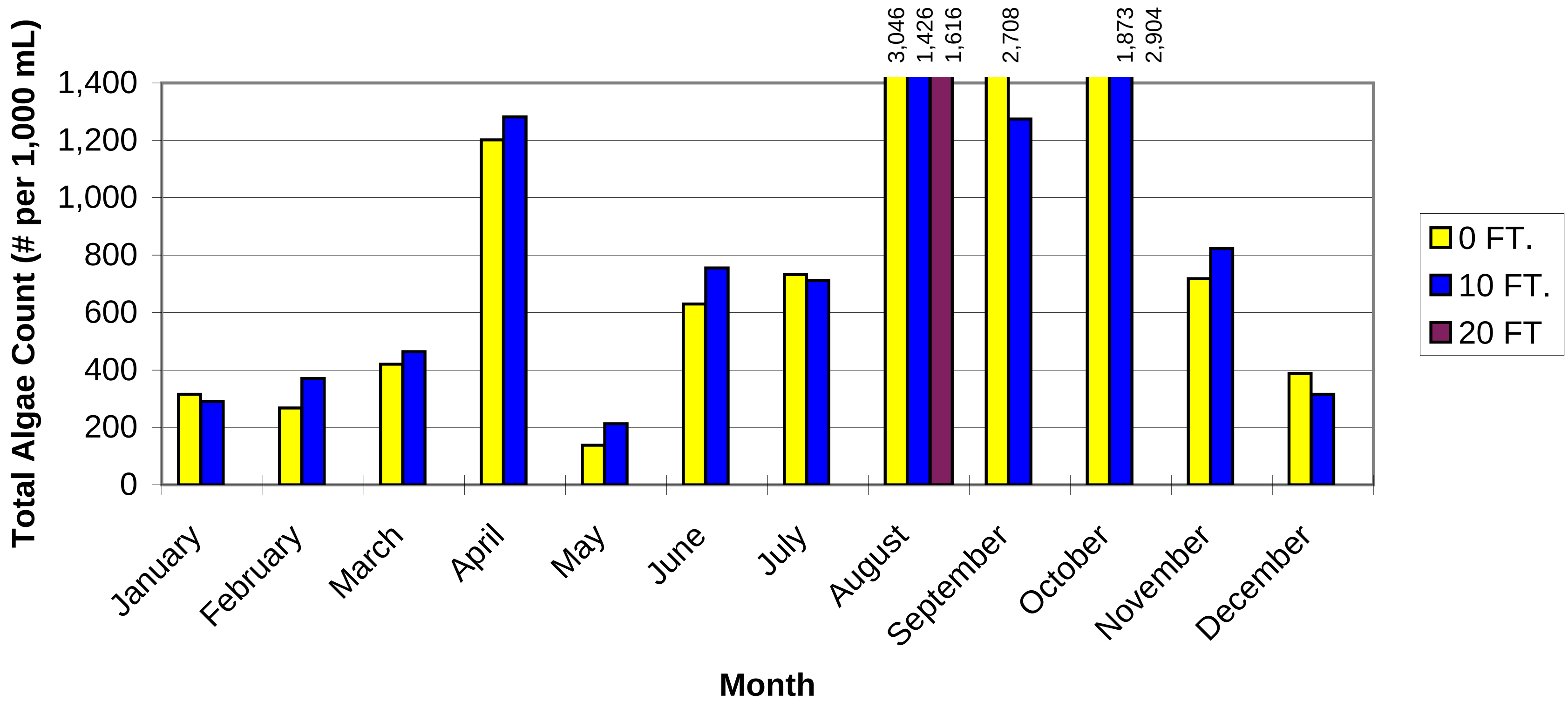


Figure 7-5c: Liberty Reservoir Average Monthly Total Algae Count

Monitoring Station NPA0105 (1994 - 2001)



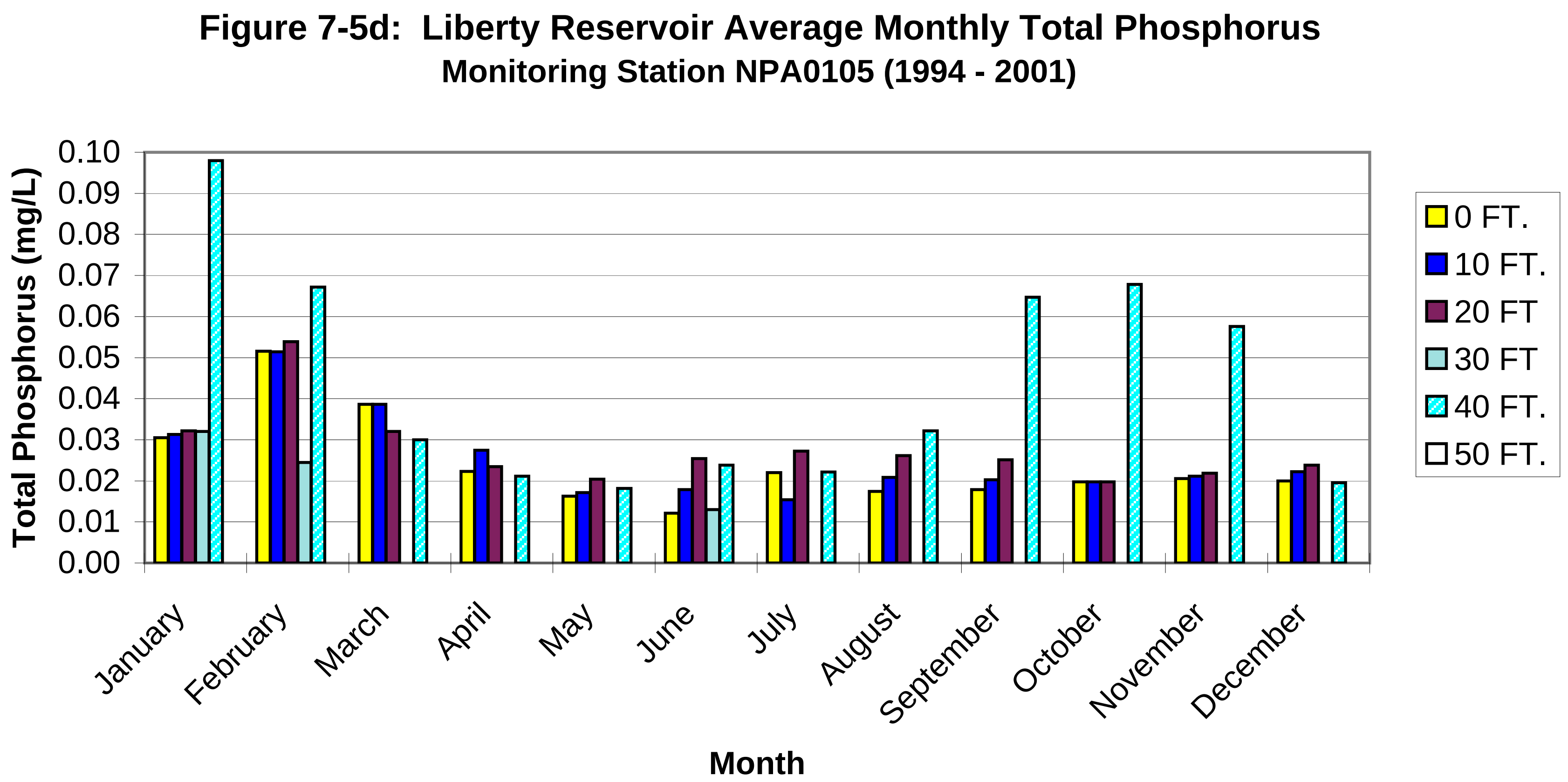
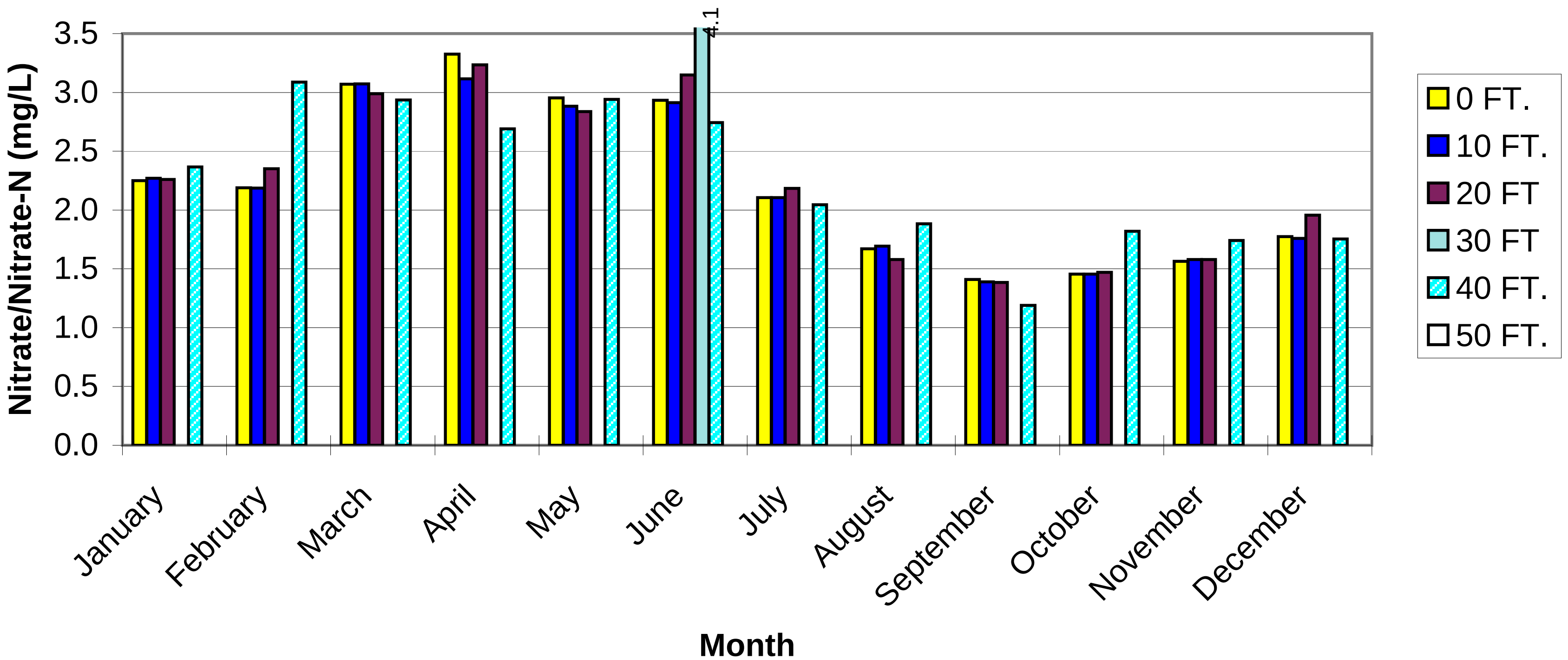


Figure 7-5d: Liberty Reservoir Average Monthly Total Phosphorus
Monitoring Station NPA0105 (1994 - 2001)
Total Phosphorus (mg/L)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
January
February
March
April
May
June
July
August
September
October
November
December
Month
0 FT.
10 FT.
20 FT
30 FT
40 FT.
50 FT.

Figure 7-5e: Liberty Reservoir Average Monthly Nitrate/Nitrite-N
Monitoring Station NPA0105 (1994 - 2001)



8.0 SUSCEPTIBILITY ANALYSIS

Each class of contaminants that were detected in the water quality data were analyzed based on the potential they have of contaminating the Liberty Reservoir and the City of Baltimore water intake. This analysis identified suspected sources or contaminants, evaluated the natural conditions that may decrease or increase the likelihood of a contaminant reaching the intake, and evaluated the impacts that future changes within the watershed may have on the susceptibility of the water intake.

8.1 Volatile Organic Compounds

Analytical data for VOCs are only available for the Ashburton Treatment Plant treated water. As discussed in Section 7, VOCs have not been detected in the treated water. Therefore, VOCs are not a current water quality problem; the primary potential source would be spillage during transportation of VOCs (Table 8-1).

8.2 Synthetic Organic Compounds

As discussed in Section 7, the City of Baltimore has not detected SOCs in its treated water, however, several SOCs have been detected during MDE's annual sampling events. Several pesticides have been detected at concentrations more than an order of magnitude less than the MCL. MDE sampled the raw water on July 17, 2000. Only di(2-ethylhexyl)phthalate (a common laboratory contaminant) exceeded 50 percent of the MCL (3.9 µg/L compared to the MCL of 6 µg/L) in the raw water sample. The primary potential sources of SOCs are agriculture and spillage during transportation of SOCs (Table 8-1). Pesticides are likely to be present in spring season runoff due to their use in agricultural practices. Due to the fact that SOCs have never been detected in treated water, SOCs are not considered a current water quality problem.

8.3 Metals

Analytical data for metals are only available for the Ashburton Treatment Plant treated water. As discussed in Section 7, none of the metals exceed 50 percent of the MCL in the treated water. Therefore, metals are not a current water quality problem; the primary potential sources of metals are natural deposits and spillage during transportation of metals (Table 8-1).

8.4 Total Dissolved Solids, Chlorides, and Conductivity

The trend of increasing total dissolved solids, chlorides, and conductivity in the tributaries to Liberty Reservoir are a potential concern. These trends may indicate that changes in human activities in the watershed are slowly having a negative impact on the water quality of the reservoir. These activities may also be contributing other undesirable chemical compounds to the reservoir. Although increases in total dissolved solids, chlorides, and conductivity can be caused by natural processes, it is more likely that the increasing trend is attributable to human activities such as industrial wastewater, domestic sewage (e.g., septic systems), urban runoff, stormwater, agricultural runoff, and salts for road de-icing. These trends serve as a red flag that development in the Liberty Reservoir watershed may be having a negative impact on water quality in Liberty Reservoir. Therefore, zoning, growth, and development need to be carefully planned and monitored to protect this source water.

8.5 Other Inorganics/Physical

This category includes nitrate/nitrite, fluoride, cyanide, asbestos, and turbidity. Of these parameters, only turbidity is a current concern. A reservoir system has considerable benefits when compared to river intakes with respect to turbidity fluctuations and maximum levels, largely due to lower suspended sediment loads. However, reservoir sources can be susceptible to turbidity problems.

The susceptibility of the system to turbidity has several facets. First, an exceedance of the MCL is not acceptable. Secondly, higher turbidity in raw water could translate into increased capital and operational costs for treatment.

Water is withdrawn from the reservoir using the intake gates that will provide the most consistency with regard to high water quality. Generally, only the middle of the three sets of Liberty Reservoir intake gates are used (located at 55 feet below the crest elevation of the reservoir) due to seasonal water quality changes at the upper water levels as well as those closer to the reservoir floor. However, during the drought of 2002, the gates at 55 feet below the normal crest elevation (as few as 30 feet below the water surface at that time) and 100 feet were opened simultaneously, and the mixed water exhibited characteristics well within the range of what can be considered normal for source water quality.

The most cost effective approach to maintain consistency of high water quality, and the most protective of the system, is to continue to strive to improve the overall water quality of Liberty Reservoir. Further reductions in algal growths should improve the anoxic conditions at depth, and should help minimize the susceptibility to turbidity. An evaluation of turbidity levels and how rapidly they fluctuate (at the reservoir intake, the raw water at the treatment system intake, and finished water) could provide additional insight into the susceptibility to turbidity. Such an evaluation could determine if there is a correlation between turbidity and treatment system operational parameters (e.g., chemical usage, filter backwashing frequency), thereby clarifying the degree to which the system is susceptible to turbidity.

8.6 Protozoa, Viruses, and Total/Fecal Coliform

All surface water sources are susceptible to pathogenic organisms. The data from the raw water testing for fecal coliform shows Liberty Reservoir to be of very high quality and poses a much lower risk from pathogenic microorganisms than most sources withdrawing directly from rivers or streams. The reservoir and intake depth provide considerable reduction in concentration of these organisms, yet not enough to say not susceptible.

The potential non-point sources of pathogenic protozoa, viruses, and bacteria in the source water of Liberty Reservoir include pasture (livestock), stormwater runoff, residential septic systems, and wildlife. Of these sources, the most significant potential increase in microbes may come from stormwater runoff due to increasing development in the source water areas. Future contamination is possible if conditions in the watershed continue to change with increased development. Each of the categories of pathogens is discussed briefly in the following sections.

8.6.1 Protozoa

Cryptosporidium and *Giardia lamblia* are protozoans that can cause gastrointestinal illnesses in humans. These protozoans have been analyzed monthly since September 1995 in the Ashburton Treatment Plant treated water; neither has been detected.

Prior to the SWA, no data existed for the occurrence of *Cryptosporidium* and *Giardia lamblia* within the watershed. Samples were collected from seven tributaries during September and October 2001 in the hours immediately following significant rain events (Table 7-7). The low concentrations of both *Giardia lamblia* and *Cryptosporidium* measured are consistent with the common occurrence of these protozoa in surface water sources throughout the U.S. and indicate the overall relatively high water quality of Liberty Reservoir.

The only detections of these pathogens in treated water were the occurrence of 8 empty *Giardia lamblia* cysts (per 100 liters) in an April 1998 sample and 14 amorphous *Cryptosporidium* oocysts (per 100 liters) in a September 1998 sample.

Although these pathogens have not been identified in a viable state in the raw water at the treatment plant, *Cryptosporidium* can remain viable in natural waters for up to 18 months. The time of travel study conducted during the SWA indicates that water from even the tributaries farthest from the intake may take less than a month to travel to the intake. Therefore, the source water must be considered susceptible to these organisms.

8.6.2 Viruses

There are no data available for viruses. MDE does not require the City of Baltimore to analyze for viruses.

8.6.3 Total/Fecal Coliform

The maximum monthly concentrations of fecal coliform analyses conducted for raw Ashburton Treatment Plant water in the last five years (1997 through 2001) were reviewed. For these 60 months, the maximum monthly concentrations ranged from 2 to 43, with a mean of 9.6 and a median of 7.8 (Table 7-2b). These low levels would not be expected to be a problem once the water is treated. The maximum monthly total coliform concentrations ranged from 7.8 to ≥ 2,400 and had a median of 70.

8.7 Disinfection Byproducts/Disinfection Byproduct Precursors

Disinfection of drinking water is one of the major public health advances in the 20th century. However, the disinfectants themselves can react with naturally occurring organic materials in the water to form unintended byproducts that may pose health risks. The EPA requires that large surface water systems comply with the Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) and the Interim Enhanced Surface Water Treatment Rule by January 2002. The maximum contaminant levels (MCLs) set for total trihalomethanes (TTHMs) and haloacetic acids (HAA), two classes of DBPs, are 80 :g/L and 60 :g/L respectively, on a system-wide running annual average (RAA).

Two modifications to the Stage 1 DBPR are upcoming under the Stage 2 DBPR. The Stage 2 DBPR will change the compliance monitoring locations and the way sampling results are averaged to determine compliance. The MCLs will remain the same; however, the compliance determination will be based on a locational running average (LRAA), as opposed to the system-wide RAA used under the Stage 1 DBPR. For LRAAs, the MCLs will have to be met at every monitoring location, whereas the RAA method allowed the system to average results over all monitoring locations.

Under Stage 2A (to be met three years after rule promulgation), all systems will have to comply with TTHM/HAA MCLs of 120/100 :g/L measured as LRAAs at each Stage 1 DBPR monitoring site, and continue to comply with the Stage 1 DBPR MCLs of 80/60 :g/L measured as RAAs.

Under Stage 2B (to be met three years after rule promulgation), systems serving 10,000 people or more must comply with the 80/60 MCLs measured as LRAAs at the monitoring sites identified during an initial distribution system evaluation (IDSE).

The City of Baltimore has been monitoring TTHMs and HAA in Ashburton Treatment Plant treated water (Table 7-2c) and points in the distribution system. In addition, DBPPs have been monitored in the raw and treated Ashburton Treatment Plant water (i.e., total organic carbon) (Table 7-2d).

All of the reported TTHMs and HAA analyses at the Ashburton Treatment Plant effluent in the past five years were less than the MCLs set by EPA. However, the concentrations of these compounds increase within the distribution system. A third quarter average TTHM concentration from remote sampling points within the distribution system was 76 :g/L (City of Baltimore, 1998), therefore it is possible that individual locations may not be able to meet the Stage 2B MCLs measured as LRAAs.

DBPPs tend to originate from terrestrial and aquatic vegetation (Cooke and Carlson, 1989). Therefore, both the land use in the Liberty Reservoir watershed and algal growths in the reservoir can contribute organic matter to the reservoir and increase DBPPs. Total organic carbon (TOC) in the raw water (annual maximum values between 2 and 3.5 mg/L) has been relatively low in comparison with similar lakes in the region. However, Liberty Reservoir generally has only one useable intake gate at elevation 365 feet mean sea level during the season of high algal bloom, although during the severe drought conditions in 2002 the elevation 320 feet gates were able to be used. Typically, during periods of high algal growth, the algae impair the water quality of the elevation 410 feet gates, and anoxic conditions impair the elevation 320 feet gates.

8.8 <u>Sedimentation</u>

Sediment transport from erosion in the watershed is transported into reservoirs where it is deposited, thereby slowly lessening the depth and volume of the reservoir. Sediment transport and deposition in a reservoir can have major adverse impacts on the water quality of the reservoir water. Usually, most of the sediment transport occurs during periods of high runoff. Although it is known that a considerable amount of suspended sediment is transported by the tributaries, as visually evident by the brown color of the tributaries during high flow events, and brown plumes in the reservoir. The extent to which sedimentation has impacted Liberty Reservoir is not currently known.

To address this issue, the Maryland Geological Survey (MGS) collected the field data required for bathymetric mapping of the reservoir in 2001. These data have not yet been compiled into a bathymetric map. MGS will also be collecting data to determine the amount of sedimentation that has occurred since the reservoir was constructed.

Once these data are available, the potential impacts of sedimentation on the reservoir can be evaluated. If sedimentation is determined to be adversely high, appropriate erosion and sediment control measures can be considered for implementation.

8.9 <u>Nutrients</u>

As discussed in Section 7, nutrient concentrations in the reservoir have been declining since the 1980s. As a result, the water quality has been gradually improving, as shown by the declining levels of algal counts as well as the increased dissolved oxygen concentrations in the hypolimnion. However, this improvement could readily be reversed. Liberty Reservoir is highly phosphorus limited, therefore, an increase in phosphorus loading to the reservoir would be expected to cause a deterioration in water quality. The recent lowering of MCLs for turbidity necessitates maintenance of current water quality at a minimum, and preferably improvement in water quality. The type, sizing, and capital and operational costs of the new filtration facilities that will be required to meet the new turbidity MCLs will be significantly affected by the water quality of the intake water.

The standard operating procedure for intake operation is to maintain the four Elevation 365 feet gates (55 feet below dam crest) open, and keep the Elevation 320 and Elevation 410 feet gates closed. This practice has resulted in water of acceptable quality being drawn throughout the year. The gates at Elevation 410 feet (10 feet below the dam crest) would draw water of poor water quality due to algal blooms during the algal growing season; the gates at Elevation 320 feet (100 feet below the dam crest) would draw more turbid water that is higher in manganese and low in dissolved oxygen during much of the period that the reservoir is thermally stratified. Under drought conditions, the water level could drop in the reservoir such that the area of algal blooms could impact the Elevation 365 gates.

Therefore, nutrients are a primary concern and threat to the Liberty Reservoir as a source water.

8.10 <u>Spills and Time of Travel</u>

The Liberty Reservoir source water must be considered susceptible to a spill of a harmful substance (e.g., hazardous material) into the reservoir or any tributary to the reservoir. The degree to which the source water is susceptible will depend on the characteristics of the material spilled (toxicity as well as the characteristics of the material such as density and solubility), the magnitude and location of the spill, emergency response time and capabilities, and the physical, chemical, and biological processes that may reduce or increase the severity of the spill. A few examples of important physical, chemical, and biological processes that may reduce the threat to the source water include dilution, turbulence/mixing, volatilization, adsorption to solids, settling, chemical precipitation, reservoir stratification, and biodegradation.

It is difficult to make general statements about susceptibility due to the wide range of factors that affect the susceptibility of the source water. It is clear that the best way to minimize susceptibility is to make every reasonable effort to keep unwanted materials from entering the waters of the Liberty Reservoir watershed. However, the most significant and likely threats to the integrity of the source water must be identified before the effectiveness of preventive measures can be evaluated and prioritized. Regardless of the nature of the spill, the greater the distance a spill is from the intake, and the longer that it takes for the spilled material to reach the intake, the less likely the spill is to adversely affect the quality of the source water at the intake. Therefore, distance and time of travel can be used as an initial criterion to evaluate susceptibility. The results of the time of travel studies conducted in the tributaries and reservoir provide information with which to conduct this evaluation.

8.10.1 Tributary Time of Travel Studies

The tributary time of travel (TOT) studies indicated that a contaminant would move slowly from the headwaters to the reservoir under low flow conditions. The dye plume became more spread out as it traveled downstream, and considerable dilution was evident. Under higher flow conditions in the tributaries, a contaminant would be flushed downstream at a much more rapid rate. The higher flow TOT data indicated that the peak concentration was approximately twice the peak concentration observed under low flow conditions.

The tributary TOT studies have implications for susceptibility of the reservoir to contaminant spills. The reservoir may be more susceptible from a spill during a higher flow event (e.g., during or immediately after a large storm) than during periods of low flow:

- A contaminant would be more concentrated when it reached the reservoir;
- The contaminant would reach the reservoir faster under higher flow events; and
- The emergency response time is considerably less for a higher flow event.

The TOT data can be used to formulate response times and locations for spills along the tributaries. Contaminants that do not readily dissolve in water (e.g. gasoline or oil) could be contained with booms at a downstream road crossing. Contaminants that dissolve readily in water would be difficult to remove prior to reaching the reservoir due to the volume of contaminated water, although spills in the headwaters under low flow conditions might be containable with advance planning.

8.10.2 In-Reservoir Time of Travel Studies

The in-reservoir time of travel (TOT) studies considered the transport of contaminants from three bridges crossing the reservoir: the Route 140 bridge, the western Route 26 bridge, and the eastern Route 26 bridge.

This study indicated the intake is potentially susceptible to a spill from the eastern Route 26 Bridge, due to its proximity to the intake.

8.10.3 Significance of Water Quality on Water Withdrawal at the Intake

Water is withdrawn from the reservoir using the intake gates that will provide the most consistency with regard to high water quality. Under normal operating conditions, it has been most advantageous to maintain raw water flow to the Ashburton Water Treatment Plant through the gates positioned at 55 feet below the crest elevation. This allows the City to maintain source water to the treatment facility that is only marginally affected by algal populations found in the upper reservoir elevations, and also relatively free from the seasonal anoxic conditions leading to dissolved iron and manganese in the lowermost elevations. However, during the drought of 2002, the gates at 55 feet below the normal crest elevation (as few as 30 feet below the water surface at that time) and 100 feet were opened simultaneously, and the mixed water exhibited characteristics well within the range of what can be considered normal for source water quality.

In the case of a spill, contaminated water might not be present at all three sets of gates. This would likely be the case during periods of reservoir stratification because the thermocline greatly reduces the vertical transport of water and contaminants. Therefore, improving the reservoir's overall water quality such that all three gate levels could be used on a more regular basis to provide higher water quality would reduce the susceptibility of the system to contamination by spills.

8.11 Susceptibility Analysis Summary

Liberty Reservoir is susceptible to several classes of contaminants. An increasing trend for total dissolved solids, chlorides, and conductivity in the tributaries indicates that human activities, such as development, are having an increasing affect on reservoir water quality. This trend is an indicator of underlying water quality problems. Turbidity is also a concern and can significantly increase water treatment costs. Liberty Reservoir is also susceptible to protozoa, viruses, and coliforms, as are all surface water sources. However, sampling data indicate that Liberty Reservoir poses a much lower risk from pathenogenic organisms than most source waters drawing directly from rivers or streams. Changing land use and algal growth may increase disinfection byproduct precursors in Liberty Reservoir, thereby making the source water susceptible to disinfection byproducts. It is currently unknown whether the reservoir is vulnerable to significant sedimentation. A study is underway to determine whether significant sedimentation has occurred in Liberty Reservoir. Nutrients are a primary concern and threat to the reservoir. Algal blooms, caused by nutrient inputs, threaten the intakes with low quality raw water. Table 8-1 provides a summary of the susceptibility analysis for the Liberty Reservoir intake.

Liberty Reservoir is also susceptible to contaminant spills, both directly into the reservoir and into the tributaries. A spill from the eastern Route 26 bridge is most likely to affect the water intake due to its proximity.

Table 8-1: Susceptibility Analysis Summary Table – Liberty Reservoir Intake

Contaminant	Water Quality (50% of MCL[1] Exceeded?)	Potential Sources	Natural Attenuation in Watershed[2]	Evaluation of Change to Natural Conditions[3]	Intake Integrity	Currently Susceptible
Volatile Organics	No[5]	Spills	Yes	Possible	No	See Text
Synthetic Organics	No[5]	Agriculture, Spills	Yes	Possible	No	See Text
Heavy Metals	No[5]	Natural Deposits, Spills	Yes	Possible	No	See Text
Nitrate/Nitrite	No	Agriculture, Septic, Residential	Yes	Possible	No	See Text
Fluoride	No Data	Natural Deposits	No	Possible	No	See Text
Cyanide	No Data[6]	Spills	Yes	Possible	No	See Text
Asbestos	No Data[6]	None	No	Possible	No	See Text
Radionuclides	No[5]	Natural Deposits, Spills	No	Possible	No	See Text
Total/Fecal Coliform	Not Applicable	Land Use, Septic	Possible	Possible	No	See Text
Protozoa	No	Land Use, Septic	Possible	Possible	No	See Text
Viruses	Not Applicable[7]	Land Use, Septic	Possible	Possible	No	See Text
TTHMs/HAA (DBPs)[4]	Yes	Natural Organic Materials	No	Possible	No	See Text
Turbidity	Yes	Erosion	No	Possible	No	See Text
Sedimentation	Not Applicable	Erosion	Yes	Possible	No	See Text
Nutrients	Not Applicable	Erosion, Septic, Residential, Land Use	Yes	Possible	No	See Text

Notes:
1. MCL- maximum contaminant level as of January 2002
2. This column refers to whether or not natural attenuation of the compound is occurring.
3. This column evaluates the likelihood that water quality conditions are likely to change (either improve or degrade).
4. DBPs/DBPPs: Disinfection byproducts/disinfection byproduct precursors
5. Based on Ashburton Treatment Plant treated water data; no data are available for the intake.
6. Not analyzed; MDE statewide waiver for cyanide and asbestos.

7. The City of Baltimore is not required to analyze for viruses.

9.0 RECOMMENDATIONS FOR SOURCE WATER PROTECTION PLAN

9.1 Liberty Reservoir Watershed Management

The Liberty Reservoir Watershed is a critical component of the City's overall water system supply system. Protection of this resource now and in the future is vital. As such, all reasonable steps must be taken to maintain, and where possible to strengthen, protections. Specific recommendations are described below.

9.1.1 Strengthening Watershed Agreement

The City of Baltimore, Baltimore County and Carroll County entered into a watershed management agreement in 1979. This agreement established a formal framework for the signatory organizations to review problems and proposed actions that may affect the watershed. This program was strengthened with the signing of the Reservoir Watershed Management Agreement of 1984. The 1984 agreement established reservoir management goals, developed an organizational framework, and provided a vehicle for the parties to establish policies to achieve the stated goals. The signatory parties formally reaffirmed this agreement in 1990. The signatory organizations were Baltimore City, Baltimore County, Carroll County, Maryland Department of Agriculture, Maryland Department of the Environment, Baltimore County Soil Conservation District, Carroll County Soil Conservation District, the Water Quality Coordinating Committee, and the Reservoir Watershed Protection Subcommittee.

On February 24, 2003, Baltimore City, Baltimore County, Carroll County, Baltimore County Soil Conservation District, Carroll County Soil Conservation District, and the Maryland Department of the Environment signed a Declaration of Reaffirmation of the 1984 Reservoir Watershed Management Agreement. The reaffirmation is a renewed commitment to the 1984 agreement and authorizes the development of a new, more comprehensive agreement and Action Strategy in the coming year.

Under the Reservoir Watershed Management Program, each participating organization retains jurisdictional authority while taking a leadership position in implementing components of the agreed upon Action Strategy. Every year, the Reservoir Watershed Protection Subcommittee reviews progress in implementing the Action Strategy and issues a report summarizing reservoir conditions and progress made in implementing the specific proposals of the Action Strategy. The Reservoir Technical Group is responsible for coordinating the implementation of the Action Strategy and provides technical guidance in support of the program.

Given the importance of maintaining and improving the water quality of the Liberty Reservoir, it is vital that the signatory parties continue to work together to protect this important regional resource. To the greatest extent possible, any outstanding differences between the signatory parties should be resolved in a manner that recognizes the importance of improving the water quality of the reservoir.

Additionally, Baltimore City's representatives on the Reservoir Technical Group must continue to work closely with Baltimore City's water plant personnel and other Department of Public Works representatives to ensure that the water system, particularly the Ashburton Water Treatment Plant and the Liberty Reservoir intake structure continue to be operated efficiently and in a manner that reflects best management practices (BMPs).

9.1.2 Protective Low Density Zoning

Maintaining low density zoning that is protective of the reservoir's water quality is a critical component for managing Liberty Reservoir as a high quality source water. Over development of the watershed will result in a deterioration of water quality. The susceptibility analysis has identified a trend of increasing concentrations of dissolved solids. This is frequently an indication that activities in a watershed are having an increasing impact on a waterbody. These activities, if not controlled and managed properly, can have a significant adverse effect on the quality of the source water, and can ultimately threaten the usability of the source water.

The use of zoning restrictions in and around the reservoir is a very important tool for controlling point and non-point sources. This tool, along with other watershed management practices, has resulted in significant improvements to the overall water quality in the reservoir. Industrial and residential development pressures, particularly in Carroll County, threaten to undermine this approach.

Based on the findings described in this report, the results of previous monitoring and analysis of the watershed and general best management approaches employed throughout the United States, reservoir protection through appropriate zoning regulations is a proven technique for protecting the water supply. Any move away from this approach will likely result in immediate and longer-term detrimental impacts to the Liberty Reservoir. As such, all possible steps should be taken to resolve this issue in a manner that is protective to the watershed and that keeps the zoning restrictions in-place.

9.1.3 Management of City-Owned Property

A forest management study was conducted for the City of Baltimore (Northrop, 2003). The study recommendations pertinent to the management of the existing City-Owned forest buffer zone around Liberty Reservoir are under review by the City. As part of the review, the recommendations in the report should be considered for implementation.

9.2 Water Quality Sampling Data for Watershed Management, Trend Analyses, and Contaminant Source Identification

9.2.1 Expanded Water Quality Sampling Program and Water Quality Trend Analyses

A complete temporal trend analysis to evaluate water quality changes over time needs to be performed for both tributaries and in-reservoir water quality parameters. To the extent possible, this analysis should be conducted in a manner that allows comparison to the 1981 through 1994 trend analyses reported in the Reservoir Watershed Management Report (City of Baltimore 1996). The goal of the trend analysis would be to identify temporal trends that may be negatively impacting the reservoir. As described in subsequent sections, some data that are required for the tributary analysis are not currently available.

In addition, particular attention should be focused on spatial trends, both among the tributaries to identify potential problem watersheds, and within the reservoir itself. Additional parameters, such as parameters to evaluate disinfection byproduct precursors, should be included in the existing tributary and in-reservoir monitoring program. Subsequent sections describe the goals in greater detail.

9.2.2 Tributary Storm Event Sampling

Until 1994, tributary sampling during storm events was specifically targeted to collect data representative of storm events that result in high tributary discharges. Tributary storm sampling was discontinued from January 1994 to September 2000. The storm sampling program was restarted in October 2000 and is currently active. Continue targeting storm event sampling of tributaries to provide data comparable to 1981 – 1993 as presented in Table 7-3. Many of the water quality parameter specific recommendations discussed below are dependent on the collection of new storm event data.

9.2.3 Nutrient Loading Control

The loading of nutrients in general, and phosphorus in particular, needs to be maintained at its current, or preferably lower, levels. Non-point sources are responsible for the majority of the phosphorus loading to Liberty Reservoir. A reduction in phosphorus loading should result in less algae growth. Some of the potential benefits from further lowering algae growth include a reduction in turbidity and suspended solids that require removal at the Ashburton Water Treatment Plant, lessening the organic carbon released by algae, increasing the dissolved oxygen in the hypolimnion, and reducing manganese concentrations in the hypolimnion.

Land use planning and implementation of BMPs for non-point sources need to be periodically reevaluated. Non-point source BMPs are managerial, structural, and nonstructural techniques that are recognized to be the most effective and practical means to prevent or reduce non-point source pollutants from entering surface waters. For Liberty Reservoir, the most important categories of BMPs for controlling nutrients appear to be stormwater controls and agricultural non-point source controls, although other sources (e.g., septic tanks, residential fertilizer use) must also be considered.

Stormwater management systems are frequently used to control sediment in surface runoff and to reduce the velocity of storm flows into stream channels. Carroll County maintains a database of performance for many of the stormwater management systems in the county and conducts visual inspections at each site at least every two years. It is estimated that there are approximately 100 stormwater management systems located within the Liberty Reservoir watershed. The existing data should be used to determine the extent of urban land that drains to stormwater facilities and to assess the effectiveness of the stormwater management systems. Existing data should be supplemented with field observations, as needed, to formulate an accurate evaluation of existing BMPs and to determine what additional BMPs would be effective in maintaining or improving the water quality of Liberty Reservoir.

Agricultural BMPs are valuable tools for minimizing the effects of agricultural related activities on watersheds. Examples of agricultural BMPs for the control of nutrients include agricultural waste management systems, runoff management systems, conservation tillage and crop sequencing, contour farming and stripcropping, filter strips, field borders, streambank protection, and wetland development or restoration, among others. The utilization and effectiveness of agricultural BMPs within the Liberty Reservoir watershed need to be evaluated. The BMPs used within the Carroll County portion of the Liberty Reservoir watershed are monitored by the Carroll Soil Conservation District for their effectiveness in protecting watershed systems. The Carroll Soil Conservation District records and maintains this information in a database to conduct studies such as soil loss analysis. A similar database is maintained by the Natural Resources Conservation Service. The two databases could be used as a starting point to assess the distribution and current status of

BMP utilization, and to provide a general assessment of the effectiveness of existing BMPs in the Liberty Reservoir watershed.

9.2.4 Disinfection Byproducts and Disinfection Byproduct Precursors

An evaluation of the source of the disinfection byproduct precursors (DBPPs) could identify a means to reduce the concentration of DBPPs in the raw water, and thereby reduce the concentrations of disinfection byproducts (DBPs) measured in the distribution system. The relative contribution of DBPPs by Liberty Reservoir source water and the other source waters should be determined. Some of the potential problem areas in the distribution system may be attributable to source waters other than Liberty Reservoir.

MDE's TMDL sampling data for dissolved and total organic carbon in tributaries and at in-reservoir stations is a good starting point for evaluating the sources of DBPPs. However, additional data are required to evaluate the loading of organic carbon seasonally (e.g., including natural organic matter, algae as a source of organic matter, sources from human activities) to Liberty Reservoir, particularly during high runoff events, and how these relate to the observed in-reservoir concentrations. Additionally, the relationship of algae to organic carbon in the reservoir should be investigated with some additional sampling. This data collection effort could be conducted concurrently with the City of Baltimore's routine tributary and reservoir monitoring program. If the primary source of organic carbon enters the reservoir via the tributaries then land use preferences and runoff control strategies may need to be reconsidered. If algae are identified as a primary source, then strategies for further reducing algal growths would need to be considered; these strategies would have to include a reduction in phosphorus loads to the reservoir to achieve decreased algal growth.

Although there are currently water quality problems at the level of the lower intake gates created by the low dissolved oxygen concentrations, it would be worthwhile to evaluate DBPPs at the lower gates. If the DBP formation potential is significantly less at the lower gates compared to the middle gates (currently used all year), the lower gates might be a better source during at least portions of the year if the other water quality problems at the lower gates could be resolved.

9.2.5 Turbidity

The City of Baltimore will be modifying its water treatment process to meet the recently lowered MCL for turbidity. From a cost perspective, improvement in the water quality of the source water would be preferable to engineering solutions at the treatment plant. The lower the turbidity and suspended solids are in the source water, the less expensive the treatment system will be to construct and operate. It is also important to consider the maximum turbidity in the intake water. Peak concentrations place the highest demands on the treatment facility, and require larger chemical costs for coagulation and/or a larger filtration capacity to accommodate more frequent backflushing and other operational requirements. The highest raw water turbidity readings have been observed from January through April (Table 7-2c) when the reservoir is not stratified, for example, turbidity exceeded 6 NTU in January 1997, February 1998, March 1998, January 2000, and April 2000.

Therefore, a rigorous study of the impact of raw water turbidity on plant performance and treatment costs is recommended. The study should use existing data to compare the turbidity in the reservoir intake water, the treatment system raw water, and the treatment system finished water to determine if there is a correlation with treatment system operational parameters (e.g., chemical usage, filter backwashing). The study should also evaluate the magnitude and rate of change of turbidity fluctuations in the raw water; both are factors that can have an impact on the efficiency and cost of operating the water treatment system. If this study identifies that the raw water turbidity has substantial impacts on plant performance or treatment costs, protective measures would need to be considered. Implementation of appropriate protective measures would require identifying the cause of the evaluated turbidity. This would require correlating raw water turbidity with in-reservoir conditions, such as algal blooms, algal die offs, precipitation and runoff, reservoir level and wind velocities and direction (e.g., exposed banks due to reservoir drawdown). Once the cause of the elevated turbidity is identified, appropriate corrective measures could be developed minimize the susceptibility of the water treatment system to turbidity.

9.2.6 Dissolved Solids

The trend of increasing total dissolved solids, chlorides, and conductivity in the tributaries to Liberty Reservoir are a potential concern. These parameters can act as surrogates for other water quality parameters; when total dissolved solids show an increasing or decreasing trend, there is a high probability something affecting other water quality parameters has occurred in a watershed. This can be an early warning signal that other pollutants may also be present. The City of Baltimore reservoir data indicate that chlorides are increasing in the reservoir. Monitoring should be conducted in all of the major tributaries to identify the cause of this trend.

The most likely potential non-point sources for chloride in the Liberty Reservoir watershed are road salt, animal wastes, agricultural and residential fertilizer, and septic tanks. Generally, chloride concentrations tend to increase with increasing development in a watershed.

A cost effective initial monitoring step would be the field measurement of conductivity to identify areas of higher conductivity (and therefore, likely higher chloride) and to establish temporal or seasonal trends. Temporal trends can provide insight into the cause of elevated chloride concentrations. For instance, higher values during snow melt periods may be due to road salt application. A reduced number of sampling locations for total dissolved solids and chlorides could then be established based on these conductivity data. Monitoring stations should be established such that potential problem watershed areas could be identified and monitored over time. Once the cause(s) of the observed trend has been identified, appropriate BMPs can be utilized to address sources of concern.

9.3 Protective Actions for Identified Contamination Threats

9.3.1 Engineering Controls for Spills at Eastern Route 26 Bridge

The feasibility and cost of installing engineering controls for spills at the eastern Route 26 bridge should be evaluated. The integrity of the water quality at the Liberty Reservoir intake is most susceptible to a spill occurring on this bridge. One possible solution to be considered should be the installation of a collection system that would collect any spilled liquid and divert it to a collection area at one or both ends of the bridge. The collection area(s) would be similar to a storm water collection basin, and would provide sufficient storage capacity to contain the spilled material. Such a system should be designed to be low maintenance with a minimum of mechanical components.

9.3.2 Traffic Accident Statistics and Pattern Analysis

Traffic accident statistics for accidents involving hazardous materials should be compiled for the Liberty Reservoir watershed to identify potential problem locations. Determining the hazardous materials involved may be useful for planning for hazardous spills. This information is available from MDE's Emergency Response office.

A traffic study should be conducted to evaluate the patterns of hazardous material transport through the watershed. The types of hazardous material carriers (including septage haulers), and the frequency of passage through the watershed need to be evaluated. Emphasis should be placed on the Route 26 bridges over the reservoir.

9.4 Additional Evaluation of Potential Contaminant Sources

Existing information identifies potential contaminant sources only by the general category of problem (e.g., leaking UST), activity (e.g., junkyard, auto business), or permits (e.g., hazardous waste generators, NPDES permits). Specific information concerning the contaminants used, manufactured, or stored at each of the potential contaminant sources identified should be compiled. This information could be obtained from existing records (such as individual permits), contacting major facilities in the watershed, and from typical potential contaminants that are used by the types of activities (e.g., petroleum products at auto businesses). This information would enhance the ability of the City of Baltimore to protect the integrity of the Liberty Reservoir water supply by providing data with which to identify, develop, and implement preventive measures and emergency response procedures.

9.5 Sedimentation

A review should be conducted upon the completion of the MGS mapping of sedimentation that has occurred in the reservoir since the reservoir was constructed. These data will be a primary determinant in the evaluation of the susceptibility of Liberty Reservoir to sedimentation. If needed, appropriate actions should be developed and implemented to further control sediment input to Liberty Reservoir.

10.0 REFERENCES

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Appendix A

Sections from the Comprehensive Plan for Water Facilities, Volume 8: Watersheds and Raw Water Reservoir Assessment Report, City of Baltimore, April 1998.

3.2.2.4 Tributary Water Quality

Watersheds are subject to urban and agricultural activities including:

- Industrial and commercial activities
- Energy facilities
- Transportation facilities
- Sewerage infrastructure
- Waste disposal
- Agriculture
- Livestock management
- Household hazardous substances

Degradation and contamination of water supplies can result from each of these activities. Reservoir tributaries serve as conduits transporting natural and anthropogenic pollution to the water supply reservoirs. Pollutants of concern include nutrients such as nitrogen and phosphorus species, sediments resulting from storm related runoff, heavy metals, herbicides and pesticides, petroleum hydrocarbons, pathogenic microorganisms, and dissolved minerals and organic matter. The presence of these contaminants can lead to eutrophication of water supply impoundments and can significantly impact treatment requirements at potable water treatment facilities.

The City recently completed a comprehensive reservoir water quality assessment that involved over 20,000 samples analyzed for multiple water quality parameters [1]. In addition to reservoir sampling, the City also sampled tributary streams and evaluated pollutant loads from point sources such as POTWs. Parameters of interest included alkalinity, ammonia-nitrogen, nitrate-nitrogen, chlorides, conductivity, flow, dissolved oxygen, dissolved phosphorus, total phosphorus, dissolved solids, suspended solids, total solids, turbidity, water temperature, and hydrogen ion. Both dry weather and wet weather sampling was completed. The results of this effort are summarized below.

The overall annual TP loads to Liberty Reservoir watersheds from wastewater effluents has decreased approximately 95% to an average of 28 kg between 1989 and 1994 vs. 512 kg between 1983 and 1986. A precipitous decline was observed between 1987 and 1988. Total phosphorus levels have remained steady since this decline. Similar declines in total nitrogen loading were also observed during this period

Total ammonia and phosphorus loads from wastewater treatment facilities also declined in the Loch Raven/Prettyboy watersheds. The average annual TP load between 1990-1994 was 71% lower than the average load between 1983 and 1988. During this period, nitrate and nitrite loads increased 1384% and 41% respectively. This can be attributed to process changes at the Hampstead Wastewater Treatment Plant.

The results of dry weather flow stream monitoring revealed that almost every station in all three reservoir watersheds exhibited increasing levels over time for nitrate-nitrogen, dissolved solids, chlorides and conductivity. In contrast, most streams in the Liberty Reservoir watershed exhibited decreasing TP levels. This is consistent with decreasing phosphorus levels in the reservoir (See discussion below). Qualitative assessments for each of the streams with respect to each of the water quality parameters measured is summarized in Tables 3.4 through 3.6.

Dry weather pollutant loadings were normalized to watershed area to allow comparison of loadings from each watershed. Bonds Run and Georges Run exhibited the highest dry weather areal loads for nearly all measured parameters. Georges Run and Western Run had the highest TP loadings. Also experiencing high TP loadings were Little Falls, Dulaney Valley Branch, the Gunpowder River at Gunpowder Rd, and Bonds Run.

Total phosphorus concentrations in dry weather tributary flows exhibited a strong seasonal effect with peaks in late summer. Total phosphorus levels reach their highest in the tributaries when the reservoirs are most susceptible to algal blooms. The highest peaks were observed in Western Run (70-80 μg/L), Gunpowder River at Gunpowder Rd (70-80 μg/L), Georges Run (90 μg/L), and the North Branch of Patapsco River at Cedarhurst (60-70 μg/L). Observed peaks were considered to be at eutrophic levels.

Other parameters such as alkalinity, dissolved oxygen, and nitrate-nitrogen exhibited typical seasonal cycling. For nitrate, the monthly median lows ranged from 1.1 to 4 mg/L while the peaks ranged from 1.8 to 5.5 mg/L. The highest nitrate-nitrogen concentrations were observed in Georges Run. Peaks occurred in winter months for the majority of the tributaries.

Table 3.4 - Dry Weather Concentration Temporal Trends Observed at Loch Raven Reservoir Tributary Sampling Stations, 1981-1993

Water Quality Parameter	Tributary					
	Dulaney Valley Branch	Beaver Dam Run	Little Falls	Western Run	Gunpowder at Falls Rd.	Gunpowder at Glencoe
Alkalinity	None	None	Up	None	Up	Up
Chlorides	Up	None	Up	Up	Up	Up
Conductivity	None	None	Up	Up	Up	Up
pH	Down	Down	None	None	None	Down
Nitrate-nitrogen	Up	Up	Up	Up	None	Up
Dissolved Oxygen	None	None	Up	None	Up	None
Dissolved Oxygen % Saturation	None	Down	Up	None	Up	None
Total Phosphorous	None	None	None	None	None	None
Dissolved Solids	Up	None	Up	Up	Up	Up
Water Temperature	None	None	None	None	Down	None

Table 3.5 - Dry Weather Concentration Temporal Trends Observed at Prettyboy Reservoir Tributary Sampling Stations, 1981-1993

Water Quality Parameter	Tributary		
	Grave Run	Georges Run	Gunpowder at Gunpowder Road
Alkalinity	Up	None	None
Chlorides	Up	Up	Up
Conductivity	Up	Up	Up
pH	None	None	None
Nitrate-nitrogen	Up	Up	Up
Dissolved Oxygen	None	None	None
Dissolved Oxygen % Saturation	None	Up	None
Total Phosphorous	None	Down	None
Dissolved Solids	Up	Up	Up
Water Temperature	None	None	None

Table 3.6 - Dry Weather Concentration Temporal Trends Observed at Liberty Reservoir Tributary Sampling Stations, 1981-1993

Water Quality Parameter	Tributary					
	Bonds Run	Middle Run	Little Morgan Run	Beaver Run	Morgan Run	North Branch Patapsco at Cedarhurst
Alkalinity	Up	Up	Up	None	None	None
Chlorides	Up	Up	Up	None	Up	None
Conductivity	Up	Up	Up	Up	Up	Up
pH	Down	None	None	None	Down	Down
Nitrate-nitrogen	Up	Up	Up	Up	Up	Up
Dissolved Oxygen	None	Up	None	None	None	None
Dissolved Oxygen % Saturation	Up	None	None	None	None	None
Total Phosphorous	Down	Down	Down	None	Down	Down
Dissolved Solids	Up	Up	Up	Up	Up	None
Water Temperature	None	None	None	None	None	None

The results from stormwater modeling revealed that TP loads were dominated by stormwater runoff loads. Dry weather loads of TP ranged from 11 to 31 % of total load for Loch Raven Reservoir depending on whether it was a dry or wet year. Loch Raven watersheds had a higher percentage of their TP and suspended solids total loads carried during dry weather as compared to the watersheds for the other reservoirs. The lowest dry weather TP and suspended solids percentages for Loch Raven watersheds were seen in Beaver Dam Run. Beaver Run, a watershed of Liberty Reservoir, had the lowest percentage of all stations. North Branch of Patapsco at Cedarhurst had the highest percentage of total suspended solids load attributed to dry weather flows. These results are summarized in Table 3.7.

The dry weather TP concentrations in the streams were similar to those observed in the lowermost Loch Raven in-lake station. The similarity between the dry weather TP loads observed in the tributaries vs. reservoir TP concentrations provides evidence that dry weather phosphorus loading may be contributing the bulk of the bioavailable phosphorus. Further investigation is needed to determine which source of the total phosphorus load (sediment bound, soluble, and benthic) are primarily responsible for controlling biomass production in the reservoir.

Table 3.7 - Total and Dry Weather Average Areal Total Phosphorus and Suspended Solids Annual Loads for Selected Tributary Monitoring Stations - 1983-1990

Tributary	Total Avg. TP (kg/km^2)	Dry Weather Avg. TP (kg/km^2)	Total Avg. TSS (kg/km^2)	Dry Weather Avg. TSS (kg/km^2)
Loch Raven				
Beaver Dam	85	7	95	1.2
Glencoe	54	7	40	1.2
Western Run	122	13	69	2.1
Liberty				
Beaver Run	110	6	110	0.4
Cedarhurst	113	9	64	1.3
Morgan Run	87	6	71	0.5

3.2.2.5 Reservoir Water Quality

As indicated above, the City recently completed a comprehensive reservoir water quality assessment that involved over 20,000 samples analyzed for multiple water quality parameters [1]. Nutrient conditions and algal growth in the reservoirs, water quality trends from the last decade, and water quality data from the hypolimnion were all presented in this report. Parameters investigated beginning in 1981 include total phosphorus (TP), total algal counts (TAC), Secchi disk depth, chorophyll a, ammonia, nitrate-nitrogen, conductivity, manganese, iron, dissolved oxygen, color, turbitiy, and pH.

Epilimnetic and hypolimnetic water quality data from the reservoir sampling stations are summarized in Tables 3.8 through 3.11. The results of this investigation yielded several key findings which are summarized below.

Table 3.8 - Year-round Epilimnetic Water Quality Median Data From Primary Sampling Stations at Reservoirs - 1981-1993

Parameter	Unit	Loch Raven	Prettyboy	Liberty
Chlorophyll a	μg/L	5.77	6.85	3.30
Total Algal Count	No./mL	225	98	648
Total Phosphorus	mg/L	0.026	0.021	0.012
Nitrate Nitrogen	mg/L	1.43	1.69	1.53
Ammonia Nitrogen	mg/L	0.05	0.04	0.04
Apparent Color	color units	7	7	NA
True Color	color units	NA	NA	4
Conductivity	μmhos	188	127	153
pH	Std Units	7.64	7.22	7.50
Iron	mg/L	NA	NA	0.07
Manganese	mg/L	0.02	0.02	0.02
Dissolved Oxygen	mg/L	9.25	9.08	8.84
Dissolved Oxygen % Saturation	%	91	94	101
Secchi Disk Depth	m	3.23	3.05	4.27
Turbidity	NTU	1.5	1.4	1.1

NA = Not Analyzed

Table 3.9 - Growing Season (April to September) Epilimnetic Water Quality Median Data From Primary Sampling Stations at Reservoirs - 1981-1993

Parameter	Unit	Loch Raven	Prettyboy	Liberty
Chlorophyll a	μg/L	7.02	6.82	3.30
Total Algal Count	No./mL	252	134	744
Total Phosphorus	mg/L	0.025	0.027	0.013
Nitrate Nitrogen	mg/L	1.50	1.74	1.81
Ammonia Nitrogen	mg/L	0.03	0.04	0.03
Apparent Color	color units	7	5	NA
True Color	color units	NA	NA	4
Conductivity	μmhos	185	125	152
pH	Std Units	8.20	7.70	7.88
Iron	mg/L	NA	NA	0.06
Manganese	mg/L	0.01	0.01	0.01
Dissolved Oxygen	mg/L	9.30	9.21	8.81
Dissolved Oxygen % Saturation	%	101	103	105
Secchi Disk Depth	m	3.78	4.12	4.88
Turbidity	NTU	1.4	1.0	1.0

NA = Not Analyzed

Table 3.10 - Growing Season (April to September) Epilimnetic Water Quality Median Data From Upper Sampling Stations

Parameter	Unit	Loch Raven	Prettyboy	Liberty
Chlorophyll a	µg/L	5.68	7.19	6.64
Total Algal Count	No./mL	117	172	1160
Total Phosphorus	mg/L	0.040	0.030	0.024
Nitrate Nitrogen	mg/L	1.68	1.78	2.04
Ammonia Nitrogen	mg/L	0.04	0.03	0.05
Apparent Color	color units	9	7	NA
True Color	color units	NA	NA	5.5
Conductivity	µmhos	185	122	167
pH	Std Units	7.70	7.70	7.55
Iron	mg/L	NA	NA	0.09
Manganese	mg/L	0.03	0.01	0.01
Dissolved Oxygen	mg/L	8.85	9.00	8.37
Dissolved Oxygen % Saturation	%	100	105	101
Secchi Disk Depth	m	2.44	3.60	2.44
Turbidity	NTU	2.2	1.25	2.2

NA = Not Analyzed

Table 3.11 - Long-Term Hypolimnetic Water Quality Median Data From Primary Sampling Stations at Reservoirs - 1981-1993

Parameter	Unit	Loch Raven	Prettyboy	Liberty
Chlorophyll a	µg/L	3.13	3.84	2.46
Total Algal Count	No./mL	70	40	307
Total Phosphorus	mg/L	0.030	0.030	0.016
Nitrate Nitrogen	mg/L	1.53	1.70	1.65
Ammonia Nitrogen	mg/L	0.11	0.05	0.06
Apparent Color	color units	11	9	NA
True Color	color units	NA	NA	6
Conductivity	µmhos	202	130	158
pH	Std Units	6.90	6.73	6.78
Iron	mg/L	NA	NA	0.1
Manganese	mg/L	0.20	0.05	0.14
Dissolved Oxygen	mg/L	2.36	6.95	6.05
Dissolved Oxygen % Saturation	%	17	63	49
Turbidity	NTU	2.5	1.5	1.6

NA = Not Analyzed

Liberty Reservoir : Total phosphorus concentrations in Liberty Reservoir are much lower than observed in the other two reservoirs. Reductions in TP have been occurring in the epilimnion since the early 1980's but may be leveling off. Total phosphorus levels in the hypolimnion are still declining. However, for some years, Liberty Reservoir exhibited higher TP concentrations in the hypoliminion implying phosphorus releases from the anoxic sediments. Total algal counts declined substantially during this period while chlorophyll a levels remained at low concentrations. Secchi disk testing revealed that the epilimnetic water in Liberty is substantially clearer than observed in Loch Raven and Prettyboy Reservoirs (4.27 m. vs. 3.23 and 3.05 m., respectively). Water clarity has been improving at Liberty Reservoir based on historical secchi disk measurements. In contrast, growing season nitrate-nitrogen levels in Liberty Reservoir were higher than observed at Loch Raven Reservoir, particularly in the upper stations. Late summer and fall hypolimnial dissolved oxygen measurements taken at Liberty Reservoir have shown substantial improvement over the last 7-10 years. Since 1986, a gradual increase in dissolved solids as indicated by specific conductance has been observed in Liberty Reservoir. Dissolved manganese levels in the epilimnion generally peak between January and March.

Reservoir trophic classification was assessed using Carlson's TSI model which produces a numeric trophic rating criteria from measured TP, chlorophyll a , and Secchi disk levels. This model is summarized below and in Table 3.12.

$$TSI\ (CHL) = 8.23 \ln CHL + 33.3$$

$$TSI\ (TP) = 14.42 \ln TP + 4.15$$

$$TSI\ (SD) = 60 - 14.41 \ln SD$$

where:

TSI = Trophic State Index, ln = natural logarithm, CHL = Chorophyll a (μg/L), TP = Total Phosphorus (μg/L), SD = Secchi disk transparency (m)

Using growing season data for TP and Chlorophyll a, it was determined that Liberty Reservoir was 13 and 16% eutrophic (TSI > 50), respectively. The percent of samples classified as eutrophic at the four in-reservoir sampling stations was estimated to be 4, 5, 8, and 35% based on TP and 6,9, 13, and 34% based on chlorophyll a. The higher eutrophic state reflects water quality conditions at the upper sampling station. Depending on which water quality parameter is utilized, the TSI for Liberty Reservoir predominantly falls between 30 and 50, except at the upper sampling station.

Water quality improved longitudinally along the reservoir with poorer water quality observed at the upper sampling stations. Percent changes in water quality parameters between the upper and primary sampling stations is summarized below.

Parameter	**% Change**
Chlorophyll a	-50
Total Algal Count	-36
Total Phosphorus	-47
Nitrate-Nitrogen	-12
Ammonia-Nitrogen	-40
Secchi Disk	100
Turbidity	-56
Color	-27
Conductivity	-9

Negative numbers denote percent improvement in water quality at the lower primary sampling station relative to the upper sampling station. Positive secchi disk results represent improved water clarity at the primary sampling station relative to the upper sampling stations.

Table 3.12 - Reservoir Water Quality Changes Related to Carlson Trophic State Index

TSI Rating	Description
TSI < 30	Classical oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes
TSI 30 - 40	Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion in the summer
TSI 40 - 50	Water moderately clear, but increasing probability of anoxia in hypolimnion during the summer. Iron and manganese problems during the summer, Raw water begins to have noticeable odor and THM precursors begin to exceed 100 μg/L
TSI 50 - 60	Lower boundary of classical eutrophy: decreased transparency, anoxic hypolimnion during summer, macrophyte problems, warm water fisheries only. Iron, manganese, taste and odor become problematic
TSI 60 - 70	Blue-green algae dominant during summer, algal scums probable, extensive macrophyte growth.
TSI 70 - 80	Heavy algal blooms possible throughout summer, dense macrophyte beds, but extent limited by light penetration, Reservoir becomes hypertrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

4.5 Liberty Reservoir

4.5.1 Description Of Intake Structure And Present Withdrawal Methods

Baltimore City withdraws water from Liberty Reservoir through an intake structure located approximately one mile north of Liberty Dam (Figure 4-1). The intake structure consists of a separate tower constructed over the terminus of the 10-foot diameter raw water conduit that carries water to the Ashburton Filtration Plant. The intake structure consists of a concrete riser, 23 feet in diameter, with eight sluice gates, each 36 inches wide by 60 inches high. Two gates are situated with their centerline at elevation 410 feet MSL, four gates have their centerline at elevation 365 feet and the last two at elevation 320 feet. The configuration of the sluice gates is shown in Figure 4-4.

The standard operating procedure is to maintain all four of the Elevation 365 gates in the 100 percent open position at all times and leave the upper and lower gates completely closed. The City's experience has been that acceptable water quality is received from the Elevation 365 gates all year long. As a result, the upper and lower gates are generally not adjusted for water quality reasons. Under normal procedures, the upper and lower gates are opened only for construction, maintenance or testing purposes. These gates are exercised once a year and were last known to be operating properly.

4.5.2 Seasonal Water Quality Trends

Water quality trending data were developed for Liberty Reservoir using turbidity, color, total algae count, chlorophyll-a, dissolved oxygen and manganese data to complete a seasonal trend analysis. The sampling points NPA0059 and NPA0042 were both selected to characterize water quality at Liberty because NPA0059, which is actually the closer sampling point (Figure 4-1), did not provide enough data to accurately represent any trends. Therefore, NPA0059 data was combined with NPA0042 data in order to determine seasonal trends in the water quality data, which are discussed below.

TURBIDITY – Turbidity data are illustrated on Chart 4.5-1. Turbidity reaches its greatest value at multiple depths in November and December at the height of thermal stratification. Turnover begins in December and turbidity at all depths increases because the layers of the reservoir are once again permitted to mix. Then turbidity values drop through April while the reservoir is homogeneous and algae growth minimal. When surface waters warm in late spring and thermal stratification has started, turbidity levels drop to their lowest values and remain low through August until deeper water quality conditions decline.

Figure 4-4

Chart 4.5.1

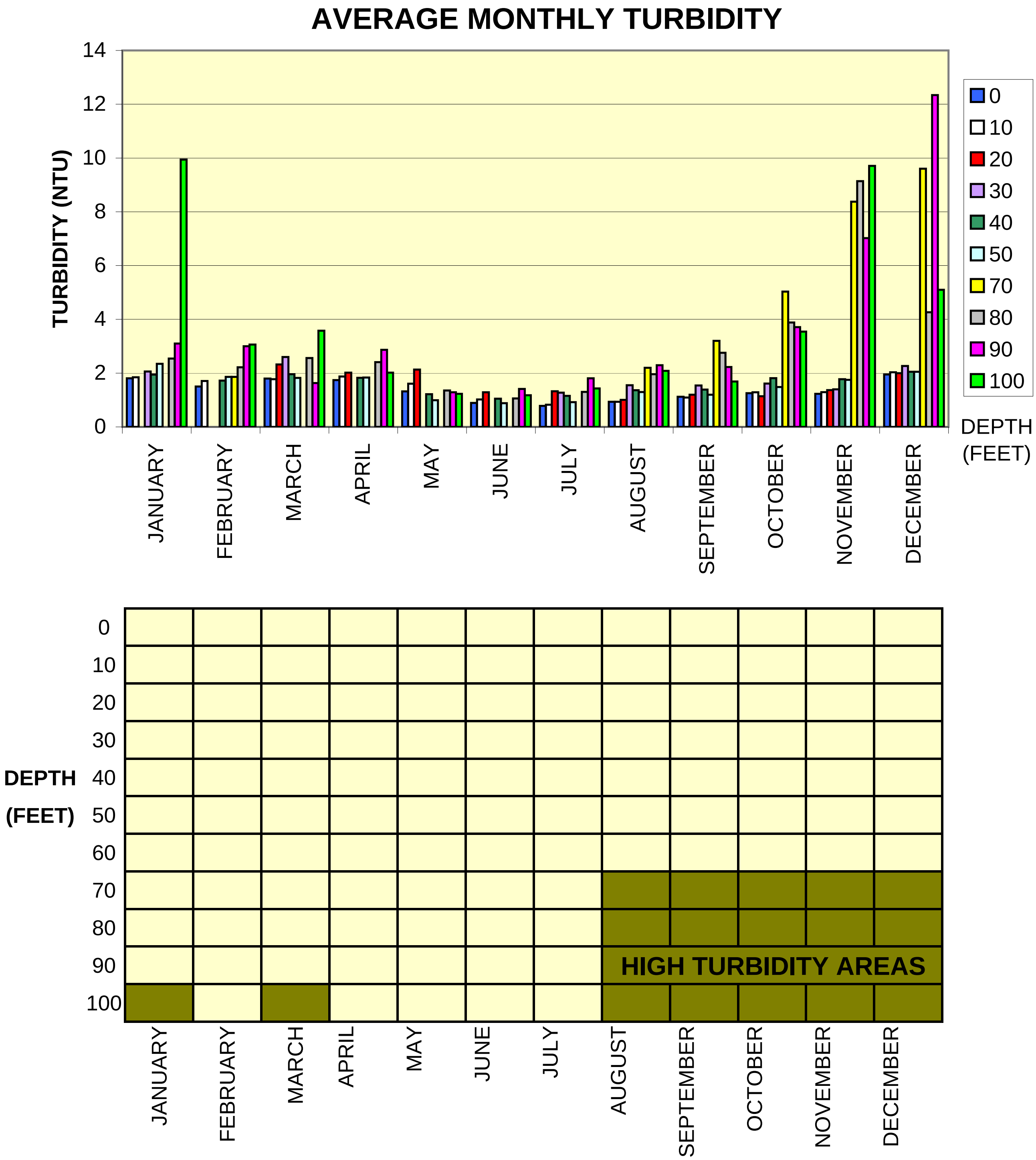
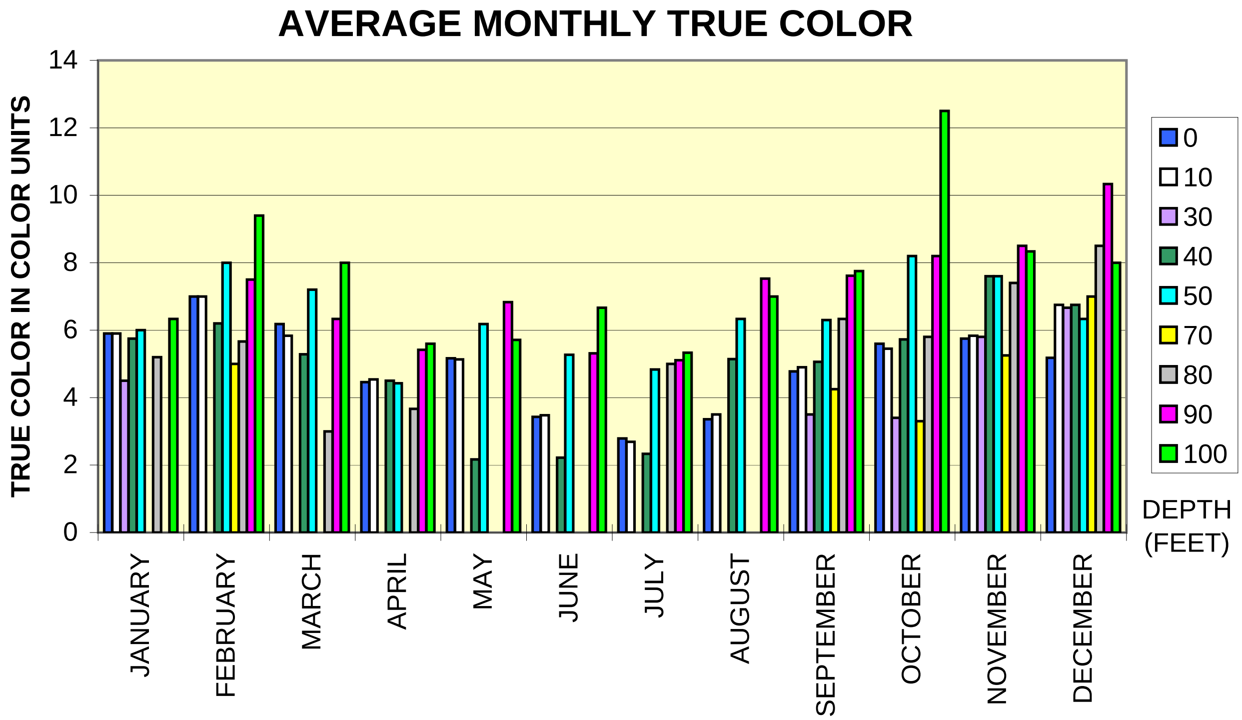


CHART 4.5-1

LIBERTY RESERVOIR

MONITORING STATION NPA0042 & NPA0059 (7/22/81 - 6/4/97)



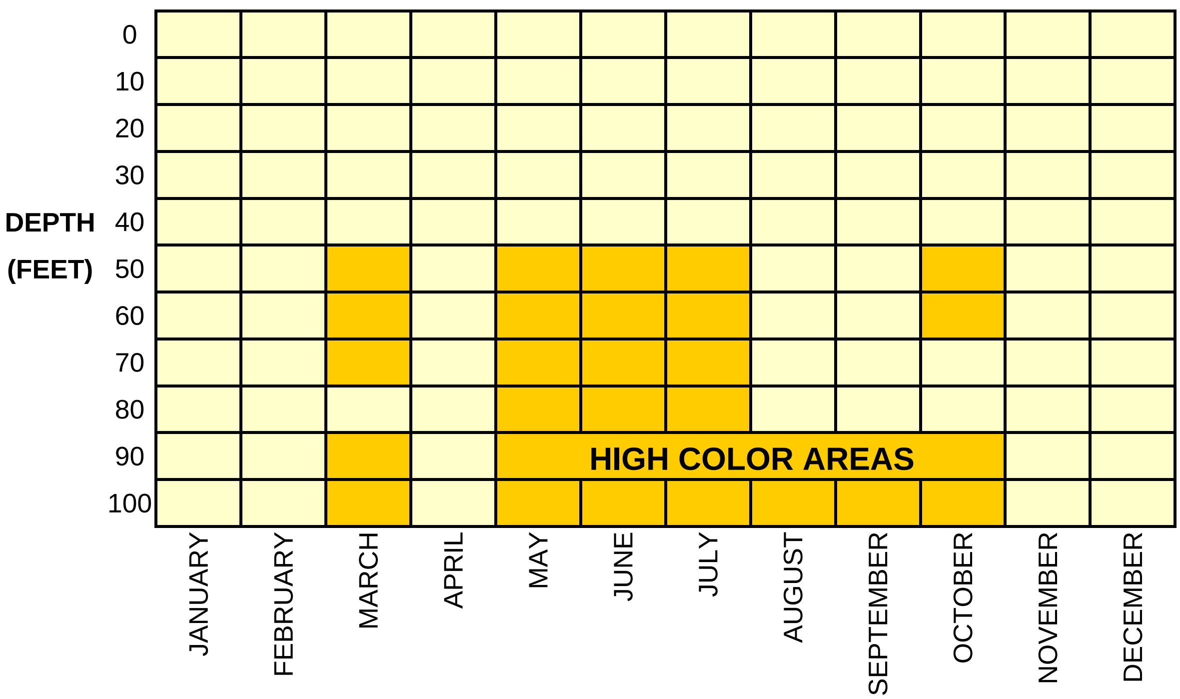


CHART 4.5-2

LIBERTY RESERVOIR

MONITORING STATION NPA0042 & NPA0059 (4/26/82 - 6/4/97)

COLOR – The water sample analytical results for color are shown in Chart 4.5-2. The seasonal trend of color is similar to that of turbidity but is not as clearly defined. This could be a result of the low color values at this reservoir as compared to Loch Raven and Prettyboy.

TAC AND CHLOROPHLYLL-A – Both the Total Algae Count (Charts 4.5-3) and chlorophyll-a (Chart 4.5-4) average monthly analytical results reveal comparable seasonal trends due to the peak algae growing season. Higher TAC occur predominantly during August through October in the upper 30 feet of the reservoir. Chlorophyll-a concentrations increase during these months as well, with peak concentrations occurring in waters of 20 to 30 feet. Increased algae growth is observed during March through May as well. Chlorophyll a concentrations at Liberty Reservoir are lower than observed for Loch Raven. In contrast TAC results were higher at Liberty Reservoir. This may be indicative of greater species diversity at Liberty Reservoir.

DISSOLVED OXYGEN – Average monthly dissolved oxygen results (Chart 4.5-5) are similar to those observed for Prettyboy Reservoir. Homogeneous waters from January through April produce an evenly distributed oxygen filled reservoir. In May when thermal stratification begins, DO levels start declining in lower layers. By September and October, rapid reduction of DO has occurred as shallow as 30 feet due to excess decaying algae depleting available oxygen. Normal conditions resume when turnover occurs in December and DO levels rise at all depths of the reservoir.

MANGANESE – Manganese (Mn) trends are illustrated in Chart 4.5-6. Dissolved Mn concentrations increase in the hypolimnion beginning in August. This is consistent with the anoxic conditions that develop in the deepter waters. Manganese concentrations in the epilimnion peak in December as turnover occurs.

COMPOSITE RESULTS - Using the historical water quality trending data, a composite seasonal water quality trend plot was prepared and is depicted on Chart 4.5.7. Darker colors (green and brown) are indicative of higher concentrations of the respective water quality parameters. As evident from this chart, the best water quality zone occurrs between 40 and 60 feet below the surface. Based on the historical water level data shown on Chart 4.5.8, this higher water quality zone generally corresponds with the Elevation 365 gates.

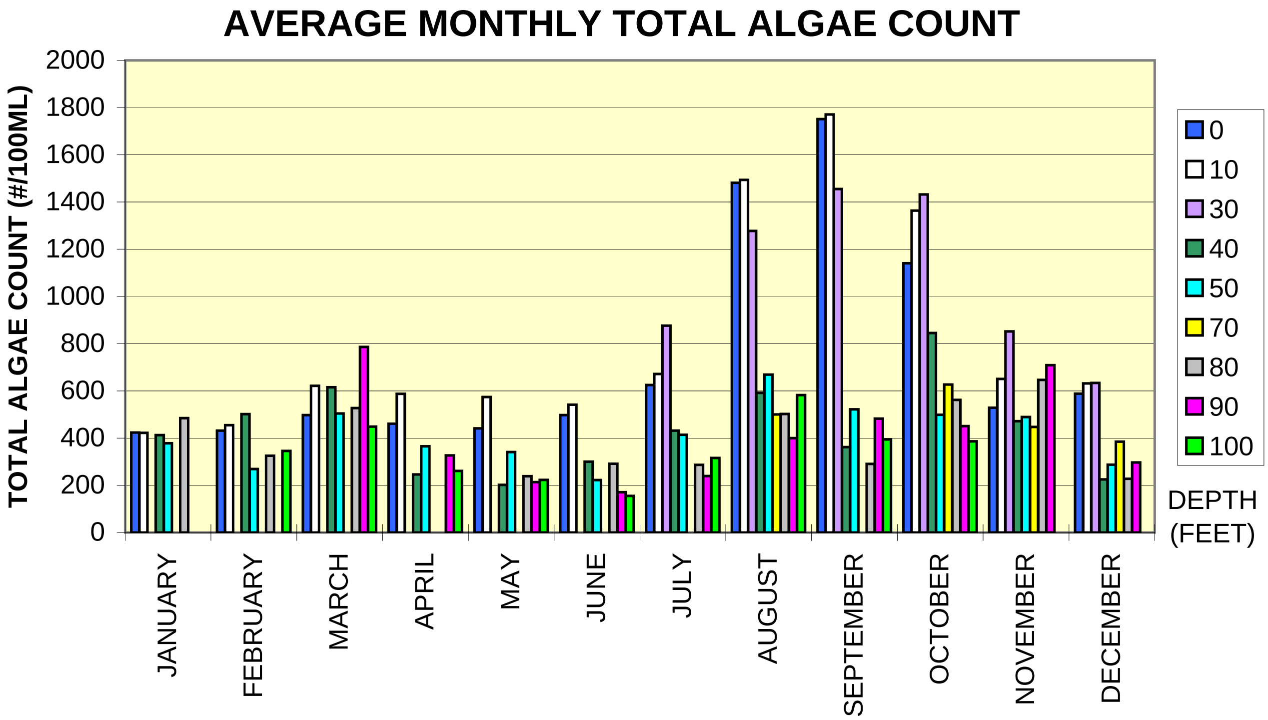
4.5.3 Operational Deficiencies

At Liberty Reservoir, only the Elevation 365 gates, at a depth of about 55 feet, are

utilized for water withdrawal. These gates have provided high quality water in the past. According to the data depicted on Chart 4.5-7, these gates do not avoid water quality problems such as low dissolved oxygen levels and high manganese concentrations on a seasonal basis. No depth in Liberty is safe from poor water quality during all months of the year.

The gates near the surface at an elevation of 410 feet could be opened when the middle gates at 365 feet are extracting unfavorable water. However, this could result in taste and odor problems due to the presence of greater numbers of algae at the shallower depths. It is also not known whether extracting water at shallower depths will to the formation of additional DBPs at the Ashburton Plant. Finally, due to surface water elevation fluctuation (Chart 4.5-8), withdrawal at 410 feet may not be possible. Surface water elevations at Liberty can vary as much as 30 feet from the normal elevation. Therefore the Elevation 365 gates could in actuality be withdrawing water only 20 or 30 feet below the reservoir surface.

Chart 4.5.2



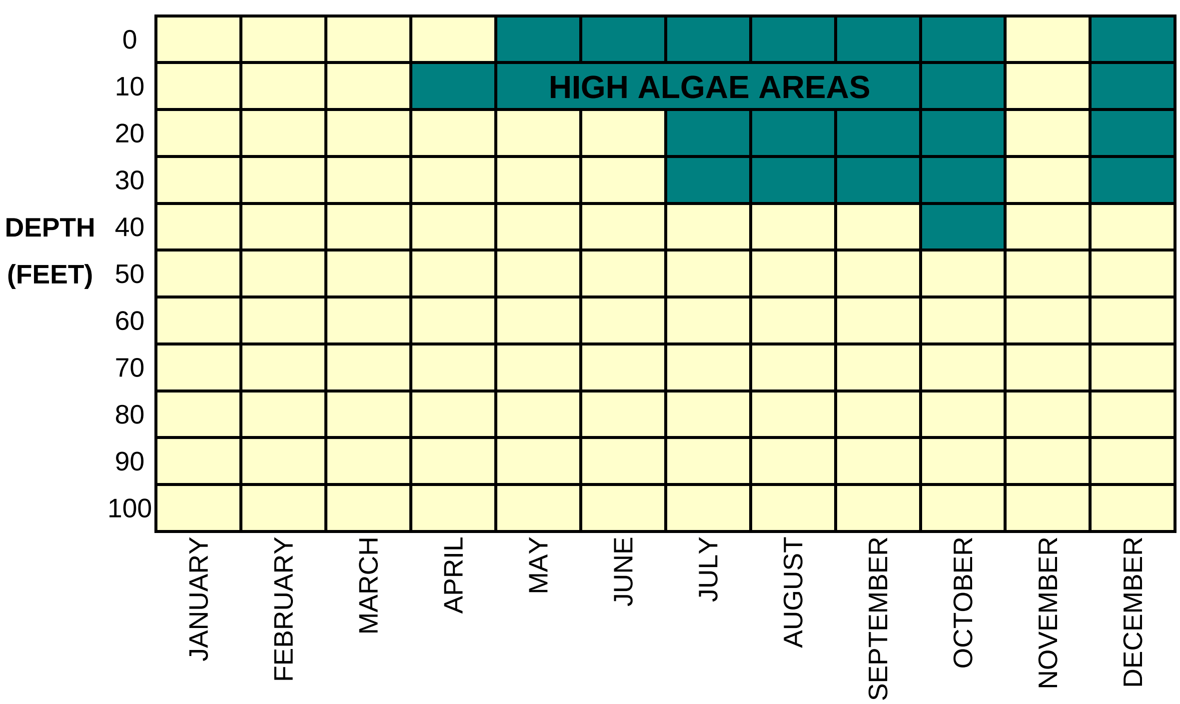
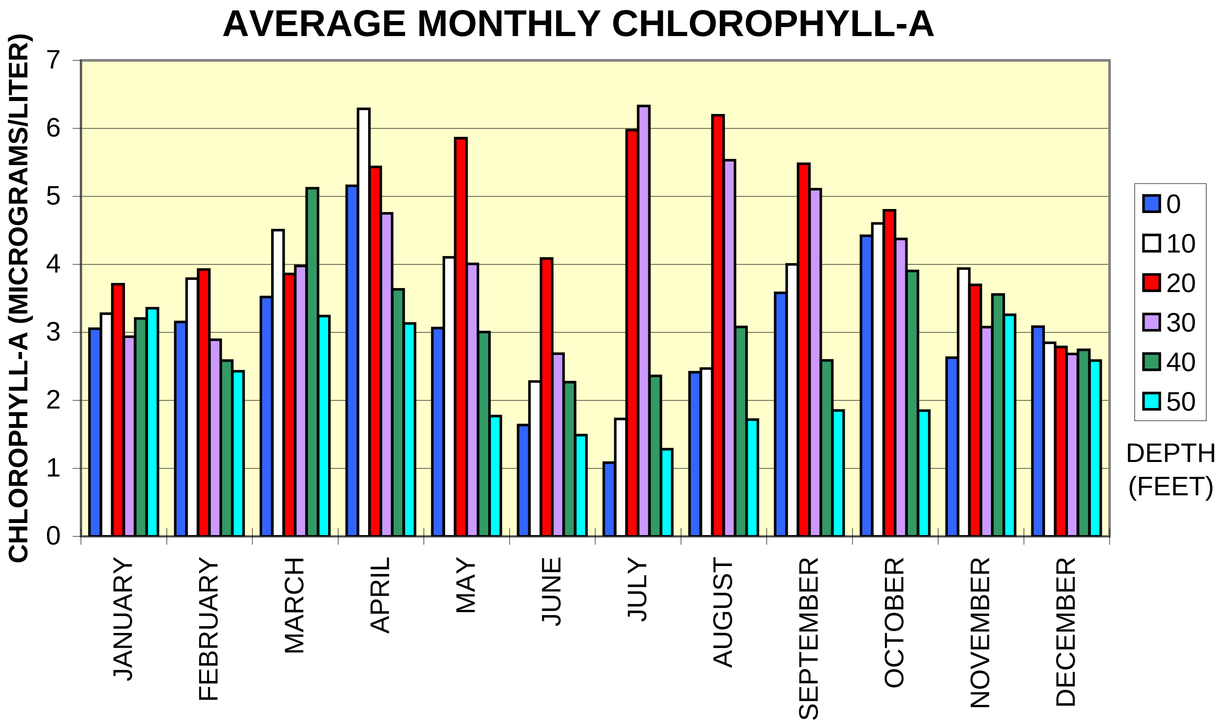


CHART 4.5-3

LIBERTY RESERVOIR

MONITORING STATION NPA0042 & NPA0059 (7/22/81 - 6/4/97)



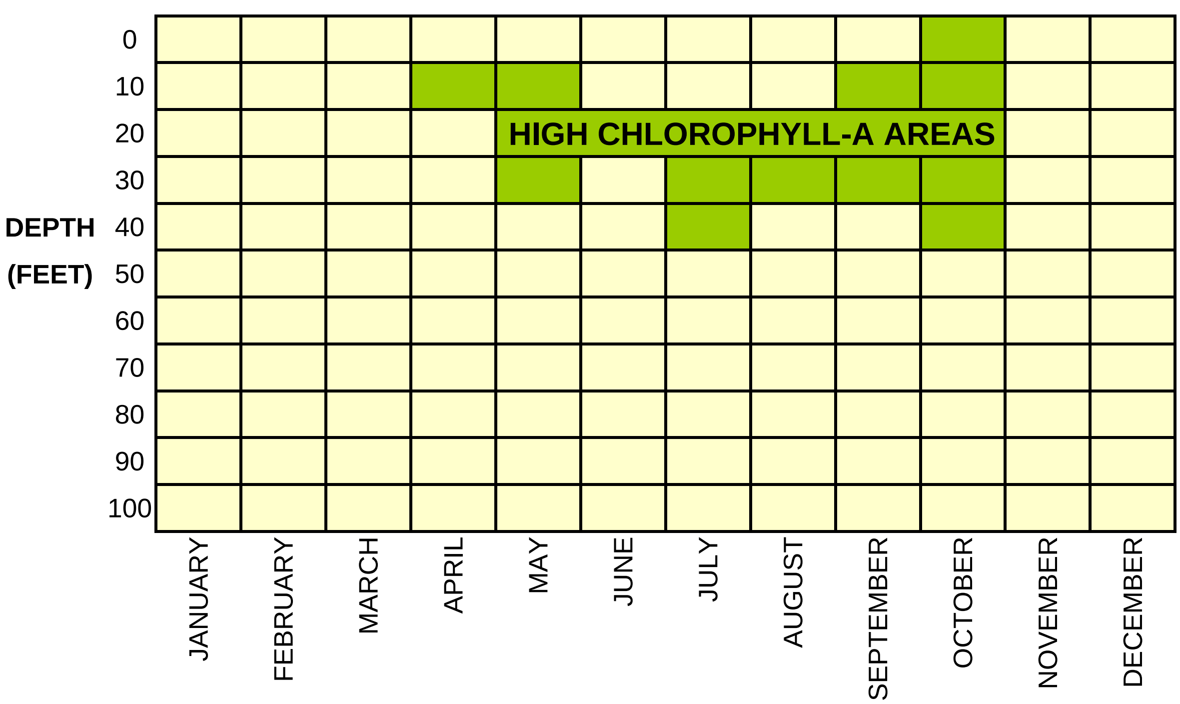


CHART 4.5-4

LIBERTY RESERVOIR

MONITORING STATION NPA0042 & NPA0059 (5/21/85 - 6/4/97)

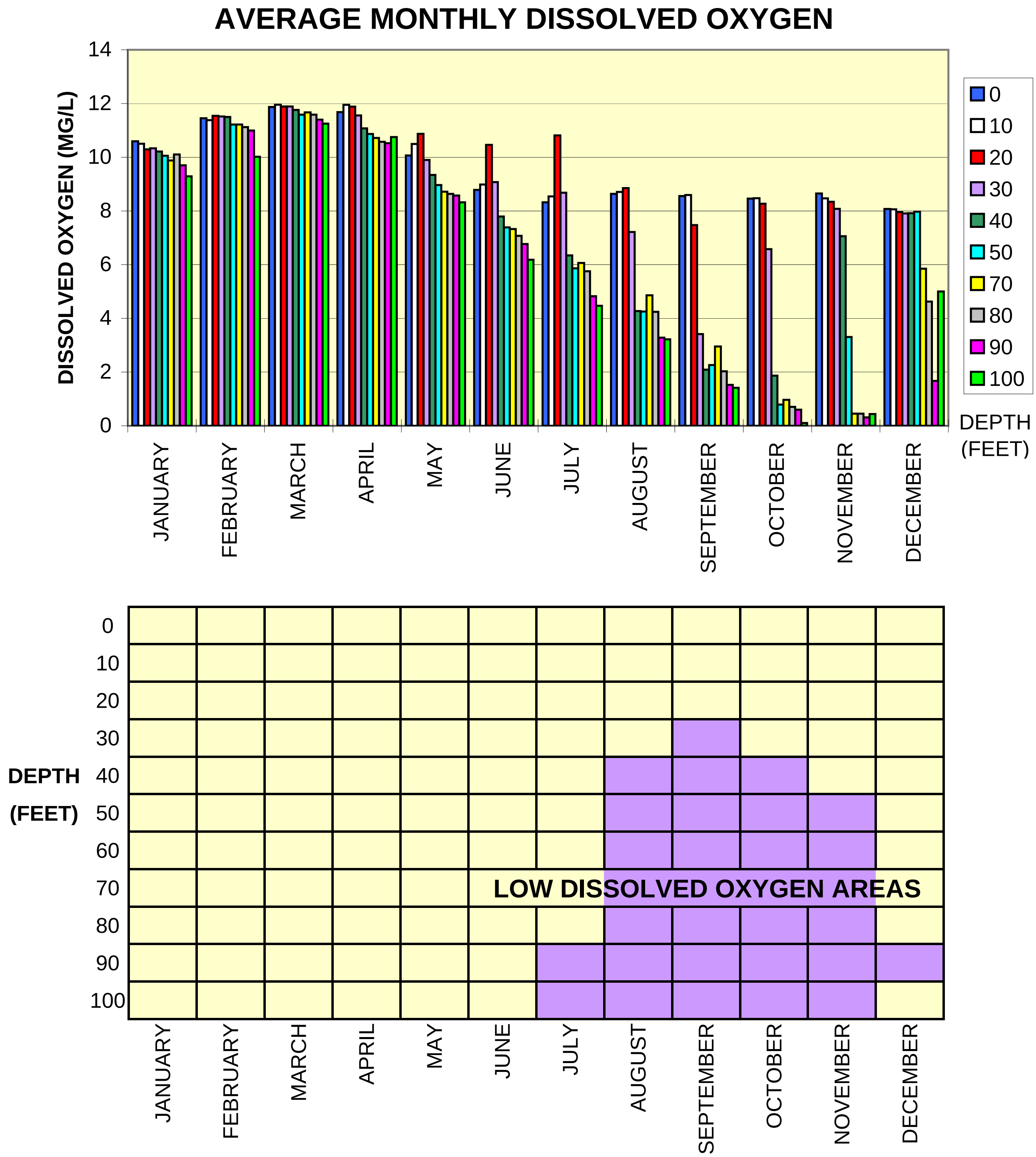
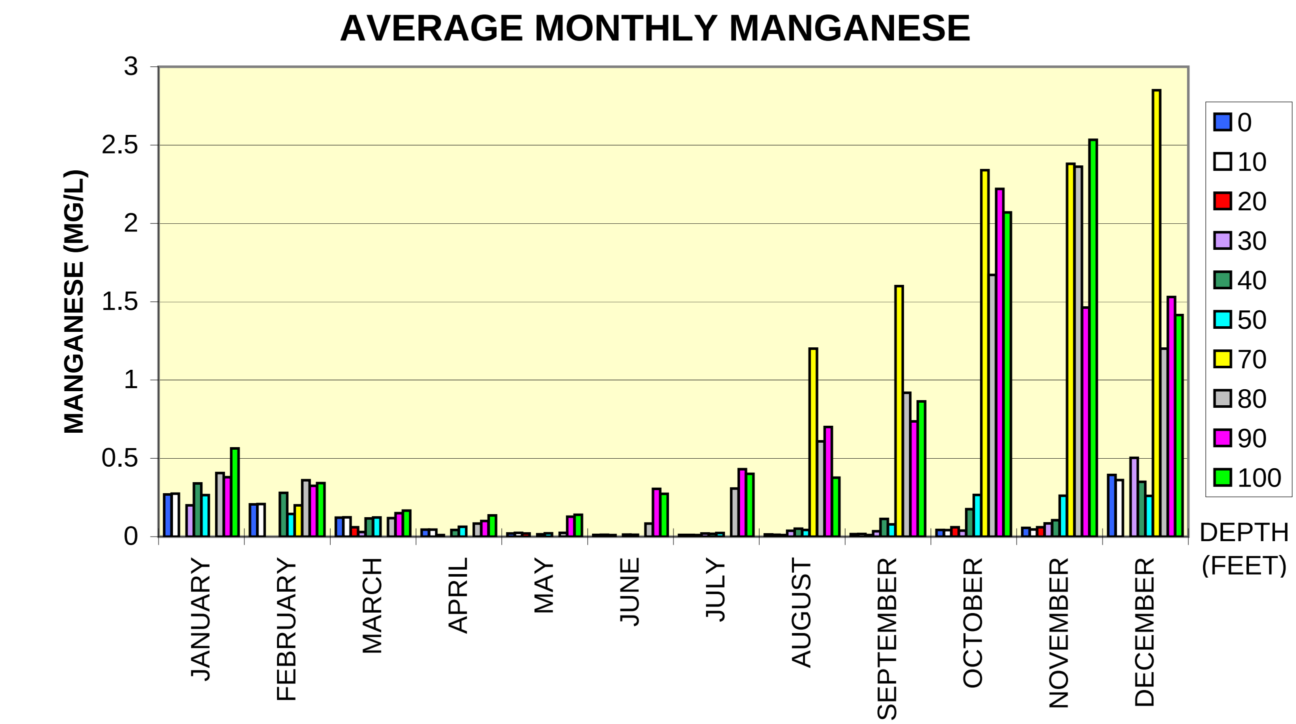


CHART 4.5-5

LIBERTY RESERVOIR

MONITORING STATION NPA0042 & NPA0059 (7/22/81 - 6/4/97)



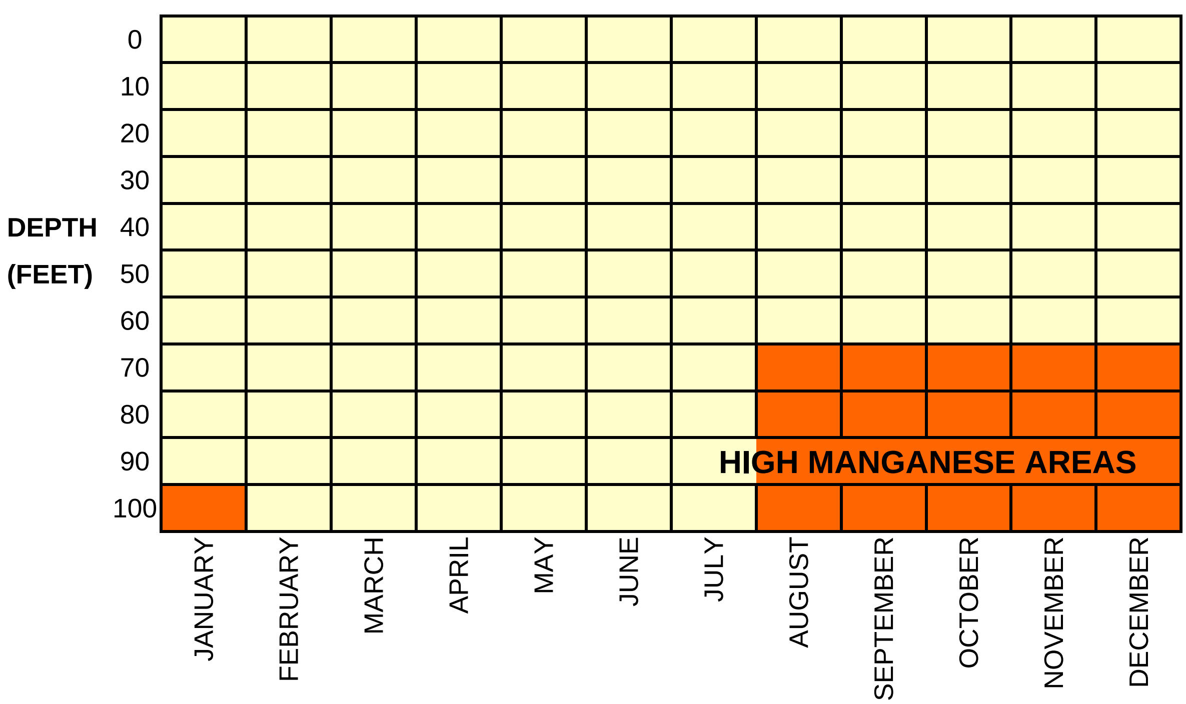


CHART 4.5-6

LIBERTY RESERVOIR

MONITORING STATION NPA0042 & NPA0059 (7/22/81 - 6/4/97)

LIBERTY RESERVOIR
SEASONAL WATER QUALITY CONDITIONS

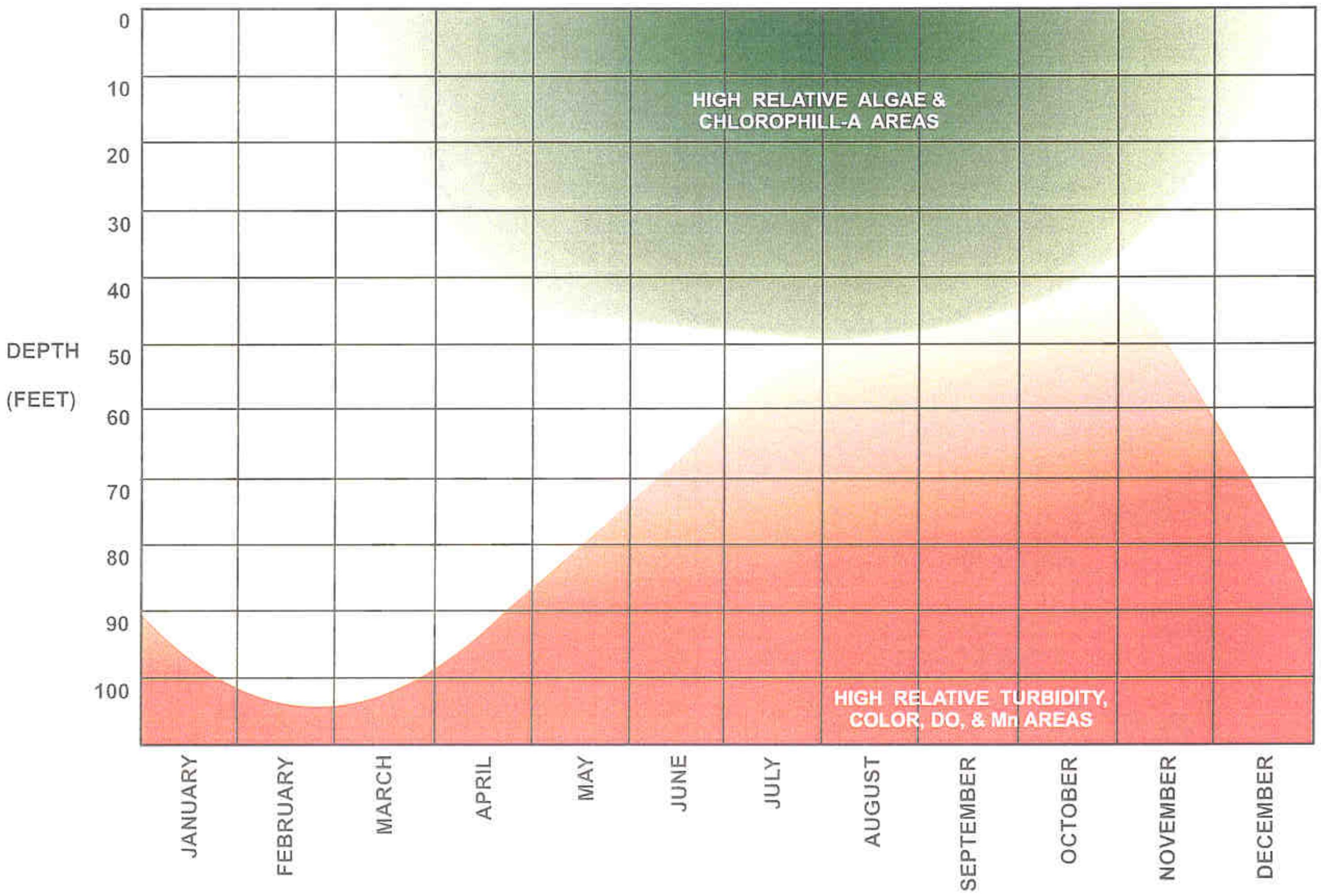


Chart 4.5-7

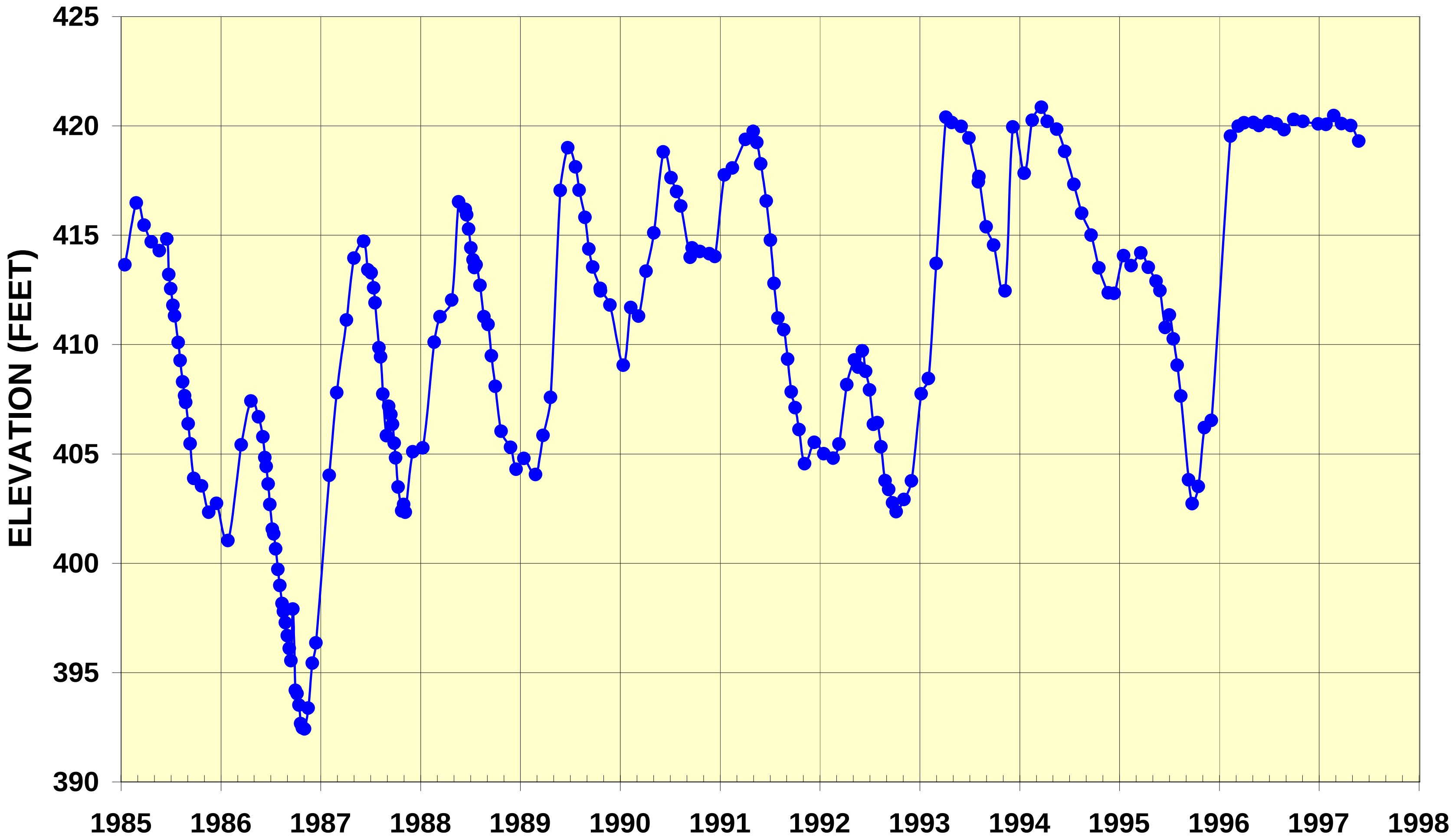


CHART 4.5-8
LIBERTY RESERVOIR WATER SURFACE ELEVATIONS

4.6 Conclusions and Recommendations

Water withdrawal improvements differ from reservoir to reservoir. The characteristics of each reservoir, intake structure and even water quality data vary enough that no generalizations can be made across the board about gate operation. The depth of the reservoir and the number of gates at various depths impact strategies for withdrawing the best quality water possible from the reservoir.

Review of the analytical data summary charts for Loch Raven Reservoir shows that current procedures for gate operation avoids the seasonal water quality problems associated with surface water and bottom water layer characteristics during thermal stratification. Throughout the year, the gates are adjusted to withdraw water from the layer of the reservoir with the best average water quality. The current procedure is satisfactory, but it is recommended that standard yearly gate closure schedules be considered to address some of the more predictable water quality criteria degradation before raw water quality is adversely impacted. For example, based on historical water quality trends, the Elevation 190 gates should be closed in July to prevent the decrease in dissolved oxygen and increase in manganese levels from appearing at the treatment plant. If water quality subsequently declines at shallower depths, adjust the Elevation 204 gates accordingly. These gates can be reopened in the spring, as usual, when an increase in water production is needed.

At Prettyboy Reservoir, withdrawing water from only the Elevation 465 gates does not totally escape seasonal water quality degradation caused by thermal stratification. Around September, the dissolved oxygen levels drop and manganese and turbidity increase at Elevation 465 where the main water intake gates are located. During this period, TAC and Chlorophyll A appear to be decreasing and more acceptable water is near the surface. The Elevation 510 gates could be utilized, if the surface water elevation is high enough. However, because the water is being discharged into a stream and not being directly transported to a filtration facility, impacts to stream life should be considered. Using the Elevation 510 gates could be detrimental to life downstream because of the temperature change. Therefore, it is recommended that no change take place unless significant water quality problems exist near the Elevation 465 gates.

Throughout the year, the best average water quality at Liberty Reservoir appears to be within the range of the water depths that supply the Elevation 365 gates. Therefore, continuing current procedures of only using Elevation 365 gates is recommended. Although, water quality seems better near the surface during summer and fall when the reservoir is stratified. Opening of the Elevation 410 gates should be considered during this time of year if deeper water conditions continue to decline and water at the Elevation 365 gates becomes worse.

Baltimore City could continue to operate their intake structures as they have in the past and still deliver quality water to the public. But, much more can be done to improve the quality of raw water by altering current withdrawal methods, thus cutting treatment costs and gaining higher consumer acceptance.