Reservoir Program Technical Report:

Water Quality Assessment, Targeted Studies and Ongoing Water Quality Issues in the Baltimore Metropolitan Water Supply Reservoirs and Their Watersheds

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Baltimore, Maryland

The **Reservoir Technical Group** is charged with coordinating the implementation of the Baltimore Reservoir Watershed Management Agreement, which was signed in 1984. The RTG includes technical staff from Baltimore City, Baltimore County, Carroll County, the Baltimore County Soil Conservation District (SCD), the Carroll SCD, the Maryland Department of Agriculture, the Maryland Department of the Environment, and the Baltimore Metropolitan Council. Harford and Howard counties and the state departments of Planning and of Natural Resources also have representatives in regular attendance at RTG meetings, as do a number of citizen-led watershed advocacy groups. The RTG meets bi-monthly at the Baltimore Metropolitan Council.

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Introduction

In attempting to manage the water quality of a stream, river or lake, it is customary to start with direct measurements of physical, chemical and biological indicators within the body of water itself. Ideally, these measurements will be taken and tabulated over a period of time and then compared with the applicable water quality standards or other "goals" for the body of water. (As just one example, do the algae levels observed in a water supply reservoir exceed the level generally believed to be acceptable for maintaining the water quality needed in a public water source?)

If repeated measurements indicate the presence or the effects of one or more pollutants in the water body, then it may be desirable to do field work in the tributary watershed(s) to see if the source of the pollutants can be located. Often we find that the sources of certain pollutants are widely scattered in a watershed and that the introduction of the contaminants to streams is largely dependent on rainfall events. In such cases, the contaminants are referred to as "nonpoint source" pollutants. In addition, site-specific analysis may be required to understand the natural processes within the body of water that might be working upon or reacting to the pollutant sources. (If we measure elevated levels of phosphorus in a lake, how much of that came from tributary inputs and how much was re-released from accumulated lake-bottom sediments?)

Sometimes, review of the water quality data collected over time reveals upward or downward trends in key parameters or indicators. In order to properly interpret these trends, it is necessary to do a systematic assessment of concurrent land use changes, relevant new human activities, and recent nonpoint-source pollution-control measures in the contributing watershed. In attempting to understand pollution sources, pathways and effects in watersheds, it is frequently true that we only have a part of the picture; yet we have to make decisions based on incomplete or imperfect knowledge.

The ultimate goal of the Baltimore Reservoir Watershed Management Program is to ensure the quality of the untreated ("raw") water in the three reservoirs. This includes keeping physical properties within acceptable natural ranges, meeting the chemical quality criteria set forth in state regulations, and keeping the lakes within normal ranges of desirable biological activity. If the desired water quality is achieved and maintained in the lakes, it will help to minimize the cost of treating (purifying) the raw water to make it meet drinking-water standards for the system's 1.8 million customers in Baltimore and parts of the five surrounding counties.

Since the Baltimore City Department of Public Works owns and operates the three reservoirs, it bears the primary responsibility for designing and maintaining the sampling programs which track the quality of the water in the lakes and in their principal tributaries. However, the City is assisted to some extent by measurements taken periodically in the tributaries by the Baltimore County Department of Environmental

Protection and Resource Management (DEPRM) and by the Maryland Department of Natural Resources. (Under state and federal law, the City is also required to sample the treated water at its two treatment plants on a daily basis, report these results to the state, and report summary data to the public once a year.)

This paper begins by summarizing our current understanding of water quality in Loch Raven, Prettyboy and Liberty reservoirs and in their respective major tributaries. *(See Figure 1 for reservoir locations and watershed boundaries.)* It identifies and discusses the major pollutants of concern, including the observed trends in pollutant levels over the past ten to fifteen years. There is a description of the in-lake phosphorus and chlorophyll concentration "goals" previously set for the three reservoirs pursuant to the 1984 Reservoir Watershed Management Agreement. Next, the paper describes the principal technical studies and analyses relating to reservoir water quality which are either recently completed or still under way. It also summarizes several different studies of reservoir watershed conditions and problems which have been carried out in recent years.

The concluding section of the paper identifies and briefly discusses technical concerns relating to the ongoing tributary water-quality monitoring and reservoir-quality monitoring programs, emphasizing several key changes which should be considered. It recommends a detailed joint review of the current sampling efforts by all the various agencies involved. It calls for a close examination of recent, anomalous trends in phosphorus and chlorophyll levels seen in several of the reservoirs and a review of the annual phosphorus loading goals previously set by the Reservoir Program for the lakes. And the final section identifies analyses which need to be made relating to long-term sediment accumulations in reservoir headwaters and to ongoing, upward trends in the measured sodium and chloride levels in the lakes.

The technical concerns identified in the paper's concluding section are expected to influence the specific program commitments made in the planned 2004 Reservoir Watershed Action Strategy.

Background: Sampling and analysis activities

For more than fifty years, Baltimore City has operated a sampling program in the three reservoirs and in their major tributary streams. Initially, sampling and analysis was limited to just a few parameters, but the list has been expanded over the years to the point where nine different parameters are measured for most samples. The indicators of greatest interest are turbidity, dissolved oxygen, chlorophyll a, total algae count and species, three forms of nitrogen, total and dissolved phosphorus, dissolved solids, chlorides, and manganese. There are also secchi disc readings, which are a standardized, simple measure of in-lake water clarity.

Because the condition of the raw water in each reservoir is the city's foremost concern, several in-lake stations are visited monthly or bimonthly, depending on the season, and samples are taken at the surface and at fixed depths below the lake surface. Because the properties of the water vary markedly at different levels in each lake and with seasonal climate changes, this data helps the city's Department of Public Works to decide at what depths in each lake they should withdraw raw water from Loch Raven and Liberty. Well-oxygenated water with low turbidity, low algae levels and neutral pH is less expensive for the city to treat. Such water will be found at depths in the lakes which vary according to rainfall events, nutrient loadings, the seasons and air temperatures.

Algae are always present in natural bodies of water, but under certain conditions in reservoirs, they will reproduce and concentrate at very high levels, which can have adverse effects on the water itself, increase water treatment costs, cause unpleasant taste and odor in the treated water, and (in extreme cases) upset the natural ecological balance of the lake. Algae populations in freshwater lakes and impoundments are typically limited by water temperature, sunlight levels, and the concentrations of phosphorus compounds in the water column. For these reasons, the city routinely measures "total algae", chlorophyll *a* and nutrient concentrations at various depths in each lake.

In addition, the concentrations of certain compounds or substances in the reservoirs are also measured by the city, because they may affect the potability of the finished water (even after treatment). For example, manganese, chloride concentrations, and total organic carbon levels are tracked by the city. (TOC can contribute to the formation of undesirable trihalomethanes in finished water during storage and distribution.) High algal concentrations in a lake will contribute to elevated TOC levels in the raw water.

Since the lakes have to be managed for the long-term, as well as for present conditions, it is important to understand the quality of the water entering the lakes through their tributaries and also to document the major in-lake processes, which can strongly influence each reservoir's future. Such processes include sedimentation, the growth of algae, stratification of the waters, and seasonal (temperature-driven) turnover of the stratified layers. In this regard, bathymetric studies have been done in recent years on Loch Raven, Prettyboy and Liberty reservoirs, in order to assess sediment accumulation in each lake

In order to understand the quality of the water entering the lakes, each reservoir's major tributaries are sampled by city crews on a regular basis. *(See Figures 2 and 3 for stations monitored by Baltimore City and Baltimore County.)* Each sample is tested for a suite of pollutants and indicators. Emphasis is placed on monitoring nutrient and sediment loadings in the streams. By combining the measured concentrations with the measured streamflow rates at each sampling point (usually from a gauging station), it is possible to estimate the pollutant loads being delivered to the lakes by their major tributaries.

For Prettyboy Reservoir, the city maintains three sampling points in the lake, plus dry-weather sampling points on each of three tributaries (Gunpowder Falls, Grave Run and Georges Run). For Loch Raven Reservoir, the city maintains five in-lake sampling stations and seven stations on six different tributaries (Gunpowder Falls, Little Falls, Western Run, Beaver Dam Run, Jenkins Run and Dulaney Valley Branch). All of these tributary stations involve dry-weather sampling, and three of them also involve storm-related sampling. For Liberty Reservoir, the city maintains four in-lake sampling stations and monitoring points on six different tributaries (Bond Run, North Branch Patapsco, Beaver Run, Middle Run, Morgan Run and Little Morgan Run). Three of the tributary stations are dry-weather only, and three involve both dry-weather and storm sampling.

Wet-weather sampling is needed because it is known that relatively large portions of the total annual pollutant loads entering the respective lakes are delivered via storm flows. Note that, at the present time, the Prettyboy tributaries are not sampled during storm events, unlike some of the tributaries of the other two lakes.

The Baltimore County Department of Environmental Protection and Resource Management (DEPRM) has carried out targeted steam-monitoring studies in the watersheds in the past. One involved wet- and dry-weather sampling of 16 stations in the Gunpowder watershed (1997-1998). This data was used by MDE to develop a computer model of the Gunpowder watershed (discussed later in this paper). The county also has maintained a long-term sampling station since 1995 on Spring Branch in the Timonium area (a tributary of Loch Raven), as required under a condition of the county's NPDES Municipal Stormwater Permit from MDE.

The county has recently introduced a baseflow and storm-event monitoring program that will focus on the Gunpowder River Basin in even-numbered years and the Patapsco/Back River Basin in odd-numbered years. Within the Liberty Reservoir watershed, Baltimore County has eight baseflow monitoring sites and no storm-event monitoring sites. There are five baseflow sites and three storm-event sites within the Prettyboy watershed, and in the Loch Raven watershed, there are 26 baseflow sites and seven storm-event monitoring sites *(refer to Figure 2)*. The county and the city presently are working together to ensure comparability of their monitoring methods and analytic results. This is expected to result in more efficient sampling of the reservoir tributaries.

The Maryland Department of Natural Resources (DNR) operates a statewide program for assessing the "health" of streams and rivers by visiting randomly chosen sites and gathering detailed physical, chemical and biological data. Between 1995-2000, sampling and observations were made under the Maryland Biological Stream Survey (MBSS) at 58 randomly selected sites in the Liberty Reservoir watershed and 19 randomly selected sites in the Prettyboy watershed.

In a report published in 2001, DNR reported that more than half of the sites in the Liberty watershed exhibited "minimally degraded" (good) conditions for fish or benthic macroinvertebrates. During 2000, all trout streams sampled in the area routinely exceeded the temperature needed to support natural trout populations. The most common causes of stream degradation were identified as extensive agricultural activity in the area, streambank erosion, and insufficient vegetated riparian buffers. Much the same results were reported for the Prettyboy watershed, with more than half the sites exhibiting generally "good" conditions for fish, but again the stream temperatures appeared to be too high to support natural trout populations. Proximity to farming, streambank erosion and the lack of sufficient stream buffers were again cited as sources of degradation in stream habitat quality.

Under the MBSS program, Maryland DNR carried out electrofishing at nine sites in the Loch Raven watershed during the summer of 2002. Five of these involved small headwater streams, where expectations of fish abundance and diversity were inherently low. Thus, only three sites proved suitable for the calculation of a fish “index of biological integrity” (IBI). Based on this index, the fish habitat in the three streams could be described as ranging from “poor” to “fair”, and it was estimated through statistics that about 50% of the stream miles in the watershed area sampled would be “fair” or better.

The benthic communities in selected streams in the Loch Raven watershed were sampled by DNR in spring of 2002, and a benthic IBI was determined for each stream, an indicator of the quality of the stream habitat for desirable benthic organisms. Based on these calculated values, it was estimated that 70% of the streams in the area sampled could be classified as providing “fair” or better benthic habitat.

Between the spring of 1996 and the spring of 2001, the Baltimore City DPW (Reservoir Natural Resources Section) carried out a study of the benthic macroinvertebrate communities in the major tributaries of all three reservoirs. This study utilized a non-randomized approach to identify trends in the benthic communities at fixed locations over the five-year period. The makeup and diversity of the benthic animal population at a stream location is usually a very reliable indicator of overall water quality and habitat quality at that particular location. By gathering very complete samples of the bottom-dwelling life, and carefully identifying and tabulating the individuals in the lab, it is possible to draw conclusions about the average stream quality without also taking chemical data. During the study period, a total of 166 macroinvertebrate community samples were taken at 17 different sampling stations in the Loch Raven watershed, 18 stations in the Liberty watershed and 11 stations in the Prettyboy watershed. By rating each sample as to its taxonomic diversity, the number of individuals in the sample, and the number representing several key desirable families, a biological score was developed for each site. This score was compared to threshold values taken from the literature as indicating “good”, “fair” or “poor” stream conditions.

Overall, the city’s data suggested that 26% of the tributary stations had good stream conditions, 59% had fair conditions, and 15% were rated as poor. However, the observed stream conditions varied by season and by watershed. The scores were more favorable when tributaries were monitored in the spring and fall, with declines observed in the ratings of stream conditions during the summer. The stations sampled in the Loch Raven watershed had scores that were consistently lower than those for the stations sampled in the other two watersheds. Over the entire study period, only 6% of the Loch Raven tributary stations were rated as having “good” average stream conditions, 59% were rated as “fair,” and 35% were rated as “poor”. For the Prettyboy watershed, 73% of the stations were rated as “good” and 27% were rated as “fair” (none received a poor rating). For the stations sampled in the Liberty watershed, 17% were rated as “good,” 78% were rated as “fair,” and 5% were rated as “poor”.

The authors of the study offered the opinion that the differing levels of stream conditions might be explained by land use differences in the watersheds draining to the sampling stations. Anthropogenic (man-made) stressors within a watershed, especially those associated with urban land uses, can have significant adverse impacts on stream biota. Such stressors might have contributed to the observed differences in stream conditions at the different sampling points.

During the 1990s, a citizens-based benthic macroinvertebrate biological monitoring program at stream sites throughout Baltimore County was coordinated by Maryland Save Our Streams and supported by Baltimore County DEPRM. There were eleven sampling sites in the county's portion of Prettyboy watershed, 52 sites in Loch Raven watershed, and six sites in the Baltimore County portion of Liberty watershed. Data was collected from 1990 through the spring of 2002 using the EPA Rapid Bioassessment Protocol II. The results for the sampling period of 1990 through 1999 indicate that overall, sites in the Prettyboy and Liberty watersheds were in good/fair condition, and sites in the Loch Raven watershed were in fair condition.

In 2003, Baltimore County initiated a new benthic macroinvertebrate monitoring program using MBSS methodology, including randomized site selection, D-net sampling and identification at the genus taxonomic level. In the odd-numbered years, sites are selected in the Patapsco/Back River Basin and in the even years, randomly selected sites are monitored in the Gunpowder Basin. Accordingly, ten sites were monitored in the Liberty Reservoir watershed in 2003. Seven sites in the county's portion of Prettyboy watershed and 71 sites in the Loch Raven watershed are being monitored in 2004.

Overview: Current understanding of water quality trends in the reservoirs and their major tributaries

The tributary streams which feed our reservoirs contribute sediment, nutrients, oxygen-demanding substances, inorganic and organic compounds, and microorganisms to the lakes. Natural processes in the lakes can sequester (tie up), dilute, transform, or break down these contaminants in a variety of ways. Over the past two decades, some pollutant loads to the reservoirs have been decreasing, even while others have increased. Some contaminants have short-term effects on the lakes, while others can have permanent effects.

For example, **sediment** delivered to the reservoirs from the respective watersheds actually represents several different problems. In the short term, sediment can serve as a delivery mechanism for some forms of phosphorus, because they tend to bind to fine soil particles. Over the long term, the continued accumulation of sediment in a reservoir reduces the volume available for water storage. In the late 1990s, the Maryland Geological Survey (MGS) did a bathymetric survey and sedimentation analysis for both Prettyboy and Loch Raven reservoirs. A similar survey was conducted by MGS in

Liberty Reservoir in 2001. The current capacity of each lake was calculated, based on the new measurements, and the percentage of the original storage capacity that had been lost since the time of construction was determined.

The survey of Loch Raven determined a present (1997) storage capacity of 19.15 billion gallons. When compared with the original capacity of the reservoir in 1913, this represented a loss of 2.3 billion gallons in storage capacity, or a 10.8% decrease from its capacity when new. The sediment had not accumulated uniformly; by far the heaviest deposits were in the uppermost reaches of the lake, where sediment thickness was measured at between 48 and 59 feet. In fact, the survey could not be conducted above the Warren Road bridge using a motor boat, due to the excessive siltation which had occurred in the upper reaches of the reservoir.

The survey of Prettyboy (1998) determined a current storage capacity of 18.4 billion gallons. When compared to the original capacity of the reservoir in 1933, this represented a loss of 1.5 billion gallons in storage capacity, a decrease of 7.5% from its capacity when new. The storage capacity of Liberty Reservoir (in 2001) was determined to be 37.67 billion gallons, reflecting a total loss of 1.28 billion gallons, a decrease of 3.3% from its initial capacity in 1954.

The MGS determined from these data that, on average, Loch Raven had an annual loss rate of 0.13 of one percent of its original capacity, Prettyboy had an annual loss rate of 0.12%, and Liberty had an annual loss rate of 0.05%. When these loss rates are adjusted for the size of the respective watersheds (drainage areas), Prettyboy has the largest annual loss rate, in tons of sediment per year per square mile (1.15), followed by Loch Raven (0.49) and Liberty reservoirs (0.42).

The Baltimore City Water Quality Management Section (WQMS) plans to work with Baltimore and Carroll counties to investigate possible sources of sediment in the landscape, to try to account for the differences in the annualized rates of capacity losses observed in the three reservoirs. The MGS cautions against relying too heavily on the estimated loss rates, because of the inaccuracy involved in converting capacity loss to watershed sediment yields. The WQMS also will be working with MGS to evaluate these capacity loss rates in comparison with the rates determined for other reservoirs located in the eastern piedmont sections of the U.S.

The unique shape of Loch Raven Reservoir allows for a comparison of the long-term average rates of sedimentation coming from two different portions of the watershed. An arm on the southwestern side of Loch Raven, fed by Long Quarter Branch, receives drainage from a watershed area that is about two-thirds developed. This includes land areas in Towson and in the York Road corridor up to Timonium, which has experienced previous intensive commercial and residential development. On the opposite side of the reservoir, Dulaney Valley Branch receives drainage from an area that is only one-third developed, mostly involving low-density residential lots. The annual average sedimentation rate on a per-acre basis (based on the sediment accumulations in these two different portions of the reservoir) over the last 85 years has been 150% greater in Long Quarter

Branch than in Dulaney Valley Branch. It was not possible to perform “dating” of these sediment cores, so we can’t be certain when annual sedimentation rates were at their greatest—although presumably it was during the periods of maximum urban development activity, in the 1950s and 1960s. Hence, there is no basis for knowing what the respective sedimentation rates from the two subwatersheds are under current conditions. (In recent years, Baltimore County has completed major stream-restoration and stormwater retrofit projects in Spring Branch and Long Quarter Branch, which are believed to have reduced stream-channel erosion in these areas.)

None of the three MGS bathymetric surveys addresses the question of sediment storage in the tributaries and headwater areas of the reservoirs. This fact was especially noted in the Loch Raven survey, with the observation that the upper part of the reservoir and the adjacent stream channels have reached a “sediment balance” and will no longer retain additional sediment delivered from upstream. The authors note, “Consequently, sediment is transported increasingly further downstream into the reservoir resulting in an increasing rate of sedimentation.”

The sampling programs described in the previous section have given us an understanding of water quality conditions in the three reservoirs and their main tributaries. From time to time, the Baltimore City Department of Public Works publishes a report which summarizes the city’s interpretation of the sampling results. The most recent such report was published in June 2001, and it describes the trends observed in the three lakes and in the major tributaries over the previous twenty years. The principal observations are discussed in the next few pages. One major, long-term concern is **algae in the reservoirs**.

Although algae are normally present in fresh water lakes, if they can grow in numbers too large, they can lead to severe biological and chemical imbalances in lakes. At higher concentrations in a lake, they can block the sunlight normally needed to support desirable aquatic grasses; they can contribute to an overenriched organic load settling to the bottom of the lake (which then causes a lack of oxygen and a rise in acidity in the deeper waters); and they can cause shifts to less desirable forms of algae, which can lead to highly objectionable tastes and odors in the water supply. For example, blue-green algae (e.g., microcystis) secrete natural toxins and when in abundance (under bloom conditions) can blanket the water’s surface. If elevated levels of algae in a reservoir are drawn in with the raw water, they can: interfere with the filtration processes at the water treatment plant, elevate the levels of taste- and odor-causing compounds, affect the health of some individuals in the population, and cause widespread customer complaints. They also can contribute to the formation of trihalomethanes after the water has been chlorinated prior to distribution to consumers. On occasion, certain bacteria naturally present in freshwater systems can also contribute to taste and odor problems.

Baltimore City records indicate that algae problems were first documented in Loch Raven in the 1930s; the city used chemical treatment in the lake (copper sulfate and activated carbon), but with limited success. During the 1960s, Liberty was the first source-water lake to experience severe algae-related treatment problems; Loch Raven began exhibiting similar, serious problems in the early 1970s. There was a growing recognition that nutrients in the runoff from developed areas and in the discharges from sewage treatment plants might be a contributing factor. In 1970-71, the Baltimore County portions of all three watersheds had comprehensive sanitary surveys carried out. In 1971-1972, Baltimore City participated in an advisory board which worked with Baltimore County's Planning and Zoning Office to establish "watershed protection zones" as a policy in the county's 1972 comprehensive land use plan. The county enacted its first Resource Conservation zoning categories in 1975. These protective land use policies have been continued to this day, and in fact have been made stronger over time.

In subsequent years, the condition of the lakes received more and more attention. Loch Raven was determined to be "eutrophic" (overenriched with algae-supporting nutrients), and analysis of the data showed that phosphorus was the controlling or "limiting" contributing factor. Under the Regional Planning Council's 208 Areawide Water Quality Program in the late seventies, the Loch Raven watershed was surveyed in the field for actual and potential pollution sources.

In 1981, a blue-green algae bloom occurred in Loch Raven, resulting in over 1800 customer complaints relating to the taste and/or odor of the finished drinking water. This was the most severe episode recorded by the city involving taste and odor resulting from an algae bloom. The first complaints were received in late July, corresponding to the onset of the blue-green algae bloom, and continued through the third week in August, when the bloom subsided.

At the same time, new growth was occurring in several rural communities served by sewage treatment plants located at the headwaters of the reservoir watersheds. City, county and state officials were concerned about the growth-inducing effects of the proposed expansions of two of these sewage plants. An early (1979) agreement to try to protect the three reservoirs from pollution sources was eventually superceded by the 1984 Reservoir Watershed Management Agreement. This was accompanied by a Watershed Action Strategy, which specified new policies and actions to be taken regarding not only the existing sewage plants, but a variety of nonpoint sources of pollution, as well. The 1984 Management Agreement, in setting forth the main goals for the cooperative reservoir program, emphasized the need to limit sediment and phosphorus loadings to all three lakes. This was in direct response to the growing concern about algae levels in the reservoirs. (See the discussion of Reservoir Watershed Management Program loading goals under the "phosphorus" heading, later in this paper.)

In studying lake enrichment (eutrophication), it is useful to define certain levels of **chlorophyll *a*** as marking the threshold between different levels of enrichment. This is one of the principles behind the widely-used Carlson Trophic State Index. Under this system, a chlorophyll *a* value of 10 ug/l (micrograms per liter) corresponds to the boundary between having a lake that is "mesotrophic" (moderately impaired) and having a lake that is "eutrophic" (severely impaired). The city has summarized chlorophyll *a* data for the epilimnion during the spring and summer months in each lake from 1985-2000. They looked to see how often the observed values from this time period equaled or exceeded the threshold value of 10 ug/l.

For Prettyboy Reservoir, the observed chlorophyll *a* values met or exceeded the threshold 26.2% of the time; for Loch Raven, this occurred 19.8% of the time; and for Liberty, the observed values met or exceeded the threshold only 9.9% of the time. Using the trophic state index method, Prettyboy seems to be the most impaired of the three with respect to chlorophyll *a* (although other measures in the city's 2001 report suggest otherwise). Liberty is clearly the least impaired of the three with respect to chlorophyll *a*, probably because its much larger volume, in comparison to its watershed area, provides more reservoir residence time (than do the other two lakes) for the natural removal of phosphorus to take place.

Chlorophyll *a* data in all three reservoirs showed signs of improvement over the 1990s. However, this trend recently seems to have been reversed, especially in Liberty Reservoir. More data is needed to determine whether this recent pattern results from the severe drought of 2001-2002 and the very wet year of 2003, or possibly from other factors.

Dissolved oxygen (DO) levels in the reservoirs are also important indicators of ecosystem balance. Epilimnial waters in the lakes (0 to 30 feet deep) measured between 1982-2000 were compared to the applicable State water quality DO standard of 5.0 mg/l, which is the minimum needed to support most fish life. Hypolimnetic waters (depths greater than 30 feet below the surface) were compared to dissolved oxygen values typically seen at depths in mesotrophic (moderately impaired) lakes, where you would expect to find DO levels at or greater than 1.0 mg/l. (DO levels in this low range will not support normal aquatic life.)

- In Prettyboy Reservoir, the epilimnion samples fell below the State surface waters standard (5.0 mg/l) 8.2% of the time. The hypolimnion samples fell below the mesotrophic benchmark (1.0 mg/l) some 25% of the time.
- In Loch Raven, the epilimnion samples fell below the State standard 15.7% of the time, and the hypolimnion samples fell below the mesotrophic benchmark 48% of the time.
- In Liberty, the epilimnion samples fell below the State standard 10.9% of the time, and the hypolimnion samples fell below the mesotrophic benchmark 12% of the time.

The city notes that "Liberty Reservoir appears to be the only reservoir where both dissolved oxygen and chlorophyll *a* indices suggest the same degree of impairment." Prettyboy appears to be the least impaired of the three, based on surface water DO levels, despite the fact that the chlorophyll *a* trophic state index suggests that it is the most impaired. (This might be explained by the fact that the DO values are measured during daylight hours, when the algae are actively producing oxygen through photosynthesis. More algae would produce more oxygen.) Loch Raven appears to be the most impaired, based on the epilimnion dissolved oxygen observations.

The city's 2001 report assesses **phosphorus** levels over time (1982-2000) in the measured tributary streams and in the three lakes. It is well established that phosphorus is the “limiting” nutrient for algal growth and reproduction in most fresh water lakes, including these three reservoirs. That is why the 1984 Reservoir Watershed Management Agreement singled out phosphorus (and sediment) loads to the lakes for control and reduction efforts in the three watersheds.

The city examined phosphorus concentrations in dry-weather samples taken from over a dozen tributary streams in the three watersheds. During the eighteen-year period (1982-2000) phosphorus data for eight of the tributary streams show a gradual, but steady, downward trend. For example, on Little Morgan Run, a tributary of Liberty Reservoir, in the early eighties, observed “total phosphorus” (TP) concentrations ranged from about 10 ug/l (micrograms/liter) to about 200 ug/l, while in the late nineties, TP concentrations ranged from 5 ug/l to about 35 ug/l. Data for Georges Run, a tributary of Prettyboy, showed a comparable steady decrease. On the other hand, samples taken on some of the other tributaries, including the Gunpowder Falls below Prettyboy, show an increasing trend over the same period.

Phosphorus loads can be large during storm events; therefore, results from storm-related sampling can be very significant. Data from 2000-2001 suggest that storm-related phosphorus loadings may be increasing in all three reservoirs. Further monitoring and analysis is needed to validate this trend.

The city performed an analysis to correlate the dry-weather total phosphorus concentrations seen in the major tributary streams (using 1990-1999 data) with the extent of forests and farmland in their respective watersheds. The data were adjusted for differences in the sizes of the watersheds in the study. The data indicated that the median TP concentrations observed in the streams were significantly lower in those watersheds where more than 30% of the land area was forested than in the watersheds where less than 30% of the land was forested. This suggests that, at least in dry weather, watersheds with woodlands generate lower TP loads than do those dominated by other land uses.

A comparison of the dry-weather TP levels in the various streams with the percentage of farmland in each tributary watershed revealed that the median TP observations for the decade were significantly lower in those watersheds where less than 40% of the land was in agriculture than in the watersheds where more than 50% of the landscape was in agriculture. The mechanism for delivery of the phosphorus from farmlands to the streams in dry weather is not well understood.

The Reservoir Watershed Management Program has relied on the Carlson Trophic State Index (TSI) to set water quality goals for the phosphorus loads entering the three lakes, ever since the initial Action Strategy was developed in 1984. Phosphorus was chosen instead of chlorophyll *a* and secchi disc indices for several reasons, including the belief that it was a more reliable indicator of potential problems in the lakes. A threshold of 26 ug/l total phosphorus (which corresponds to a TSI between the mesotrophic and euthrophic boundaries) was adopted in the 1984 Action Strategy as the goal for the lakes. Data from epilimnion samples taken from the reservoirs during April through September (essentially for the period 1982-1999) were compared to the threshold criterion of 26 ug/l total phosphorus. (Data gathered in 1998-2002 suggested that TP levels remained low in all three lakes, with the exception of an increasing trend in storm-related inputs, briefly noted above.)

- The total phosphorus in Prettyboy's epilimnion met or exceeded the criterion 55.5% of the time.
- The TP in Loch Raven's epilimnion met or exceeded the criterion 57.2% of the time.
- The TP in Liberty's epilimnion met or exceeded the criterion 15.7% of the time.

Taken in combination with the DO evaluation described above, these phosphorus data would suggest that Loch Raven is the most impaired of the three reservoirs. The TP data for Prettyboy suggest that it could be almost as impaired as Loch Raven. The relatively low TP concentrations in Liberty Reservoir, together with the comparatively favorable chlorophyll *a* levels observed in the epilimnion, suggest that it is the least impaired of the three. Certainly, at least in the case of Loch Raven and Prettyboy, the lakes are not remaining below the target level (26 ug/l) for total phosphorus in the epilimnion which was adopted by the Reservoir Watershed Program in the mid-eighties.

The city's report notes that the differences in TP concentrations observed among the three reservoirs are more likely a result of the physical properties of the lakes (such as storage volumes and residence times) than of the differences in their annual pollutant loadings from tributaries. It notes that estimated tributary phosphorus loads are greater per acre in the Liberty watershed than in the Loch Raven watershed. However, because Liberty Reservoir has about twice the volume of Loch Raven, yet has almost half the watershed drainage area, the water has a much longer residence time in Liberty. This might permit more sedimentation of tiny P-bearing particles out of the epilimnion level in Liberty, resulting in relatively lower TP concentrations in the upper waters of the lake.

Soluble **nitrogen compounds** also contribute to the growth of algae in lakes, but in "phosphorus-limited" situations, such as we have with the Baltimore area reservoirs, nitrogen is normally available in excess of the metabolic needs of the algae. However, because many of the simpler nitrogen compounds are highly soluble in water (thereby moving easily with both surface waters and groundwater), and because fertilizers, animal wastes and human wastes are rich in nitrogen, the observed nitrate concentrations can be indicators of the effects of human activities in the landscape. Baltimore City's 2001 report notes that the epilimnion (top 30 feet) of Liberty Reservoir shows a gradual increase in observed nitrate concentrations from 1982 to about 1995, but then seems to level off for the rest of the nineties. In comparison, the nitrate levels seen in Loch Raven and Prettyboy showed no discernable trends during the same time period. All measurements of nitrate levels in the water withdrawn for water supply from Loch Raven and Liberty reservoirs over the past decade are less than 3.0 mg/l, with the average being about 1.6 mg/l. The maximum allowable nitrate concentration for protection of human health is 10 mg/l.

The city reviewed samples taken on the major tributaries during the period 1982-2000. Dry-weather nitrate concentrations in the tributaries were higher than the concentrations in the lakes, and almost all of the streams studied showed gradually increasing nitrate levels from the early 80s to the mid-90s, at which point they seemed to level off for the rest of the decade. The city reviewed the tributary nitrate data for any correlation with land use. As with the phosphorus data, the median nitrate concentrations observed in the streams in the 1990s were lower in those watersheds having the higher percentages of forest cover (with above 25% of the land being forested), as compared to the concentrations seen in the watersheds having the lower percentages in forest.

Turning to contaminants which don't directly relate to biotic cycles in the reservoirs, the city has been monitoring **chloride** levels in the lakes since the early 1990s, and measuring **conductivity** (which can be used as a surrogate for chloride concentrations) since the early 1980s. Elevated chloride levels in the raw water are not reduced by the processes used at the city's treatment plants (most chlorides are highly soluble).

Standards have been established by the EPA for drinking water not to exceed 250 mg/l of chloride to protect against salty taste. This level reflects the average person's sensitivity to the effects of chlorides on taste, and it does not provide protection for those people who have a lower sensitivity. Likewise, commercial and industrial processes have different sensitivities to the levels of chlorides and other dissolved solids present in the public water supply. Concerns have been raised by some facilities being served by the Baltimore area system, involving the effects on their operations of increased chloride concentrations in the finished water.

While not as extensively monitored by Baltimore City as chloride, **sodium** levels are somewhat proportional to chloride levels, because the major source of chloride in the raw water is from the salt (partially sodium chloride) used for de-icing roads. Since 1973, sodium levels in the finished (treated) drinking water have increased almost three-fold in the water withdrawn from Liberty Reservoir (and treated at the Ashburton plant) and almost four-fold in the water drawn from Loch Raven (and treated at the Montebello plant).

The 1.7 million customers relying on city water have varying sensitivities to the level of sodium in their drinking water. EPA advises people on a very restricted diet for sodium (total intake not to exceed 500 mg/day) not to consume water exceeding 20 mg/l of sodium. During 1999 and again in 2003, the sodium concentrations in the finished water leaving the Montebello plant repeatedly exceeded this level (up to a maximum reading of 28 mg/l), and they were consistently higher than the levels seen at that plant in the preceding decades. Similarly, the sodium concentrations in the water leaving the Ashburton plant between 1999 and 2003 ranged from 10-16 mg/l, which exceeded almost all previous readings at that plant.

The EPA also notes that for the general population, these concentrations in the drinking water are in fact a very minor portion (<5%) of their total daily intake of sodium. Persons who are more sensitive to the taste of salty water will notice a taste at concentrations between 30 mg/l and 60 mg/l, while most of the population will not be able to detect a taste in this concentration range. While the EPA has not established an actual standard for sodium in drinking water, they recommend a level not to exceed 30 to 60 mg/l of sodium, to protect the more taste-sensitive members of the population.

In this part of the country, chlorides in a watershed most often originate from the use of road de-icing compounds, but they also can come from animal wastes on farms and from residential septic systems (from human wastes, water-softening compounds, and some household detergents.)

The city's 2001 report indicated that **chloride** levels in the epilimnion (the top 30 feet) of Liberty Reservoir had increased dramatically during the 1990s. Measured concentrations ranged between 16-22 mg/l (milligrams per liter) during 1992 and increased over the years until they ranged between 24-30 mg/l in 1999. Conductivity (an electrical measure of the dissolved inorganic salts in the water) has been routinely measured in the three reservoirs since 1984. Over that time period, conductivity readings have increased more or less steadily in all three lakes, with the Loch Raven epilimnion experiencing generally the highest readings (recently about 200 micromhos), the Liberty epilimnion showing slightly lower readings (around 190 umhos in 1999), and the Prettyboy upper waters having the lowest readings of the three (around 150 umhos at decade's end.) While the observed levels are well below the concentrations at which they can cause taste or health problems for the end consumers, the trends observed in the reservoirs over the past two decades seem to represent a cause for concern.

The city reports that measurements of dry-weather chloride levels, conductivity and dissolved solids in all of the tributary sampling stations have also increased since the early 1980s. In order to try to identify the sources of the chlorides in the streams, the Baltimore Metropolitan Council carried out an analysis in which the 1999 median dry-weather chloride levels observed at 13 different tributary monitoring stations were compared with a variety of factors present in the watershed above each sampling point. The factors tested included such things as the percentage of each small watershed that was in agricultural, forested, residential, and commercial/industrial land use; the 1999 road length per unit of land area; and the number of homes in each subwatershed that were on septic systems.

The strongest positive correlation found (at approximately + 0.80) was the one between the 1999 median chloride concentrations in the streams and the percentage of commercial/ industrial land use in each subwatershed. Because these land uses usually involve the paving of relatively large areas, which are routinely treated with de-icing agents after winter storms, the report concluded that the de-icing agents were a significant source of the chlorides in the streams. There was another strong positive correlation (approximately + 0.68) between wintertime (Jan-Mar, 1966-1999) median chloride concentrations in the streams and the 1999 road density (average road length/unit land area) in each subwatershed. Again, the data suggest that road de-icing is a factor.

There was no correlation observed between tributary chlorides and the percentage of residential land use in each area, and there were weak negative correlations between median chlorides and the percentage of land in agriculture, and between median chlorides and the percentage of land in forest. The analysis did not discover any statistical relationships which might help to explain the trend of increasing dry-weather chloride levels seen in all the sampled tributary streams ever since the mid-1980s.

Water samples from Liberty and Loch Raven reservoirs are analyzed for a **variety of contaminants,** in accordance with the federal Safe Drinking Water Act. These contaminants are classified in several broad categories, based on the types of elements or compounds being measured. A review of all the chemical data collected by Baltimore City over the past decade indicates that the EPA drinking water standards are being met. A brief discussion, organized by type of contaminants, follows.

Volatile organic compounds These compounds include gasoline components, such as benzene and toluene, and dry-cleaning solvents, such as tetrachloroethylene. They have not been detected during the past five years in the water leaving the city's treatment plants.

Synthetic organic compounds These compounds include pesticides and other man-made compounds, such as PCBs and plasticizers. Analytical laboratories have reported the presence of several synthetic organic compounds in the water supplied by Liberty and Loch Raven reservoirs. Compounds detected include atrazine, simazine, and dalapon (all three are herbicides), and di(2-ethylhexyl)phthalate (a plasticizer). Concentrations of the three herbicides were all well below the EPA standards. Di(2-ethylhexyl)phthalate was reported in a number of samples, but also concurrently in laboratory "blanks". Of the 57 samples from the Baltimore City water treatment plants analyzed for the compound over a fourteen-year period, two sample results were reported above EPA standards and three other results were reported as being greater than half the EPA standard. Di(2-ethylhexyl) phthalate was also reported to be present in laboratory blanks analyzed concurrently with these samples. Therefore, the highest results are believed to be due to laboratory quality-control factors, and not due to actual levels in the environment.

Heavy metals Other than naturally-occurring iron and manganese, no heavy metals have been detected at levels of concern in samples of the water supply from Loch Raven and Liberty reservoirs. Manganese can occur at nuisance levels due to its release from bottom sediments under anoxic (lowest DO) conditions, which occur in the deepest water levels in each reservoir. Iron concentrations typically do not exceed the EPA secondary standards. Elevated manganese occurs at greater depths in the reservoirs from late summer to early winter. Closing the deeper intake gates during these periods minimizes the impacts on water treatment costs and prevents nuisance conditions from developing in the distribution system. Improvements in manganese levels in the raw water could be achieved if the quantities of oxygen-consuming material (organic matter) which are deposited in the hypolimnion (lower level) of each reservoir could be reduced.

Prettyboy and Loch Raven reservoirs were placed on the State's 303(d) list in 1996 (a list required under federal law) as being impaired by heavy metals, and Liberty Reservoir was listed as being impaired by chromium and lead. These listings for heavy metal impairment were considered questionable for several reasons: no specific metal was being listed; the original listing was based on total metals, not dissolved (standards are based on dissolved metals); inappropriate sampling techniques were used; and there was no associated hardness data (hardness of the water affects the metals toxicity). MDE contracted with the University of Maryland, Chesapeake Bay Laboratory to perform a Water Quality Assessment (WQA). The assessment consisted of both appropriate water-column sampling within the reservoirs and toxicity studies of lake sediments. The results of the WQAs indicated that there was no aquatic life impairment in the reservoirs due to heavy metals. These WQAs have been accepted by the EPA.

The State's 303(d) list in 2002 included listings for mercury contamination for all three reservoirs. The listings were based on observed mercury content in fish tissue and on a recent change in the EPA methodology for calculating risk due to human consumption of contaminated fish. Total Maximum Daily Loads (TMDLs) have been completed for all three reservoirs and submitted to EPA for approval. This work is discussed in more detail in a later section.

<u>Microbiological contaminants</u> Fecal coliform and *E. coli* are among the most dependable "indicators" of the likely presence of disease-causing organisms in water supplies. Coliform measurements in the water withdrawn from Liberty and Loch Raven reservoirs over the past six years indicate that all samples fell below the State water quality standard of 200 mpn/100 ml, with the monthly average concentrations ranging from 1/25 to 1/100 of the water quality standard. The three reservoirs offer substantial removal of pathogenic organisms in the water column through sedimentation and because of natural disinfection by sunlight (ultraviolet radiation). While pathogens are always a concern in any surface-water supply, the Baltimore reservoirs greatly improve the microbial water quality over that delivered by the tributaries.

<u>Disinfection byproducts</u> EPA regulations require that two types of disinfection byproducts be monitored in public water systems. Disinfection byproducts are formed in the finished water when a disinfectant (such as chlorine) reacts with organic matter present in the raw water. The two types of byproducts are trihalomethanes (THMs) and haloacetic acids (HAA5). Monitoring for these compounds is required throughout a water system's distribution system. Current regulations require that the average value for the entire distribution system be within the EPA standard for any twelve-month period. Future regulations will require that any single location sampled within the water distribution system also meet the standard for a twelve-month period.

Levels vary within the distribution system due to the effect of elapsed time on the generation of the compounds and on the potential for the biodegradation of haloacetic acids with extended time. Typically, the highest levels of THMs are seen in the furthest reaches of the distribution system, while the highest levels of HAA5 are present at midpoints within the system. The values also vary seasonally due to the effect of ambient temperatures and the changing concentrations of reactive organic matter in the raw waters.

Monitoring by Baltimore City of treated waters supplied from Liberty Reservoir indicates that treated water at certain locations in the outer reaches of the distribution system may not meet the location-specific future THM standard. In order to understand the causes of this problem, it would be useful to determine the relative proportion of reactive organic carbon that is generated as a result of reservoir eutrophication, compared to the proportion of the organic carbon coming from terrestrial sources, such as decaying leaves in the waterways.

Targeted analyses which focus on reservoir/watershed water quality issues

As is discussed above, the reduction of seasonally high algae levels in the epilimnion (the uppermost 30 feet) of each reservoir has been a concern of Baltimore's regional reservoir managers ever since the early 1970s. During the early 1980s, Baltimore City worked with researchers at the Johns Hopkins University (JHU) to develop models to determine the relationship between tributary phosphorus loadings and in-reservoir concentrations. These models showed that each reservoir is different in the annual loadings of phosphorus that it can assimilate without developing nuisance algal bloom conditions. One of the purposes of this effort was to determine the desired average annual phosphorus load for each lake.

The results of this work helped the newly-established Reservoir Watershed Management Program to set a specific annual phosphorus-loading goal for each lake. As part of the 1984 Action Strategy for the Reservoir Watersheds, the Carlson Trophic State Index (discussed earlier in this paper on pages 9 and 11) was used to establish reservoir phosphorus and chlorophyll *a* (algae) goals for each reservoir. The modeling work done by JHU allowed these in-reservoir goals to be translated into the required phosphorus load reductions in the three respective watersheds.

The accuracy of the measurements of these loads (and their reductions) increased dramatically as a result of a tributary monitoring program begun by the city's Water Quality Management Section in the early 1980s, which involved the establishment of six permanent stream-gauging stations, as well as the regular monitoring of certain major streams during storm events.

Based on this monitoring, the city subsequently estimated that in 1990, Loch Raven Reservoir was receiving total phosphorus loads of 54.5 tons per year, while the estimated "goal" (acceptable input level) was 40.7 tons/year. Prettyboy was believed to be receiving 15.0 tons of phosphorus per year, while the desired input level was 13.4 tons/year. And Liberty was receiving 34.4 tons/year of phosphorus, while the goal was set at 29.3 tons/year. (These goals need to be reviewed and possibly adjusted. See the final section of this report.) Since, by 1990, the phosphorus levels in the effluents of the Hampstead WWTP (upstream of Loch Raven) and the Manchester WWTP (upstream of Prettyboy) had been significantly reduced, the Reservoir Watershed Program assumed that *most of the remaining needed phosphorus load-reductions in each watershed would come from actions taken on the landscape to reduce nonpoint source loads.*

In the latter half of the 1990s, MDE, DNR, Baltimore City, and the counties joined together to carry out a **comprehensive study of the Gunpowder watershed** above Loch Raven Reservoir. This included a number of aspects, several of which are summarized here. The objectives of the study focused in two complementary areas of concern: studying the potential or existing threats to Prettyboy and Loch Raven reservoirs, and investigating specific stream stability and water quality concerns in the Piney Run watershed, located southeast of Hampstead and a tributary (indirectly) of Loch Raven.

(1) Intensive tributary monitoring in the Gunpowder watershed

One major aspect of the study involved intensive monitoring of streams in the Gunpowder watershed (10 stations above Loch Raven), with special emphasis on the Piney Run subwatershed and the Hampstead WWTP (6 monitoring stations). Some sampling stations were in urban watersheds, some were in mixed-use areas, and some were in rural watersheds. The monitoring was intended: to provide information on the potential risk to drinking water quality and aquatic health from the concentration of pollutants in major tributary streams; to assess the risk to drinking water from water-borne bacteria and pathogens; to obtain data for use in calibrating (setting up) computerized models of the Gunpowder watershed above Loch Raven; to try to estimate in-stream pollutant loads based on land use; and to determine the effect of the Hampstead WWTP effluent on the stream flows and quality of Piney Run. Some of the major findings are summarized here.

- Watersheds representing urban, suburban and agricultural land uses were found to have elevated nutrient concentrations for both nitrogen and phosphorus (relative to background levels) under both base-flow and storm conditions. The monitoring sites in those watersheds having the greater percentages of forest cover exhibited the lowest N and P concentrations (compared to other stations) during both base-flow and storm-flow conditions. In-stream nitrate concentrations were <u>higher</u> under base flow conditions (which depend on groundwater inputs) than under storm flow conditions at 13 out of the 15 monitoring stations. These data suggest that groundwater contributions to the streams are the most significant sources of the nitrogen entering the tributary streams.

- Low dissolved oxygen does not appear to be a problem in the streams above Loch Raven, and the measures taken for in-stream oxygen demand (as indicated by BOD, COD and TOC) indicated a low potential for oxygen depletion within the stream system itself.
- Three sampling stations (one at an agricultural location and two in urban settings) showed high fecal coliform concentrations during base flow periods. The agricultural site was an animal operation, which could account for the high bacterial levels seen there. There was no obvious explanation for the high numbers seen at the two urban sampling stations.
- Selected tributary streams and reservoir location(s) were sampled for two water-borne protozoans, *Cryptosporidium parvum* and *Giardia lamblia*. Analytical methodology available at the time had low recovery (detection) rates. The lack of detection of these protozoans, or the detection at low levels (which were both reported) should not be interpreted to mean that they are not present in the tributaries or that they could not be present in significant numbers. Ongoing sampling of the intake raw water for fecal coliform and for *Cryptosporidium* and *Giardia* suggests that Loch Raven Reservoir itself provides a substantial level of treatment and removal of these organisms.
- Based on the sampling results, it appears that metals are not a threat to the raw water quality of Loch Raven. Four metals (arsenic, barium, chromium and nickel) did not exceed the applicable water quality standards during either base flow or storm flow conditions. Two metals, copper and lead, might be a threat to local stream life at certain locations. For these two elements, the samples taken during storm events typically displayed a higher exceedance of water quality standards than did the base-flow samples. This might be explained by the accumulation of the metals on impervious surfaces (atmospheric sources) during dry weather and subsequent washoff during storm events.
- Stream temperatures at most stations did not exceed the temperature water quality standard of 20 deg. C. However, four of the stations exhibited recurring summer temperature problems. These included the effluent discharge from the Hampstead WWTP, Piney Run at Butler Road, Spring Branch and Jenkins Run. (More recent sampling of Piney Run—in 2000, 2001 and 2004 by DNR and others—found different age classes of both warm- and cold-water fish species at several stations, including a station just downstream of the Hampstead plant.)
- A pH of less than the water quality standard of 6.5 (which would indicate acidic conditions) was rarely encountered at the Piney Run stations and was never encountered at the ten main watershed sites. Exceedances on the alkaline side (pH greater than 8.5) were seen more often, but seemed to be associated with the local soils and underlying geology.
- The effluent from the Hampstead WWTP comprises the majority of the baseflow in the headwaters of Piney Run. For example, during the summer, when area streams most often reach their lowest base flow levels, the treatment plant effluent accounted for 81.8% of the stream's base flow. This means that during dry weather, the quality of the plant effluent dominates the water quality of the stream for quite some distance down the watershed.

- The WWTP effluent at peak flow is less than 10% of the peak storm flow observed in the stream just below Hampstead. This suggests that the treatment plant effluent was not a major factor in the stream channel erosion that had been occurring in Piney Run below the community.
- When evaluating the samples taken at the foot of the Piney Run watershed (i.e., the station at Butler Road), the Hampstead WWTP effluent accounts for varying proportions of the in-stream nutrient loads, ranging from a low of 8.6% of the observed in-stream TKN to a high of 18.7% of the observed nitrate/nitrite levels. The remaining pollutant loads seen in the stream at Butler Road are coming from nonpoint sources in the watershed. This conclusion is based on both storm-event and baseflow monitoring. The nitrogen loads in Piney Run are comparable to the loads observed in other subwatersheds, especially agricultural subwatersheds. However, the per-acre total phosphorus loads are lower in Piney Run, compared to loads in other agricultural subwatersheds. The data indicate that there has been a reduction in the total phosphorus concentrations for both baseflow and storm events, when we compare the results from the city's earlier Piney Run Study to the results of the Gunpowder Study. It appears that the Gunpowder Study validates the city's earlier conclusion that the targeted application of agricultural BMPs in the relatively small Piney Run watershed during the early 1980s had reduced nonpoint source nutrient loadings to the stream.

(2) Development of the Gunpowder Watershed Model (MDE)

It is generally agreed that we need to develop a better understanding of the generation, transport and delivery of key pollutant loads to the reservoirs, as well as a better understanding of the in-lake processes which act upon those delivered loads. For many years, Baltimore City has been concerned about the delivery of sediment and nutrients (especially phosphorus) to its reservoirs. (As noted earlier, phosphorus is known to be the "limiting" nutrient in Prettyboy and Loch Raven reservoirs.) The generation of pollutant loads in the Gunpowder watershed above the two lakes involves (a) the permitted discharges from two sewage treatment plants, Hampstead and Manchester (whose respective loads can be measured directly at the points of discharge) and (b) the nonpoint source (NPS) loads generated by human activities and by natural processes in the respective watersheds. The NPS loads in a large watershed can only be estimated, not measured directly.

Computerized models of watersheds allow us to recognize the varying importance of different types of land use in the generation of NPS loads, and the effects of natural stream processes on those loads between the point of generation and the point at which they eventually reach the downstream receiving water (here, a reservoir). Beginning in 1998, the Maryland Department of the Environment (MDE) worked to develop a detailed computerized model of the entire Gunpowder watershed above the Loch Raven dam. Using a generic model known as HSPF (hydrologic simulation program in Fortran), MDE combined detailed current land cover data, average literature values for pollutant loads from a variety of different land uses (in pounds/acre/year), and measured streamflow data to develop a computer model of the watershed above Prettyboy and the entire watershed above Loch Raven. This project is referred to as the Gunpowder Watershed Model (the GW model). The goal of this effort was to develop a modeling tool which would help MDE to establish daily load limits (Total Maximum Daily Loads or TMDLs) for nutrients reaching the two reservoirs.

The HSPF model is not intended to simulate the in-lake processes which sequester and transform the delivered pollutant loads. That ideally is done using a different computer model which is better suited to analyzing lakes. (Work on such models for Prettyboy and Loch Raven was begun by a contractor to MDE, but has not yet been satisfactorily completed. The agency continues to work with the consultant in refining the lake model, and hopes to have a model suitable for TMDL development in the near future.)

Work on the Gunpowder watershed modeling effort by MDE continued over several years, then encountered some delays, and was essentially completed in 2002. (For a full discussion of the modeling process, the reader should refer to the documentation report prepared by MDE. Only the highlights of the model are described here.)

The model consists of both on-land and in-stream processes which are adjusted based on actual field data, as well as data from the scientific literature. The HSPF model calculates a nutrient load which is "delivered" to each of the two reservoirs.

The model divides the upper Gunpowder watershed into seventeen "segments" which correspond to the major subwatersheds in the actual watershed. *(Refer to Figure 4.)* Measured streamflows at permanent stations in the watershed from 1990-1997 were used. Using 1994 maps of actual land cover (based on aerial photos), plus cropland data from the Farm Service Agency and other sources, provision was made in the model for eleven different types of land cover (pervious urban, impervious urban, no-till cropland, conventional-till cropland, pasture, forest, etc.) Within each segment, the total acreage in each land cover type is subjected to different processes occurring at different rates and time periods (e.g., erosion, denitrification), which results in different pollutant loading rates for each land use type. The processes in the model are calibrated to literature values, and the calculated final loading rates from each land use are compared to values from the scientific literature.

The model then performs calculations which simulate the loss (say, through deposition) or the transformation of the pollutants (say, by biological activity) during the time the pollutants are flowing down through the stream segment. By adding up the output loads for each segment (as modified by downstream transformations), the model estimates the pollutant loads delivered to each reservoir. To calibrate (adjust) and verify the model, the calculated values (say, for sediment, nitrates and phosphates) can be compared with values calculated from actual data on in-stream concentrations and stream flows. In cases where other models have been developed for a particular watershed, the present calculated values (in the new model) can be compared with the calculated values from those earlier efforts.

The Gunpowder Watershed model developed by MDE calculated the average annual loads of total phosphorus, total nitrogen and total suspended solids delivered to Loch Raven Reservoir and to Prettyboy Reservoir. These calculations accounted for the measured point source loads (from the two sewage plants in the watersheds) and for the estimated total NPS loads from the basin's landscape.

The GW model allows us to compare the relative influence of different land "covers" in the generation and delivery of the different key pollutant loads to the lakes. For example, the model calculated the following percentages of the annual total loads to the Prettyboy Reservoir which were attributable to the various major groups of land cover types in the entire Prettyboy watershed. *(Note* that urban runoff loads are relatively small in this case because urban uses are such a very small portion of the Prettyboy watershed. Urban runoff typically contributes greater nutrient loads per acre than most other land-use types. In addition, this analysis does not account for the pollutant loads originating from streambank erosion in developed areas, and it does not fully account for many of the nonpoint source BMPs already installed in the watershed.)

Gunpowder Watershed Model calculated share of annual loads to Prettyboy

Land Cover Type	Total Suspen. Solids	Total Nitrogen	Total Phosphorus
Urban (runoff)	2%	8%	10%
Septic systems	0%	6%	0%
Cropland (all types)	77%	53%	66%
Pasture	14%	19%	9%
Manures	0%	9%	9%
Forestlands	7%	5%	6%

Mercury loading limits for Liberty, Loch Raven and Prettyboy Reservoirs

Federal (EPA) regulations pursuant to the Clean Water Act require that, for bodies of water from which fish are taken for human consumption, a detailed analysis must be done for any pollutant that appears to be approaching the maximum allowable concentration (for safe consumption) in the edible flesh of the fish. The Maryland Department of the Environment (MDE) announced a statewide fish-consumption advisory for lakes in 2001, based on mercury data in fish tissue from a subset of lakes across the State. The advisory was established statewide as a precautionary measure because the primary source of mercury is understood to be atmospheric deposition, which is widely dispersed. Based on additional fish-tissue data, MDE verified that mercury levels in largemouth bass taken from the three Baltimore-area reservoirs were approaching levels that might make these fish unsafe to eat on a regular basis. MDE then measured water-column mercury concentrations and developed estimates of current mercury inputs to the lakes.

Summary statistics for mercury levels and allowable limits in the three reservoirs appear in the following table. Current total mercury water-column concentrations (reported as a geometric mean) range from 1.32 ng/L (nanograms per liter or parts per billion) to 4.95 ng/L. These values are well below Maryland's ambient water quality standard for total mercury of 0.51 µg/L (micrograms per liter or parts per million)—the same as 510 ng/L. Calculating backwards from the desired "safe level" of mercury in the fish tissue, and making appropriate allowances for bioaccumulation of the metal through the food chain, MDE determined the acceptable water-column concentrations of total mercury in the three reservoirs. These concentrations ranged from 0.589 ng/L to 2.27 ng/L. MDE estimated that about 85% to 95% of the mercury entering the lakes came from atmospheric deposition, largely from near and distant coal-fired power plants, which MDE and EPA consider to be the largest anthropogenic sources of mercury emissions in the nation. Thus, the principal means of reducing the loadings would come from mandated improvements in coal-fired plants (and other sources of atmospheric mercury emissions) under provisions of the Clean Air Act.

MDE submitted its determinations of Total Maximum Daily Load of mercury for each of the three reservoirs to EPA in late 2002, and is awaiting final approval. EPA is currently refining its air-deposition model to better estimate the existing atmospheric loadings of mercury.

Summary statistics for total mercury concentrations in the Baltimore-area reservoirs

Reservoir	Total mercury water-column concentration (observed)	Acceptable water-column concentration	Percentage of mercury entering the lake due to atmospheric deposition
Liberty Reservoir	1.32 ng/L	0.589 ng/L	95
Loch Raven Reservoir	4.95ng/L	2.27ng/L	85
Prettyboy Reservoir	3.86ng/L	1.56ng/L	98

Source Water Assessments for Liberty and Loch Raven Reservoirs

The 1996 Amendments to the federal Safe Drinking Water Act require the states to carry out "source water assessments" to evaluate the safety of all public drinking water systems. MDE has the lead responsibility for this effort in Maryland. Working in cooperation with MDE's Water Supply Program, the Baltimore City DPW and a private consulting firm recently completed a source water assessment (SWA) for Liberty Reservoir (2003). As of June 2004, MDE's Water Supply Program has developed a final draft SWA for Loch Raven Reservoir.

The SWA studies involved a number of aspects relating to the safety and reliability of Liberty and Loch Raven as continuing water sources. These included an in-field review of the condition of each dam and the intake structure at each reservoir, and an assessment of current land use, land-use trends, and types and locations of potential contaminant sources in the watershed above each reservoir. Actual in-field testing of travel times for water flows from key points on several major tributaries to reach the Liberty Reservoir was conducted under low-flow and high-flow conditions. In addition, records of Baltimore City lab analyses of the quality of the raw water for a recent five-year period were reviewed and summarized. All analytical results within MDE's data base were reviewed, as well. Finally, the overall susceptibility of each reservoir to contamination from a spill somewhere in its watershed or close to the lake was assessed.

The two SWA reports present a wide range of conclusions in these several subject areas. Focusing here on the quality of the raw water (as it is taken from the reservoir), the reports concluded that several groups of compounds did not present significant problems, including volatile organic compounds, synthetic organic compounds, and metals--except for iron and manganese. Noting a trend over time towards increasing dissolved solids, chlorides and conductivity in the tributaries above both Loch Raven and Liberty, the authors offered the opinion that the increases were most likely attributable to human activities in the respective watersheds. The trend of increasing sodium levels in Loch Raven raw water also was noted. Both reports highlight the importance of not overdeveloping the reservoir watersheds, as a means of protecting water quality.

The SWA reports note that in-lake turbidity can be a concern under stormflow conditions. This derives from turbidity (fine suspended solids) delivered by the tributary streams and by direct runoff to the reservoirs. In addition, algae which grow and live in each reservoir can contribute to elevated turbidity levels. High turbidity can lead to increased operating costs at the two water treatment plants. The city restricts its use of the intake tower in each lake to certain depths, in order to avoid taking in the most turbid water. The reports noted the importance of further reducing algae levels by making additional efforts to reduce phosphorus inputs. In addition, the Liberty report recommends further study of turbidity levels in the reservoir and of their patterns of fluctuation as a possible future guide to more effective management of the intake levels at Liberty and of the treatment processes at Ashburton. The Loch Raven report recommends studying the benefits of dredging accumulated sediment out of the upper reaches of the reservoir, as this area no longer provides the intended sediment removal, and the main body of the reservoir is beginning to fill in more rapidly.

The SWA reports note that nutrient concentrations in the two lakes have been declining gradually since the 1980s, which seems related to declining algal counts in the epilimnion of each reservoir over the same time period. The authors of the Loch Raven report, however, had access to more recent data and therefore highlighted the recent reversal observed in the phosphorus trends and the corresponding chlorophyll *a* levels in Loch Raven. Both reports describe the respective lakes as "highly phosphorus limited", which means that any future increases in phosphorus loadings to the reservoirs could be expected to cause a decrease in water quality due to increased algae levels. Phosphorus is identified as "a primary concern and threat to the Loch Raven and Liberty reservoirs as a source water." A reduction in phosphorus loadings is recommended in both SWA reports, with more specific recommendations featured in the Loch Raven final draft. The benefits of healthy, forested lands for reducing in-stream phosphorus levels and for improved water quality are touted in both reports.

After reviewing the data on fecal coliform counts, the SWAs indicate that the raw water taken from Loch Raven and Liberty reservoirs is of high quality and poses a lower risk to consumers from pathogenic microorganisms than does water delivered by many other public systems which withdraw directly from rivers or streams. The long residence time in each reservoir and the variable intake depths employed by the city provide considerable reduction in the concentrations of these organisms in the raw water. The reports note that however, under certain conditions, elevated pathogen levels could be present. The Loch Raven report also highlights the potential impact from occasional failures of the public sewage collection system which is located close to the reservoir.

The two SWA reports also address the formation of disinfection byproducts (DBPs) in the finished (treated) water. These are potentially harmful compounds produced by the reaction of various forms of organic carbon in the finished water with the chlorine added to the water for disinfection. Two of the major classes of DBPs are total trihalomethanes and haloacetic acids. The city has been monitoring finished water for these compounds at many different collection points out in the distribution system. Concentrations of DBPs often were seen to *increase* as the water went out through the system. Concentrations of total trihalomethanes are greatest at points in the distribution system where the water has the greatest residence time. Because organic carbon can come from natural sources in the reservoir landscape (leaves, detritus, etc.) and also from algae living in the reservoir, the SWA reports recommend that a more detailed evaluation of the relative importance of the terrestial sources of carbon versus the algal sources in the formation of DBPs be carried out, in order to better target watershed protection efforts.

Loch Raven Watershed Water Quality Management Plan (Baltimore County)

The Water Quality Management Plan for Loch Raven Watershed was completed in 1997. The plan was among ten plans produced by Baltimore County in partial fulfillment of the county's National Pollutant Discharge Elimination System (NPDES) – Municipal Stormwater Discharge Permit. Baltimore County relies on the services of consultants for the preparation of its watershed management plans. While the details of the respective plans will vary, a common framework is followed in developing each plan. This framework includes:

1. watershed modeling using the EPA Storm Water Management Model (SWMM);
2. stream-stability assessment, using Rosgen classification methodology Levels I,II,III;
3. identification and ranking of water quality problems in each study area;
4. development of nonpoint-source control management strategies;
5. prioritization of recommended programs and projects; and
6. preparation of the final document, integrating the above tasks and preparing maps and tables to document the results and recommendations.

Due to the large size of the Loch Raven Reservoir watershed within Baltimore County (139,400 acres and over 822 miles of streams), a slightly different approach to the stream stability analysis was taken, compared to the approach used for the other, smaller, watersheds in the county. A subset of fourteen (14) subwatersheds out of 46 subwatersheds in the Loch Raven drainage basin was selected for the stream-stability analysis. A total of approximately 80 miles of second- and third-order streams within these subwatersheds were assessed. The subwatersheds were selected to represent the range of land-use types within the Loch Raven watershed, with a primary focus on the urban/ suburban subwatersheds and on those subwatersheds lying in close proximity to the reservoir. These same fourteen subwatersheds were used as case studies for the development of recommended management actions.

Calculations made using the pollutant load model SWMM were used to identify those subwatersheds with high per-acre pollutant loadings for sediment, nitrogen, phosphorus and zinc. Higher sediment loads were mainly associated with the agricultural subwatersheds, as were the higher total phosphorus loads, but several of the more urban subwatersheds also had relatively high phosphorus loads. Total nitrogen loads were mixed, with a subset of both agricultural and urban subwatersheds exhibiting the higher per-acre nitrogen loads. The highest pollutant loads for zinc were associated with the urban subwatersheds.

The stream-stability assessment for the 14 subwatersheds found that 11.6 % of the stream miles assessed were rated in the "poor" or "very poor" stream-stability categories. The streams found to have the highest percentages in the poor or very poor categories (Beaver Dam Run, 22.5%; Goodwin Run, 22.4%; and Loch Raven Reservoir/Hampton Branch, 20.5%) were in urban/suburban subwatersheds. Two partially rural subwatersheds (Oregon Branch, 18.7%, and Carroll Branch, 16.3%) also had relatively higher percentages of poor and very poor stream-channel stability.

Four separate "management areas" were identified to help target the county's management programs and restoration efforts within the Loch Raven Reservoir drainage basin. The potential sources and causes of current water quality impacts, the possible management actions, and the potential restoration projects (based on the case study areas) were identified and prioritized for each management area. *(Refer to Figure 5.)*

- Management Area 1: Reservoir Protection Subwatersheds – These subwatersheds are adjacent to Loch Raven Reservoir. Water quality impacts due to urban land use, agriculture and recreational use were identified. Recommended management actions include environmental controls on new development; retrofitting existing development with storm water controls; and promoting environmental stewardship in the existing parks and golf courses.
- Management Area 2: Rapidly Urbanizing Subwatersheds – These subwatersheds, lying mainly outside of the county's Urban/Rural Demarcation Line (URDL), have extensive RC4 and RC5 residential zoning. Water quality impacts due to existing urban development and the potential for future rural residential development were identified. Recommended management actions include: develop an inventory of stream restoration and stormwater retrofit opportunities in the existing developed areas; provide environmental controls for new development; explore stream-crossing designs to minimize adverse

stream impacts; and review and update the regulations for the siting and installation of on-site waste disposal systems.

- Management Area 3: Parkland and Forest Areas – These subwatersheds are located mainly below Prettyboy dam, and they include much of Gunpowder State Park. Water quality impacts were mainly identified as resulting from potential future development, based on the existing zoning. Recommended management actions include: develop a public education strategy for the implementation of forest best management practices; encourage land acquisition to preserve tree cover and stream buffers, and to protect steep slopes; use fencing to protect existing stream buffers from grazing; and apply environmental controls to all new development.
- Management Area 4: Agriculture and Headwaters Areas – These subwatersheds lie in the northern and western portions of the Loch Raven watershed. Water quality impacts resulting from agricultural activities were identified, including the absence of forest riparian buffers and some stream-channel instability. Recommended management actions include: targeting nutrient management and erosion control to those areas with the highest nonpoint source loadings; and expansion of the current extension programs to better assist small farms and ranches.

In addition to the areawide management actions detailed above, specific restoration activities were identified in each of the fourteen "case study" areas. These restoration activities have provided the framework for the county's Waterway Improvement Program in the Loch Raven watershed. To date, six stream-restoration projects have been completed in the watershed, and one more is in the design stage. *(Refer to Figure 5.)* Several additional stream-restoration projects are in the Baltimore County capital budget for the future years.

The completed stream-restoration projects have restored 17,200 linear feet of stream channel. The additional stream-restoration project which is in the design phase will result in the restoration of an additional 2,500 linear feet of degraded stream channel. Two new stormwater management wet ponds have been installed in the Loch Raven watershed to date. These two facilities provide water quality benefits and peak-flow attenuation for a total of 186 acres of urban land. The county's current capital budget includes funding for three additional stormwater retrofits, one stormwater facility conversion, and seven stream-restoration projects. Approximately $4,900,000 has been spent by the county on restoration projects in the Loch Raven Reservoir watershed to date, with another $4,800,000 allocated in the capital budget over the next six years.

Water Resources Action Strategy for Liberty watershed within Carroll County

As a party to the Reservoir Watershed Agreement, Carroll County is concerned about protecting the water quality of Liberty Reservoir. The Maryland Department of Natural Resources (DNR), through its Unified Watershed Assessment process, rated Liberty Reservoir as having the highest-priority need for both protection and restoration.

Funding was made available to Carroll County to develop and implement a Watershed Restoration Action Strategy (WRAS), which identifies impairments within the Carroll County portion of Liberty Reservoir watershed and which propose solutions to those impairments. *(Refer to Figure 6.)* The goal of this project was "to develop a Watershed Restoration Action Strategy for selected subwatersheds which is intended to maintain and enhance the water quality of the streams draining to Liberty Reservoir."

With the assistance from partner agencies, the Carroll County Bureau of Resource Management (BRM) developed a process to 1) assess watershed conditions in the field, 2) identify water quality issues of concern within the watershed that could reduce the drinking water quality of Liberty Reservoir, and 3) target subwatersheds to implement action strategies designed specifically to improve stream conditions and water quality.

Watershed assessments involve gathering and updating watershed-related information, creating new data layers of information, and working cooperatively with DNR to collect water quality information within the selected subwatersheds. Together, the County and DNR conducted stream-corridor assessments, estimated dry-weather pollutant loadings, and assessed the stream's aquatic insect community. The end result of these efforts was a characterization of the overall condition of each of the selected watersheds. The stream-corridor assessments proved to be an essential part of determining the health of each watershed. Field crews evaluated, mapped and quantified different types of impairments, such as eroding stream banks, inadequate stream buffers, barriers to fish migration, pipe outfalls, etc.

The Carroll County BRM then combined and analyzed all of the field and office information in order to determine the likely causes of the impairments observed in the field. Based on this evaluation, each of the smaller subwatersheds was assigned to one of three categories: restoration, protection, or "needs further study". Within each category, subwatersheds were then prioritized for follow-up, based on the quantity and severity of the impairments.

The BRM selected two watersheds (Middle Run and Snowdens Run; *refer to Figure 6)* on which to test the watershed assessment, evaluation, and prioritization procedure. From the actual stream-corridor assessments, the most common stream impairments observed were eroding stream banks and inadequate stream buffers (defined as less than 50 feet of trees along the stream bank.) The field observations were mapped and documented in the WRAS report prepared by the county and DNR.

Seven action strategies were developed to address the causes of the impairments identified during the evaluation phase of the process. When fully implemented, these strategies will improve conditions within the Middle Run and Snowdens Run watersheds and ultimately improve the water quality of Liberty Reservoir. The seven strategies are:

Strategy 1: Nutrient Source Tracking
Strategy 2: Agriculture Best Management Practice Targeting
Strategy 3: Stormwater Retrofit/Storm Drain Repair

Strategy 4: Stream Buffer Planting
Strategy 5: Database Maintenance
Strategy 6: Establish Watershed Implementation Groups
Strategy 7: County Program Coordination

The process established and refined under the WRAS grant will enable Carroll County to target its efforts for improving watershed conditions in the future. It is important that this procedure be followed when adequate resources eventually become available. Limits on funding make it important that a rigorous evaluation procedure be followed when selecting specific watershed restoration measures to be implemented.

Since the completion of the Liberty watershed WRAS report, a Watershed Implementation Group has been formed by the county. Its members have received maps of the targeted subwatersheds within the Middle Run and Snowdens Run watersheds. (In late 2003, county staff completed initial field work within two high-priority subwatersheds of the Middle Run watershed.) During 2004, the group is focusing on implementing the Nutrient Source Tracking strategy, in cooperation with watershed staff from Baltimore City DPW. Plans also include completing the inspection of storm drain outfalls in these two targeted watersheds, in order to determine if repairs are needed and to evaluate the potential for providing stormwater management in key locations. County staff also are working with staff from the Carroll Soil Conservation District to update the existing watershed database with information on new agricultural BMPs installed over the past year.

Trust for Public Land Source Water Stewardship Project for Prettyboy Watershed

In 2002, the Prettyboy watershed (the drainage basin) was among four water-supply watersheds in the eastern U.S. selected by the Trust for Public Land, a nationwide conservation group, for its Source Water Stewardship Project, which was supported with EPA funding.

The project had several major facets. One was to demonstrate the usefulness of GIS-based analysis of physical parameters of the watershed (such as land cover, slope, forest cover, and soil depth to bedrock) as a means of setting priorities for outreach and technical assistance by conservation agencies in the watershed. GIS data sets covering the watershed were provided by state and local agencies to TPL’s consultant (the Forestry Department at the University of Massachusetts), who produced a set of maps highlighting the specific areas where improved forestry application and farm conservation measures would seem to offer the greatest return, in terms of water quality protection. Staff at Baltimore County DEPRM performed another GIS analysis for the Baltimore County portion of the watershed, which “scored” all areas of the watershed based on their conservation priorities and their restoration priorities. The conservation priorities were based on the development potential of individual parcels of land, using their current zoning. The restoration priorities were based on the present extent of forest cover in priority management areas, such as stream buffers.

The second major facet of the TPL project was the process of holding a week-long workshop (called a Stewardship Exchange) in the watershed, based upon the presentation of detailed data about the reservoir and its tributary areas to a team of "visiting experts" assembled for the week by TPL--the so-called Exchange Team. The Stewardship Exchange was held in the second week of April 2003, and all of the week's meetings were held in either Westminster or the Prettyboy area. During the various work sessions, local and state agency representatives and interested citizens presented data about forestry, agriculture, residential development, stream habitat and water quality in the watershed (as well as socio-economic information) to the five-member Exchange Team. Counting the state and local technical staff and the citizen participants, over seventy-five people participated in one or more of the week's meetings.

At the end of the week, the team members drafted an evaluative report, based on the technical publications they had been given to review and the presentations they had heard. This was revised and improved upon over the summer, and the final Exchange Team Report was released to the public at a meeting in October 2003. (For more information about the report, contact the BMC.) The team's recommendations covered a broad range of issues. Only the ones relating to water quality and land use assessment are listed here.

- The Exchange Team recommended that the agencies responsible for managing the reservoirs enhance their ability to analyze the existing data about the lake and its relation to the land in the watershed. They recommended the development and application of enhanced quantitative tools to improve our understanding of how existing land cover, land use and management practices are affecting water quality in the basin. This better understanding should help us to identify where and how land protection efforts, forest restoration and improved management would best contribute to water resource protection and improvement.
- The Exchange Team recommended that local governments work to develop consistent GIS data layers across political jurisdictions. They noted, "Excellent data layers have been developed for Baltimore County, but not for Carroll or York Counties." By having data sets that are of comparable quality and detail, it would make it easier to evaluate trends in land use and resource management all across the Prettyboy watershed. They noted the need to develop the following data sets in all three counties: digital land parcel data (such as tax maps showing every lot); natural resources (forest type and cover, water resources, soil types, etc.); and updated information on the lands protected by either public ownership or private participation in a variety of easement/protection programs.
- The watershed "priority area maps" generated by the University of Massachusetts and by Baltimore County DEPRM for the Prettyboy Stewardship Project should be "ground truthed" by local and state personnel. The team noted that the respective watershed maps pointed to potential high-priority areas for protection and/or restoration efforts, but that these areas need to be inspected in person to confirm land uses and conditions, to verify stream condition, and to identify specific sites where protective or restoration measures should be taken.

- The team noted that a better "water quality baseline" for the reservoir and its tributaries needs to be established, in order to be able to document changes in water quality that might result from future land-use changes and land protection/management efforts, such as the establishment of stream buffers or the better use of agricultural BMPs. Better technical tools, such as data loggers and additional flow-gauging stations, should be employed to establish a more complete picture of water quality changes over both shorter and longer periods.
- There is a need for "a long-term commitment to monitoring that is consistent across jurisdictions and integrated into existing programs." The monitoring data should be available to and understandable by all parties, including the interested public. The availability of such data should help to encourage landowners in the watershed to participate in land protection programs and to install BMPs where they will be most effective.
- Monitoring by trained citizen volunteers of stream conditions is an excellent way to educate the public and to help build a constituency that will advocate on behalf of wise land use, water resource protection, and targeted restoration projects in the Prettyboy watershed.
- The Exchange Team determined that, although Prettyboy in-lake water quality is fairly well understood, there is "insufficient high-quality data for the tributaries." The current stream monitoring program should be enhanced to include several new aspects. Monitoring should be conducted throughout the watershed and in a consistent manner across all jurisdictions. Probability-based (randomly selected) and fixed sampling-stations should be employed, so that inferences can be made about stream quality beyond just the sampling points. The program should include physical monitoring (for stream-channel stability and erosion), chemical monitoring (provides a "snapshot" of water quality), and biological monitoring (evaluates the longer-term effects of water quality on the desired aquatic community.) And the tributary monitoring program should include both dry-weather and wet-weather sampling, because most of the pollutant loadings to a lake are typically delivered as a result of storm flows.
- The Exchange Team recommended that groundwater-related data should be compiled and mapped in a consistent fashion which: records the measured water quality parameters in all new and existing community supply wells, identifies the older residential areas (such as Lineboro) with potentially failing septic systems, and delineates spray irrigation sites. This would help to identify areas where nutrient loadings to surficial groundwater flows are potentially high.
- Local agencies should carry out a stream-channel stability survey in the Prettyboy watershed. Not only is stream-channel erosion a source of downstream sedimentation and nutrient loadings (ultimately to the reservoir), but in many cases, it can hamper the restoration and maintenance of riparian forest buffers.

Although the work of the Stewardship Exchange Team focused exclusively on the Prettyboy watershed, many of these technical recommendations also would be relevant for the current monitoring efforts in the Loch Raven and Liberty watersheds.

Ongoing and emerging water quality assessment issues in the reservoir watersheds

The previous sections of this report have summarized the major efforts by local agencies to monitor water quality in the three water-supply reservoirs and in some of their major tributaries. Trends since the mid-1980s of key water quality parameters, particularly trends seen in the reservoirs themselves, have been described. In addition, the scopes and major findings of a number of water quality studies performed in one or more of the watersheds since the mid-1990s have been reviewed. There should be no doubt in the reader's mind that state and local agencies have expended much time and effort over the years to understand the phenomena occurring in the reservoirs and in their major tributaries. As noted in earlier sections, some of these efforts are continuing, such as the work by MDE to create complete and reliable computer models of the Loch Raven and Prettyboy watersheds and lakes.

This section of the document will stress the principal technical water quality concerns that carry over from the past, as well as a few that have recently emerged as new issues. It is expected that the issues examined here will provide the basis for portions of the new Reservoir Watershed Action Strategy, which will be developed by the participants in the Reservoir Watershed Management Program during 2004-2005.

Previously in this report, we have summarized the twenty-year trends in various key water-quality parameters, as measured in the reservoirs and in their major tributaries. As might be expected, the overall picture is complex. In general, certain pollutants have decreased since 1984, some have shown no clear trends, and other ones have increased. Some parameters which previously had declined have, for unknown reasons, risen since 2000. The last significant water-quality "crisis" which affected the system's customers (in 1981) involved a blue-green algae bloom in Loch Raven. Yet, brief algae blooms occur in each lake once or twice each year. And, somewhat unrelated to pollutant inputs, all three reservoirs were placed under extreme stress as they were "drawn down" during the region's severe drought of 2001-2002.

Baltimore City's attempts over the years to analyze the available in-lake data, taken together with a careful review of the available literature, indicate that the reservoir systems are very dynamic and are sensitive to climatic changes, as well as to the changing sources of nutrients in their watersheds. "Good" conditions observed in a lake today can change to "poor" conditions in a relatively short period of time. A successful watershed protection program should be able to detect changes in lake quality as they occur and then act in a timely manner to prevent more serious problems from developing.

With the expansion of the city's and Baltimore County's monitoring efforts and analytical capabilities over the past twenty years, we are in a much improved position to look for trends and to detect possible new problems in the lakes. Yet there is more we would like to know. Speaking in the broadest terms, we need to develop a better understanding of the sensitivity of the three reservoir systems to selected key pollutant inputs; we need to refine our knowledge about pollutant sources and pathways in the reservoir watersheds; and we need better analytical tools to simulate or predict future water-quality conditions.

The following continuing and emerging technical issues should be considered in the development of the 2005 Reservoir Watershed Action Strategy:

1. It is essential for us to maintain the city's ongoing stream-monitoring program, which keeps track of the concentrations and loadings of nutrients and sediment delivered to each of the reservoirs from the major tributaries. Tributary monitoring is needed to detect adverse trends, to identify sources, to document cleanup progress, and to relate reservoir water quality to changes occurring in the watersheds. The establishment of more frequent tributary sampling for wet-weather events is particularly critical, because storm flows typically deliver relatively large pollutant loads. Monitoring for the different forms of phosphorus (dissolved, particulate, organic and inorganic) is needed to better assess the possible in-lake effects of the nutrient and to help determine the sources of the loads. The city and the two counties must use existing stream-quality data and must expand their monitoring programs to help identify pollutant sources by means of watershed assessments.

2. In-stream, benthic biological monitoring should be used to evaluate the health of smaller tributaries, to establish baseline conditions, and to identify the areas which are experiencing excessive sediment delivery. The purpose of the biological monitoring is to look for water quality problems that might not otherwise be detected through chemical monitoring, which is more transient in nature. Biomonitoring can help to identify subwatersheds which are contributing contaminants and can provide the basis for deciding to conduct watershed assessments. The results can be used by the SCDs, the forestry agencies and the two counties to identify subwatersheds which should be targeted for BMP (best management practice) implementation.

3. The city must continue its ongoing in-lake monitoring program, which measures key water-quality parameters within the reservoirs. The existing multi-depth, multiple-parameter program provides invaluable long-term information for tracking changes over time. Certain key parameters should be added to the reservoir sampling program. For example, monitoring of total organic carbon and dissolved organic carbon should be routinely conducted in the reservoirs and tributaries, given the relationship of these types of compounds to the formation of disinfection by-products in the finished water (see the earlier section summarizing the two Source Water Assessments) and their role in the calibration of a water quality model by MDE (discussed below). Algal speciation data also should be included in future water quality assessments, so that the presence of and the trends in (toxic) blue-green algal concentrations can be better understood. Periodic monitoring for specific taste and odor compounds in the lakes also should be considered.

4. As is documented earlier in this report, Baltimore City, Baltimore County, Carroll County and the Maryland DNR each carry out different kinds of stream-monitoring efforts in the reservoir watersheds, while the city performs all in-lake sampling and analysis. Each of these programs was designed and implemented to meet specific informational needs, and each has evolved on its own since the time of its inception. There is a pressing need for all the parties to review their programs jointly and in detail. At the very least, this review would reveal any important "gaps" in coverage and would identify key areas where duplication of effort could be avoided and operational efficiencies increased. During 2004, the city, the two counties and the state began to carry out such a detailed, coordinated review of their monitoring programs.

5. Recent (last 2-4 years) in-lake chlorophyll *a* and phosphorus data have shown increasing trends for all three reservoirs. Total phosphorus levels in the water columns in both Loch Raven and Prettyboy are in excess of the in-lake phosphorus concentration goal of 26 ug/l (micrograms per liter) for most of the readings taken between June 2001 and December 2003. The cause of these recent, elevated phosphorus concentrations is not fully understood. The data from tributary stations need to be reviewed along with the in-lake data. Prettyboy Reservoir experienced algal blooms in 2002 and 2003. Average levels of chlorophyll *a* in Prettyboy are typically above the accepted in-lake target of 10 ug/l during the growing season. Chlorophyll *a* levels are lower in Loch Raven than in Prettyboy. And while they are normally below the desired 10 ug/l level, Liberty's chlorophyll *a* levels nevertheless show a consistent increase for the past three years. The data should be reviewed to document where, when, and possibly why these increases have occurred in the most recent years. Then new management strategies might need to be developed by the Reservoir Program to address these impacts.

6. There is a need to revisit and possibly to revise the total phosphorus annual loading goals previously adopted by the Reservoir Program for each lake. We should support MDE's ongoing efforts to develop effective, calibrated watershed models and link them to reservoir models based on nutrient transport and assimilation. Working together, such models can simulate reservoir responses to broad-scale changes in land use patterns and to hydrologic events. They will help us to better calculate the nutrient loadings acceptable for each lake's long-term protection (i.e. to set nutrient loading goals). Along these lines, MDE needs to make a decision about whether or not to set TMDLs for phosphorus loads to each lake.

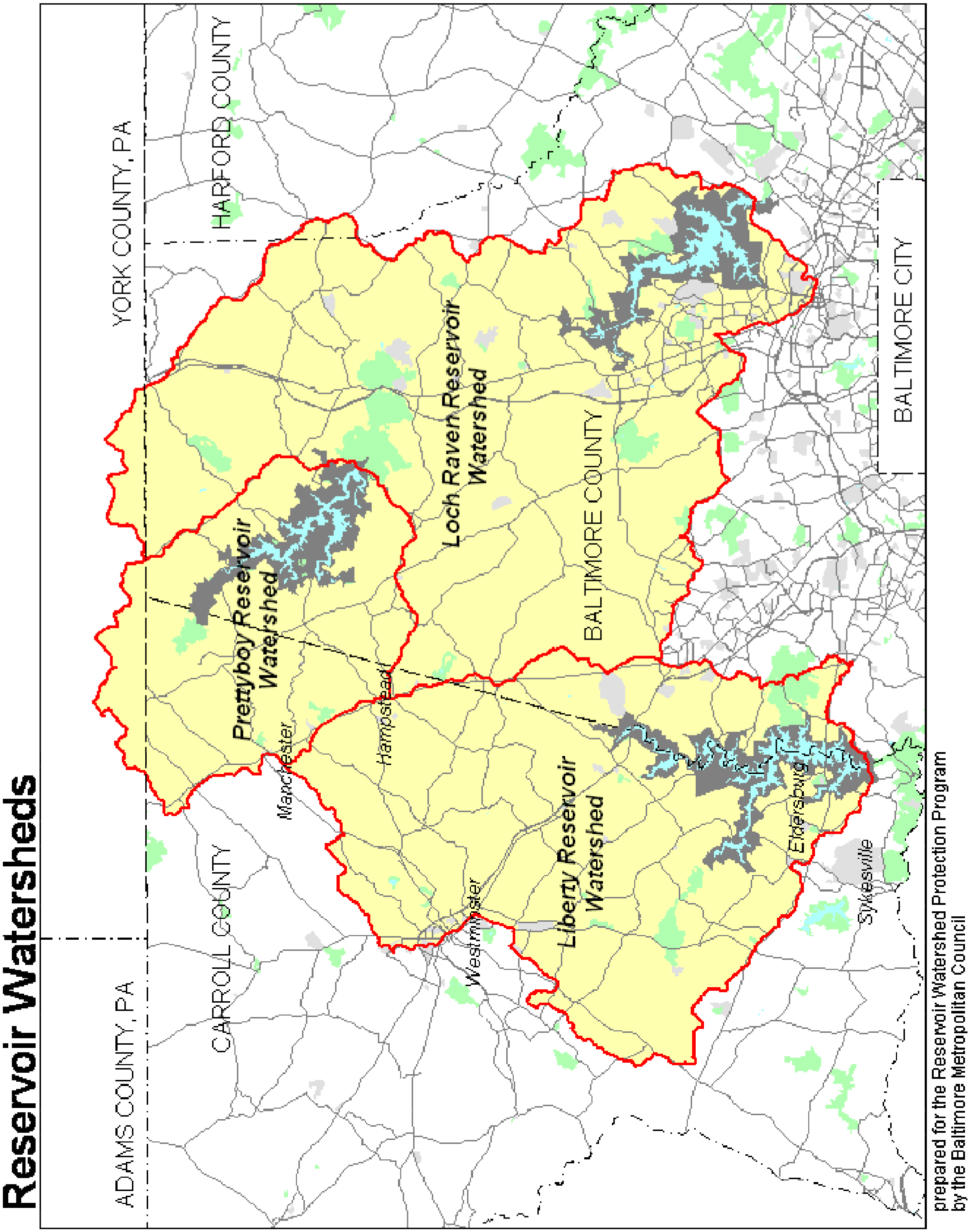
7. The bathymetric study of Loch Raven Reservoir done by the Maryland Geological Survey (MGS) in 1997 concluded that no more sediment removal (deposition of sediment) was occurring in the headwater pools, which were designed for that purpose. As a result, all sediment transported from the northerly tributaries is now depositing in the main body of the reservoir. Loss of reservoir storage capacity obviously affects the long-term "safe yield" of the entire water-

supply system. The locations of the current major sediment-infill areas are documented in the recent MGS bathymetric studies. Plans should be made for monitoring the changes in these parts of each reservoir once every 5 years, in order to track the present rates of loss of storage capacity. In addition, full bathymetric surveys should be carried out once every 15-20 years. A cost/benefit analysis of removing the accumulated sediment from the upper pools (and possibly from other locations) in each reservoir should be carried out by the city. There also is a need to carry out a field assessment of the potential for significant future streambank erosion in the reservoir watersheds, with the aim of identifying the key areas needing protection.

8. The continuing gradual rise in chloride levels seen in the reservoirs and in their tributaries over the past few decades should be explored more thoroughly, possibly by making modifications to the monitoring program. Monitoring for sodium should accompany the city's monitoring for chloride, as there are potential health concerns for individuals who are adhering to a sodium-restricted diet. There is recent evidence that sodium concentrations in the "finished" drinking water during the winter months slightly exceed the EPA "guidance level" set for people who are on a limited-sodium diet.

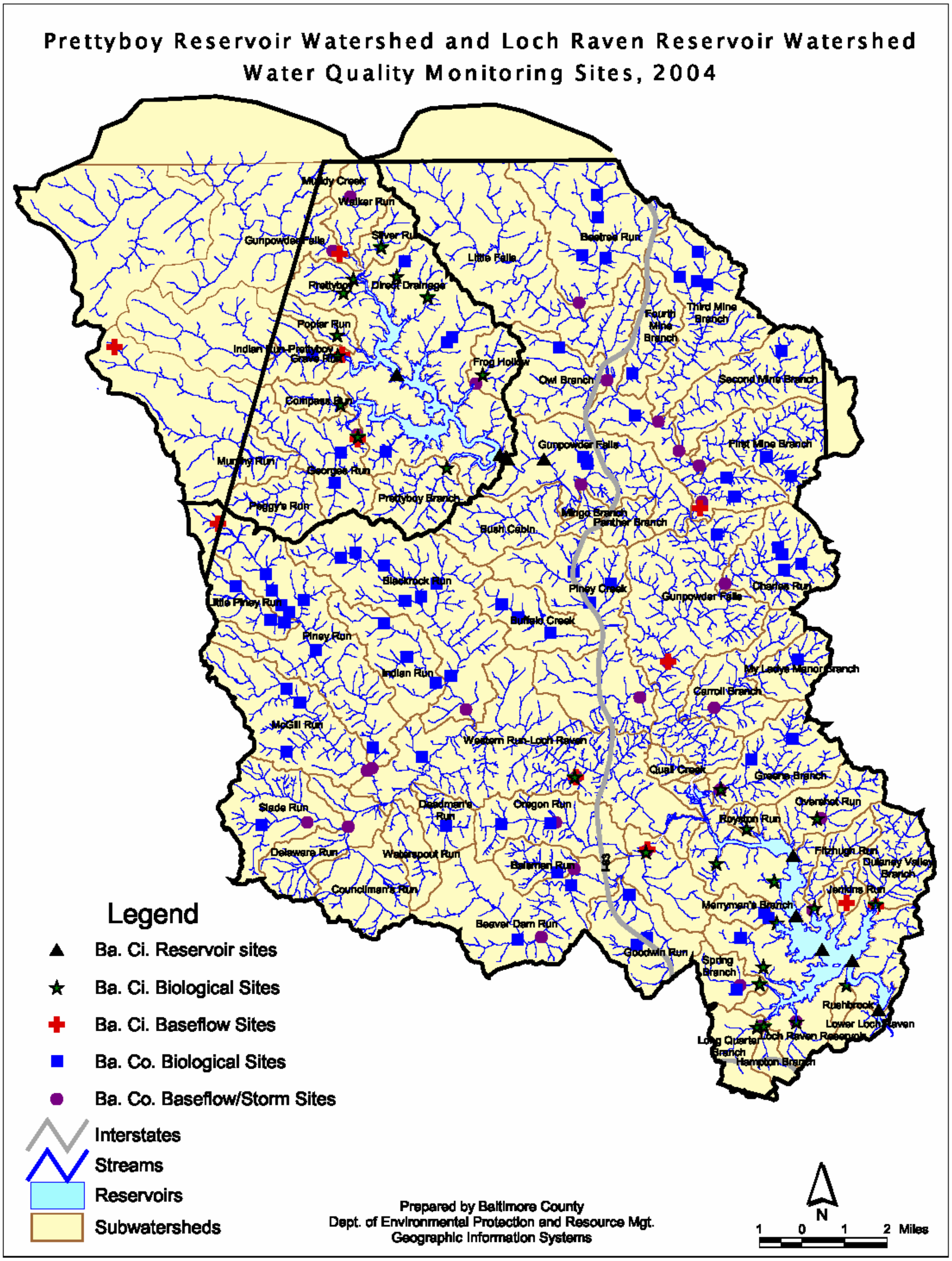
9. An annual or biennial workshop focusing on the Baltimore metropolitan reservoir watersheds should be organized by the Reservoir Program to provide an opportunity for the many stakeholder partners to present and review new water quality data and trends, and to discuss the significance of any new findings.

Figure 1: Reservoir Watersheds



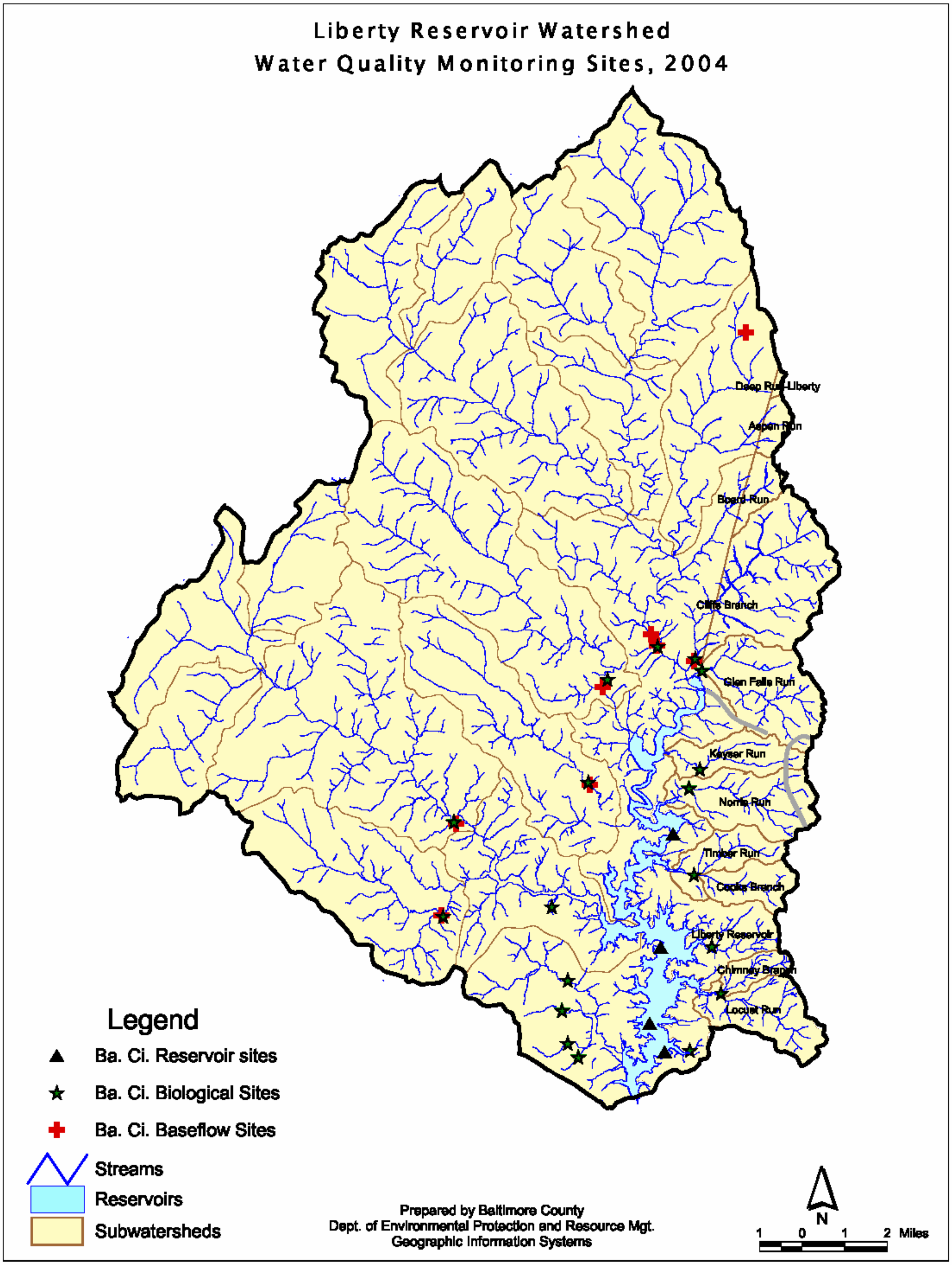
Source: Baltimore Metropolitan Council

Figure 2: Prettyboy Reservoir/Loch Raven Reservoir Watershed Water Quality Monitoring Sites



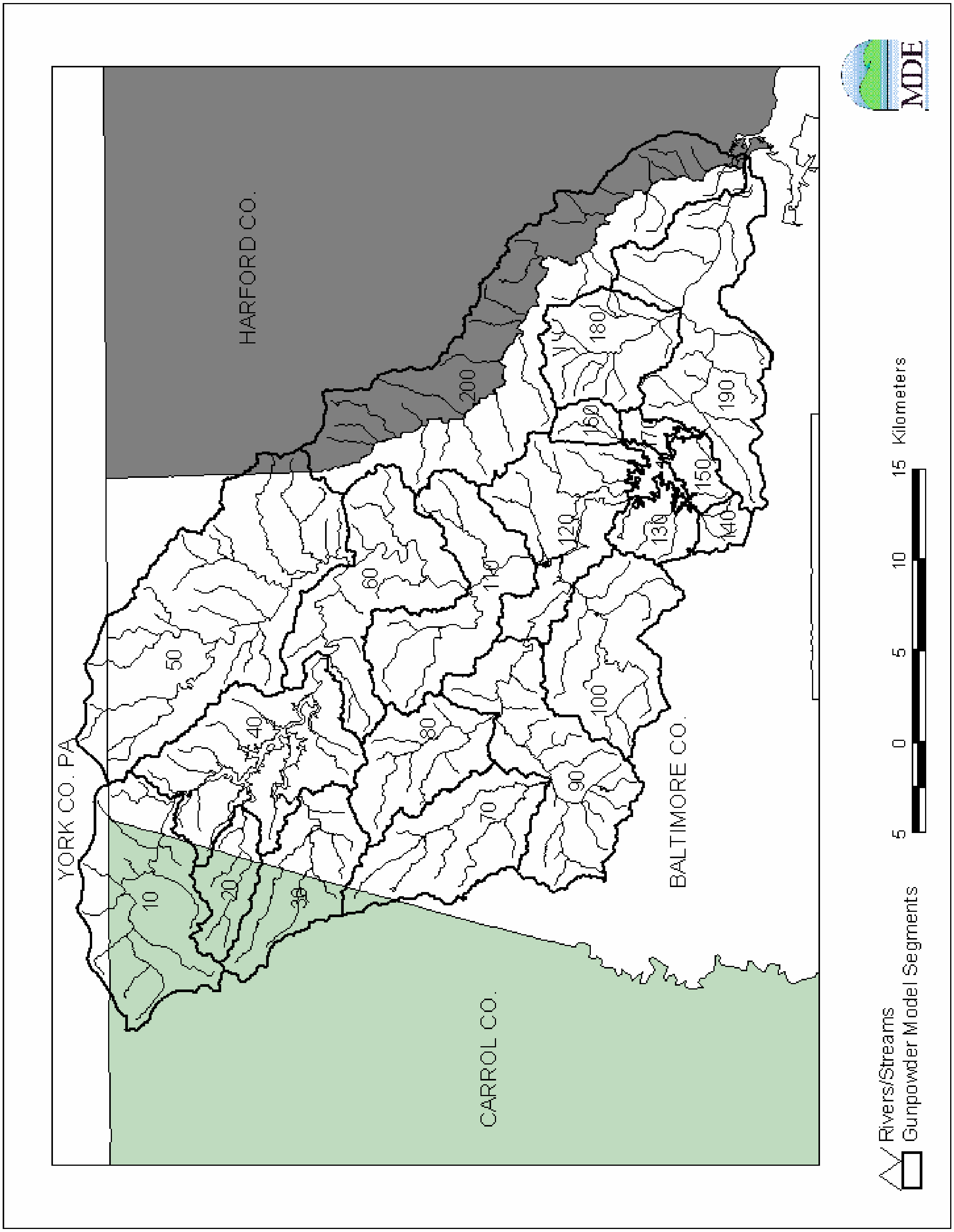
Source: Baltimore County Department of Environmental Protection and Resource Management

Figure 3: Liberty Reservoir Watershed Water Quality Monitoring Sites, 2004



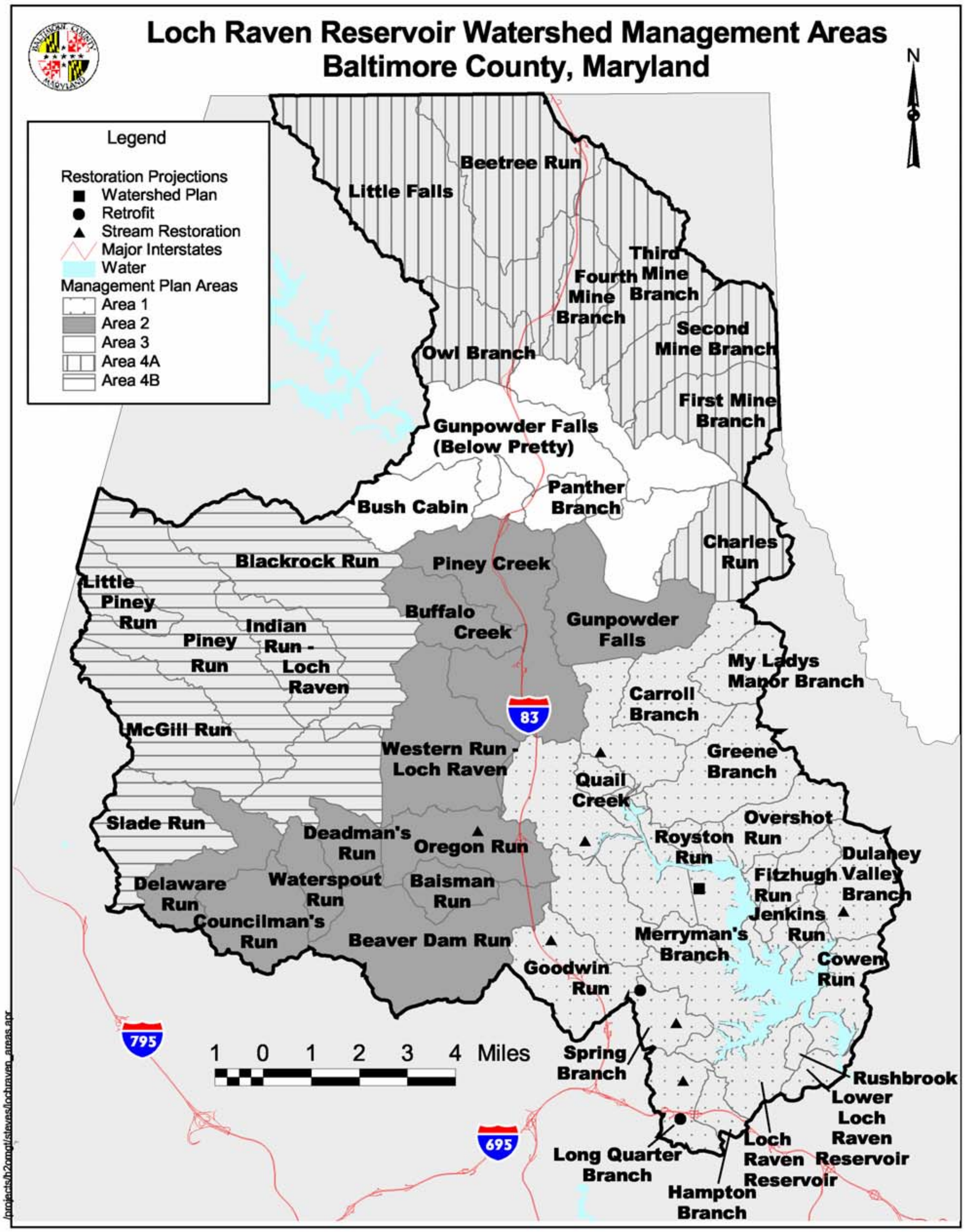
Source: Baltimore County Department of Environmental Protection and Resource Management

Figure 4: MDE Gunpowder Watershed Model Segments



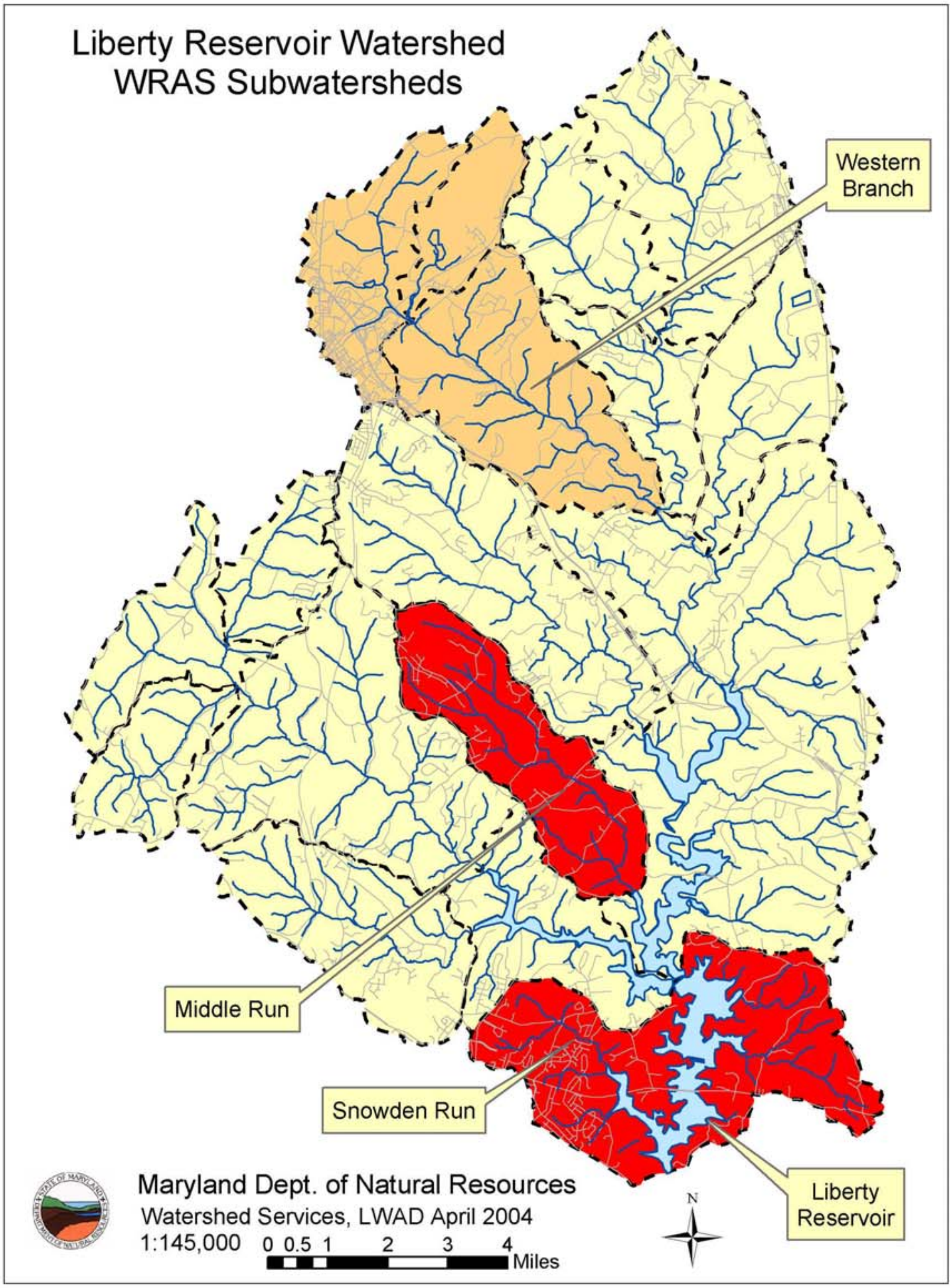
Source: Maryland Department of the Environment

Figure 5: Loch Raven Reservoir Watershed Management Areas and Project Sites



Source: Baltimore County Department of Environmental Protection and Resource Management

Figure 6: Liberty Reservoir Watershed WRAS Subwatersheds



Source: Maryland Department of Natural Resources

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