Lake Maumelle – Source Water Protection

Report to Central Arkansas Water

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Executive Summary

The Cadmus Group, Inc. (Cadmus) of Watertown, Massachusetts, was retained by Central Arkansas Water (CAW) of Little Rock, Arkansas, to assess the source water protection plan for Lake Maumelle, CAW's principal water supply reservoir. This report addresses the history of CAW's efforts to monitor Lake Maumelle and protect its raw water quality. This report also makes recommendations regarding the current protection efforts and what needs to be done to formulate a comprehensive watershed protection plan.

A safe and plentiful supply of affordable drinking water is a fundamental asset to any urban community. An adequate drinking water resource directly affects public health and safety, quality of life, and economic viability. However, providing this critical public resource has become more challenging for most water utilities as sources of clean water have been affected by development, while, at the same time, requirements for drinking water purity have increased. Ironically, the pressures of development, which threaten a raw water source, often come from the very communities that rely on the threatened water resource. Water utilities have had to become increasingly aware of the relationship between land use and water quality.

Since the mid-1980s, CAW and its predecessor, Little Rock Municipal Water Works (LRMWW), have demonstrated concern for and taken action to protect Lake Maumelle as a sustainable source of raw drinking water. LRMWW and CAW have collaborated with the U.S. Geological Survey (USGS) and other researchers to conduct water quality monitoring and analyses of Lake Maumelle. In general, the analyses demonstrated that Lake Maumelle has good source water quality due to the relatively undeveloped nature of its watershed. However, these studies have also found Lake Maumelle to be particularly vulnerable to eutrophication (a high level of biological activity and the generation of organic matter), should nutrient loading increase.

Eutrophication has water quality, public health and safety, and financial cost consequences. Because increased biological productivity increases organic matter in the water, a greater concentration of disinfection by-products (DBPs) is likely to be generated with conventional drinking water treatment methods (e.g., the system deployed by CAW at this time). DBPs such as trihalomethanes are associated with increased cancer risk and miscarriages. Removing DBPs from drinking water requires the use of expensive treatment processes, such as granular activated carbon. In addition, increased biological productivity may create taste and odor problems in the water. Furthermore, increased biological productivity shortens the life of reservoirs by accelerating sedimentation, and increases the potential for algal blooms that produce harmful toxins.

In light of the findings from early studies, the LRMWW Commission passed a resolution on July 31, 1992 to institute a Lake Maumelle watershed protection program. The resolution authorized the manager of LRMWW to purchase Lake Maumelle watershed lands that were necessary for the proper operation and management of LRMWW. Based on this authority, a one-quarter-mile buffer was established around Lake Maumelle and any lands within the buffer that were not owned by LRMWW were purchased or condemned. This purchase program resulted in the acquisition of 1,005.35 acres of land.

A second phase of watershed protection activities was authorized by the LRMWW Commission on October 16, 1998. The 1998 resolution established two major sub-basins in the Lake Maumelle watershed and established three zones, primarily to facilitate the prioritization of land acquisition efforts. As part of the 1998 resolution, LRMWW was to purchase lands in the eastern portion of the watershed around Lake Maumelle, to the extent possible, and was to begin prioritizing potential land acquisitions in the western portion of the watershed according to their contamination potential. In addition, the resolution provided LRMWW with non-purchase options (e.g., lease-back and management agreements, along with land use agreements and existing regulations) that were to be used for lands identified as being lower priorities for watershed protection.

In March 2001, the North Little Rock Water Department and the LRMWW merged and formed the CAW. On September 4, 2003, the CAW Commission adopted a revised version of the 1998 resolution by establishing two major zones for land acquisition and various protective activities, thereby adopting the concept of zones established in 1998. Any undeveloped properties in Zone 1 (i.e., land surrounding the eastern portion of the lake) were to be acquired by CAW. Also to be acquired as they become available were any lands identified as critical property to the west of Zone 1 in the Lake Maumelle watershed, as well as property within the 300-foot buffer around critical tributary streams to the lake.

These determinations to restrict and protect against development in the watershed are appropriate and conform to accepted and recommended approaches advocated by both the American Water Works Association (AWWA) and the U.S. Environmental Protection Agency (EPA). In particular, precluding residential development in Zone 1 is consistent with the objective of preventing increases of pollutant loading to Lake Maumelle from any developments and disturbances in Zone 1.

The specific problems associated with land development in Zone 1 are summarized below.

1. On the basis of soil characteristics in Zone 1, the U.S. Department of Agriculture (USDA) Soil Conservation Service (now the Natural Resources Conservation Service or NRCS) determined that many of the soils in Zone 1 are associated with medium and rapid runoff, severe to very severe erosion hazard, and severe limitations for town and country planning because of low bearing capacity, high shrink-swell potential, low permeability, predominantly clayey materials, and steep slopes. In addition, an examination of slope steepness data reveals that much of the land within Zone 1 has slopes greater than 10 percent, with a high percentage of the slopes in the range of 15 percent to 25 percent. More importantly, over 15 percent of the lands in Zone 1 are associated with slopes greater than 25 percent. In general, slopes of 15 percent to 25

percent are hazardous due to potentials for erosion and landslide, and site-specific hazards should be identified and addressed. Slopes of 25 percent or higher are generally unsuitable for development because of high development and municipal service costs, along with severe erosion potential. Although best management practices (BMPs) can reduce surface-runoff-borne pollutants, they cannot completely eliminate them. The conditions in Zone 1 will increase the cost of implementing and maintaining any BMPs while at the same time undermining their effectiveness.

2. The proximity of Zone 1 to the water intake of CAW greatly increases the threat of contamination. Any sources of potential pollutant input on lands in Zone 1, for example, from accidental gasoline spills, debris and fire-suppressants from fire-fighting, and chemicals used for landscape maintenance and pest control, can potentially reach the lake - and the water intake - in a short time. The current water treatment processes in place do not address many of these potential pollutants. Although it is possible to retrofit CAW's treatment processes to deal with a wide range of pollutants, such a practice is very expensive and often is cost-ineffective. Prevention, when compared to treatment, is the better and more cost-effective strategy for safeguarding drinking water from such pollutants. The steep topography and thin soils in Zone 1 contribute to a shortened travel time for any released pollutants to the water intake, thus limiting CAW's ability to respond to these events. In addition, the narrowness of the watershed in Zone 1 severely shortens the travel time for runoff to reach Lake Maumelle. Given the proximity of Zone 1 to the water intake and the short travel time for pollutants to reach the water intake, dilution and attenuation processes would be less effective in reducing the risks associated with any pollutants released in Zone 1.

The risks to the water quality of Lake Maumelle from the development of Zone 1 should not be underestimated. It is also important to consider the setting of precedent by allowing development in areas with steep slopes and poor soils. If such areas are developed, it may be difficult to prevent further development of the area around the lake. The introduction of additional residential and commercial developments, and associated infrastructure, can be anticipated to bring additional sediment, nutrient, and contaminant loads to the lake.

Advances in our understanding of hydrology and contaminant fate-and-transport processes have led to a better ability to predict the relationship between land use and water quality. Acting on this improved knowledge, efforts have been made to restrict development to reduce water quality impairments in watersheds throughout the U.S. with deteriorating water quality. Where some development does occur in a watershed, efforts to protect source water may include implementing construction and residential development BMPs. Although BMPs are effective in restoring and, to some extent, preserving water quality, they cannot completely eliminate the threats that many land uses pose to water quality.

A 2002 study of 27 water suppliers conducted by the Trust for Public Land (TPL) and the American Water Works Association (AWWA) found that treatment costs increase significantly when development leads to deforestation of a watershed. If development and deforestation are not adequately controlled in the watershed, the added burden on CAW to monitor water quality and remediate degradation (e.g., using advanced treatment processes) would be extremely costly. Safeguarding the water quality of Lake Maumelle through source water protection is a cost-effective and efficient first barrier to protect the drinking water and health of the residents of the greater metropolitan area of Little Rock.

On the basis of current land use patterns, it has been estimated that about 12,140 pounds of phosphorus enter Lake Maumelle annually. The conversion of forested lands to low density residential use in Zone 1 will cause an increase in the phosphorus load to Lake Maumelle. Because of the adverse site conditions in Zone 1, it is anticipated that the per unit area contribution of phosphorus from land disturbances in Zone 1 would be much higher than those areas in Zone 2 that are more suited for development, especially those areas where BMPs can effectively be implemented.

The Cadmus Group, Inc. concludes that CAW's phased Lake Maumelle source water protection program is rational, but additional action items (such as more extensive water quality monitoring and remediating problems posed by existing land use activities) should be included as a part of a dynamic water quality management plan. CAW's land acquisition approach is consistent with watershed management activities undertaken by other municipal water suppliers, such as those in Boston, New York City, Salt Lake City, and Seattle. Due to the high cost of land acquisition, a phased approach to prioritize land purchases is sensible. The need to maintain the highest level of water quality at the eastern end of the lake, the steepness of the terrain and poor soil conditions, along with the proximity of Zone 1 to the water intake, justify the determination that residential development should be precluded in Zone 1.

Cadmus recommends that the land acquisition program be continued in both the eastern portion of the Lake Maumelle watershed and in critical areas in the rest of the watershed. In particular, acquisition should focus on buffers along the major tributaries to the reservoir, including the Big Maumelle River. Finally, it will be necessary to implement a comprehensive plan to establish and implement development restrictions and BMPs throughout the entire watershed.

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1.0 Introduction and Scope of the Report

Central Arkansas Water (CAW) is a metropolitan drinking water supply system that services an area that encompasses over 360 square miles and serves over 117,000 residential, commercial, and industrial customers in the Pulaski and Saline counties of the State of Arkansas, primarily in the Little Rock metropolitan area. The CAW system consists of Lake Maumelle and Lake Winona, two raw water supply reservoirs; a hydraulic regulating and storage facility; two treatment facilities; about 2,190 miles of pipeline; 20 booster pumping stations; and 23 remote storage facilities.

Lake Maumelle is a water supply reservoir on the Big Maumelle River, west of Little Rock, Arkansas. Construction of the reservoir was completed in 1956. It supplies up to 120 million gallons per day (MGD) of drinking water for Little Rock, North Little Rock, and surrounding cities and communities. The Big Maumelle River Basin has a drainage area of 137 square miles and a surface area of about 8,900 acres. The maximum length of the reservoir is 11.8 miles with an average depth of 24 feet. The current safe yield (withdrawal amount that would not deplete the water available) from Lake Maumelle is about 93 MGD. Concerns about the sustainability of the quality of this drinking water source have grown over the past few decades.

The Cadmus Group, Inc. (Cadmus) of Watertown, Massachusetts, was retained by CAW to assess the source water protection plan for Lake Maumelle, CAW's principal water supply reservoir. Cadmus was charged with addressing two main questions:

1. Is residential development in Zone 1 of the Lake Maumelle watershed (i.e., areas surrounding the eastern portion of the lake where the intake is located) consistent with the need to protect CAW's raw water resource?

2. What else should be done to protect Lake Maumelle's water quality over the long term?

Cadmus gathered available data from the U.S. Geological Survey (USGS) and other sources and met with CAW staff to review the proposed projects. This report is based on information collected and compiled through October 2004.

2.0 Factors Controlling Water Quality in Lakes and Reservoirs

The condition of a lake at any particular point in time is the result of a complex interaction of many physical, chemical, and biological factors. Rainfall patterns, watershed characteristics, lake morphology (e.g., shape and depth), and local geology all contribute to the condition of a lake. Changes to physical and chemical factors in the watershed will affect the community of biological organisms in the lake.

A lake receives water, dissolved materials carried in water, and particulates, such as soil, from its watershed, along with particulates and gases from the atmosphere. Direct precipitation, surface water runoff, and groundwater flow all contribute to keeping a lake filled with water. Similar to a bathtub, when the volume of entering water exceeds the capacity of the lake, the lake overflows. The average time required to completely renew a lake's water volume is called the hydraulic residence time. If the lake volume is relatively small and the inflow of water is relatively high, the hydraulic residence time can be very short (e.g., 10 days or less) so that algae produced in the water are washed out of the lake faster than they can grow and accumulate. Longer water residence time (e.g., over 100 days to several years) provides plenty of time for algae to grow and accumulate if sufficient nutrients are available.

Particulates (e.g., soil, leaves, twigs, and other organic debris) can be carried into a lake by water running off the watershed. Human activities that disturb the natural, vegetated land cover promote the movement of particulates from the watershed. Particulates add to the turbidity of lake water, thereby decreasing water transparency and the light needed by algae to grow. On the other hand, nutrients, such as phosphorus, attached to particulates can promote excessive algae growth.

Dissolved materials enter a lake with surface runoff and groundwater discharge. Phosphorus and nitrogen are two of the most important dissolved materials entering a lake. While phosphorus and nitrogen occur naturally in leaf litter, soil, and organic debris, they are readily exported from the watershed to the lake through runoff when people disturb the land (e.g., growing row crops, building structures, and keeping livestock). In addition, applications of fertilizer further increase the export for phosphorus and nitrogen from the land. Other dissolved materials of potential concern that are commonly found in lakes include heavy metals, pesticides, herbicides, household and industrial chemicals, and petroleum products.

As surface water warms up in the spring, it becomes lighter than the cooler, denser water at the lake bottom. As the surface water continues to warm, the lake becomes thermally stratified. The well-mixed, uniformly warm surface waters are called the epilimnion and the unmixed, uniformly cold bottom waters are called the hypolimnion. These two layers of waters are separated by a zone of rapidly changing temperature and density called the metalimnion. As the epilimnion cools in the late summer and fall, the temperature difference between the layers decreases and mixing becomes easier. With the cooling of the surface, the mixing layer gradually extends downward until the entire water column is again mixed. This mixing process is known as the fall overturn. When a lake becomes stratified, the hypolimnion is isolated from gas exchanges with the atmosphere during the summer and is often too dark for algae to produce oxygen. Therefore, a hypolimnion can become anoxic during the summer as decomposing organic matter consumes its reserve of dissolved oxygen. In addition, under anoxic conditions, nutrients such as phosphorus and nitrogen are released from the bottom sediments to the water column.

Algae are photosynthetic organisms that form the base of the aquatic food chain in lakes. Microscopic algae that have little or no resistance to water currents and live in suspension in lake water are called phytoplankton. Other forms of algae, know as periphyton, are found attached to substrates in the water such as rocks, artificial structures, and plants.

Algae are classified according to color: green algae, blue-green algae, golden algae, and so on. Blue-green algae are the most primitive algae and are similar to bacteria. They are more correctly referred to as Cyanobacteria.

When there is enough light for photosynthesis, the availability of nutrients controls phytoplankton productivity. Phosphorus, in particular, can severely affect a lake's biological productivity, food chain structure, energy flow, and nutrient cycling.

Because lakes are temporary (in a geological sense) features of the landscape, they evolve over time through a series of phases throughout the process of eutrophication. Eutrophication is defined as the excessive addition of inorganic nutrients, organic matter, and silt to lakes, thereby increasing biological productivity (Cooke et al., 1993). Eutrophication can be unnaturally accelerated when residential development or other human activities result in the delivery of increased amount of nutrients to the lakes.

Water quality in a lake is generally related to the "trophic state" or amount of biological activity in the lake. High nutrient concentrations promote biological activity that can lower the lack of clarity of lake water (or "cloudiness" and depth of visibility), and too much biological activity tends to degrade water quality.

Limnologists are in general agreement regarding the measures used to categorize lakes into various trophic states, ranging from oligotrophic to mesotrophic to eutrophic (Table 1). Variations suggested by various investigators are due to regional differences and the heterogeneous nature of the data. Additional categories - such as mesotrophic (i.e., between oligotrophic and eutrophic), ultraoligotrophic and hypereutrophic (i.e., beyond oligotrophic or eutrophic) – can be used to extend and better characterize the continuum of lake conditions along a fertility gradient that spans several orders of magnitude of nutrient concentrations.

Table 1. General Characteristics of Oligotrophic, Mesotrophic, and Eutrophic Lakes

Characteristic	Oligotrophic	Mesotrophic	Eutrophic
Plant Production	Low	Medium	High
No. of Algal Species	Many	Medium	Few
Dominant Algae	Diatoms	Variable	Blue-greens
Aquatic Rooted Plants	Sparse	Medium	Abundant
Hypolimnion Oxygen	Present	Variable	Absent
Dominant Fish	Deep-dwelling, coldwater fish, such as trout, salmon, and cisco	Warmwater fish species such as walleye, whitefish, and perch	Surface-dwelling, warmwater fish such as pike, perch, and bass; also bottom-dwelling fish, such as catfish and carp
Water Quality for Recreation, Domestic, and Industrial Use	Good	Variable	Poor

Source: Rast and Lee, 1978; USEPA, 2000; University of Florida Extension, 2003; OECD, 1982.

One can estimate the trophic state or water quality condition of a lake by measuring changes in quantities of total phosphorous and total nitrogen, two important nutrients. Because phosphorus and nitrogen concentrations are closely correlated in lakes (Downing and McCauley, 1992), either phosphorus or nitrogen measurements can be used to measure the trophic state of lakes (Table 2). In general, phosphorus samples taken from lakes in summer are better predictors of trophic state than phosphorus samples taken during other seasons (Nurnberg, 1996). Another direct way to estimate trophic state is by measuring changes in algal biomass (e.g., measuring changes in chlorophyll-*a*), which are caused by changes in nutrient levels. In addition, observed changes in lake clarity (e.g., by measuring the depth to which a Secchi disk is still visible in the water column) are directly related to changes in algal biomass (Carlson, 1977).

Table 2. Trophic State Limits Proposed by Various Authors (Units are micrograms per liter or µg/L).

Variable	Oligotrophic-Mesotrophic	Mesotrophic-Eutrophic	Eutrophic-Hypereutrophic	Reference
Total Phosphorus	10	30	100	Nurnberg (1996)
	15	25	100	Forsberg and Ryding (1980)
	10	25	100	Jones and Knowlton (1993)
Total Nitrogen	350	650	1,200	Nurnberg (1996)
	400	600	1,500	Forsberg and Ryding (1980)
	300	500	1,200	Jones and Knowlton (1993)
Chlorophyll-*a*	3.5	9	25	Nurnberg (1996)
	3	7	40	Forsberg and Ryding (1980)
	3	7	40	Jones and Knowlton (1993)

In lakes without excessive fine, suspended sediment (mineral turbidity), lack of water clarity is a direct result of algal biomass and is readily interpreted by the general public as a simple measure of water quality. ***An objective of lake management is to regulate nutrients to control levels of algal biomass and improve water clarity. This process will not only improve the clarity of the water but is likely to prevent the negative health effects associated with consuming water from lakes with degraded water quality.***

3.0 Impacts of Land Development on Drinking Water Source Quality – A Brief Overview

A safe and dependable supply of drinking water is critical to public health. Although water is a renewable resource, its quality can be impaired. Runoff from residential developments, commercial and industrial sites, and agricultural fields, along with aging wastewater infrastructure, very often threaten the quality of a drinking water supply source. To protect our drinking water supply sources, the human activities that create these threats must be managed. Human land use activities in watersheds (such as urbanization and development, agriculture, and forestry) can cause pollution and are important influences on water quality.

The most cost-effective way to ensure a safe drinking water supply source is to prevent problems and threats from developing in the first place. The contamination of drinking water supply sources can lead to degraded drinking water quality, serious public health threats, and supply shortages.

Over the past 100 years, water suppliers in the United States have adopted a multi-barrier approach to ensure the delivery of clean, safe drinking water. These barriers include (1) drawing water from the cleanest raw water sources available, (2) treating the water to remove contaminants, and (3) ensuring safe delivery of the water to end users. Until the mid-1980s, emphasis in our nation was placed on the use of treatment to remove contaminants. However, the discovery of a wide range of contaminants in raw water sources throughout the United States led to the creation of the federal Wellhead Protection Program (WHPP) under the Safe Drinking Water Act (SDWA) Amendments of 1986. The WHPP focuses on protecting groundwater sources of drinking water supply, which make up about 80 percent of the nation's community water systems (i.e., water systems that have at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents). In 1996, the SDWA was further amended to bring all raw sources of public drinking water supply under the Source Water Protection Program (SWPP). The SWPP provided grants to the states to assess the risks to raw water quality and continues to provide technical and financial assistance to support source water protection activities. These activities may include prohibiting contaminant sources from surface water supply watersheds and wellhead protection areas, especially near raw water intakes.

There is a growing prevalence of disease-causing pathogens in water supplies. Both human and animal sources, including pets, can act as sources of these pathogens. Recent source water contamination examples include the *Cryptosporidium* outbreak in Milwaukee, Wisconsin in 1993, in which it is estimated that more than one hundred people died and nearly half a million people were made ill, and the *E. coli* outbreak in Walkerton, Ontario, Canada in 2000, which resulted in seven deaths and more than 2,000 illnesses. An effective way to control water-borne disease outbreaks is through the use of conventional filtration and disinfection (i.e., the use of chlorine) to treat raw water. However, an increase of organic matter in the raw water would increase the generation of chlorination disinfection byproducts (DBPs) such as trihalomethanes and haloacetic acids, which are cancer causing chemicals. EPA is currently developing the Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) to reduce disease incidence associated with the DBPs that form when water supply systems add disinfectants.

Partly due to new contaminants found in drinking water supplies, the need for source water protection, as well as sound treatment and delivery practices, has become one of the most important issues for the protection of public health. These new contaminants include chemicals such as perchlorate and methyl-tert-butyl-ether (MTBE) and pathogens such as microsporidia. Many of these contaminants are not removed using standard water treatment and disinfection practices.

Activities associated with residential development, including improper use, handling, and disposal of domestic and commercial chemicals, pesticides, and fertilizers, can contaminate drinking water supplies. Vehicle accidents and regular use of road ways can also contaminate water with gasoline, hydraulic fluids, and heavy metals. Contamination potential is often exacerbated by poor site conditions (e.g., poor drainage, highly erodible soils, steep slopes, and close proximity to the water source).

Many studies have demonstrated that development has negative, long-term impacts on water quality. The remainder of this section provides examples from around the United States of the impacts of increased development on drinking water supplies. In addition, examples are provided of the use of various approaches, including land acquisition, to preserve and protect the quality of drinking water sources. This section includes a discussion of the costs associated with poor source water protection planning, and concludes with a summary of lessons learned from other communities regarding protection of drinking water supply sources

3.1 Water Supply Reservoirs Impaired by Watershed Development

Reservoirs in the Ozarks Region and other parts of the United States have been impaired by development. The following case studies illustrate how reservoirs and lakes used as raw water sources have been impaired.

Beaver Reservoir

Beaver Reservoir in northern Arkansas was developed in 1963 and has a surface area of about 28,000 acres. Currently, it serves as the water supply source for over 300,000 residents of Benton and Washington counties.

Beaver Reservoir is affected by both urban and agricultural activities. Although agriculture is the major land use in the Beaver Reservoir watershed, the city of Fayetteville discharges about one-half of its sewage effluent into the White River, which is upstream of the reservoir (Haggard and Green, 2002). In addition, parts of the cities of Rogers, Springdale, and all of Huntsville and Elkins also drain into the Beaver Reservoir.

Erosion and the resulting siltation have been associated with both urban development and agricultural activities in the watershed. Bathymetric analyses of Beaver Reservoir show that the thickest sediment accumulations are located in proximity to steep slopes composed of limestone cliffs capped by regolith or weathered rock materials (Hansen and Boss, 1999). The topography and slopes adjacent to the areas of thick sediment are similar to those observed in the eastern end of the Lake Maumelle watershed.

Within the drainage basin of Beaver Reservoir, two water bodies (i.e., West Fork and White River) are listed as impaired waters (due to excessive siltation) by Arkansas in 2002. In addition, Town Branch and Holman Creek have been impaired by excessively high nitrate levels. The watershed of Beaver Reservoir was selected in Arkansas' Unified Watershed Assessment as the "top priority" for implementation of watershed restoration practices.

As a result of urban developments and agricultural activities, Beaver Reservoir is affected by high phosphorus levels that have resulted in an accelerated eutrophication process. Average phosphorus concentrations at various locations in Beaver Lake from 1992 to 1996 ranged from 92 to 141 µg/L (microgram per liter), with an average concentration of 115 µg/L (Soerens *et al*., 1997), indicating that Beaver Lake was generally eutrophic. This condition was confirmed by chlorophyll-*a* concentration data, which ranged from 7.17 to 14.34 µg/L, collected during the same period.

From 1992 to 1996, the annual orthophosphate load (i.e., a portion of the total phosphorus load) to Beaver Lake declined from about 258,000 to about 165,000 pounds (117,000 to 75,000 kilograms) per year. However, on the whole, studies by the USGS have suggested that the upper end of the lake may have become increasingly eutrophic over the last 10 years (Haggard *et al*., 1999), whereas the middle and lower portions of the lake can be considered mesotrophic (Green, 1998). Nevertheless, any increases in nutrient loading could alter the overall trophic state for the lake from mesotrophic to eutrophic (Haggard and Green, 2002).

Lake Taneycomo

Lake Taneycomo, which consists of about 1,730 surface acres, lies within the White River Basin in southern Missouri and northwest Arkansas. The surface of the watershed is primarily composed of Jefferson City-Cotter dolomite. The lake is the largest source of the City of Branson's public drinking water supply. All of the lake and 100 percent of the watershed that feeds it are in Missouri. The Lake Taneycomo watershed is estimated at 93 percent forest, 4 percent pasture, and 3 percent urban (Missouri Department of Natural Resources, 2004). Despite this relative undeveloped condition, rapid development and steep slopes in the Branson area have raised concerns regarding pollution.

Major source of pollutants in the lake include point sources (specifically, nutrients from municipal wastewater treatment plants) and nonpoint sources (NPSs), such as storm water runoff from pastures, cropland, and sites where animal manures are land applied. The largest point source discharges to Lake Taneycomo come from the Branson wastewater treatment plants, which contribute 69 percent of all wastewater discharged to the lake. These discharges to the lake are large because of the significant population growth in the Branson area, where development has raised the population of Taney County by 33 percent from 1990 to 1997. Continuing urban and suburban development in the watershed has increased sewage loads and stormwater runoff problems in the lake and in area streams. Water quality data for Lake Taneycomo show an increasing eutrophication problem in the lake from 1977 to 1998 (Missouri Department of Natural Resources 2004).

Significant NPSs within the Lake Taneycomo watershed include stormwater runoff from cattle pastures and dairies and stormwater runoff from suburban and urban areas. Some of the major pollutants from these NPSs include nitrogen, phosphorus, sediment, and bacteria. Contaminants often associated with suburban and urban runoff include heavy metals or toxic organics. Other potential NPSs include sedimentation from erosion in disturbed watersheds, sludge application from sewage treatment facilities, stormwater runoff from mining sites, and seepage from septic tanks. In addition to concern regarding land use activities in the watershed, there is a general concern that onsite sewage disposal systems on lakeshore properties may not be functioning properly because they lie below the lake's high water level.

In a significant effort to protect the water quality of Lake Taneycomo, a rule limiting the point source discharge of phosphorus into the Taneycomo watershed was approved by the Missouri Clean Water Commission and became effective in 1994. The rule limits total phosphorus to no more than 0.50 mg/L in effluent discharged by wastewater facilities with design flows of greater than 22,500 gallons per day. Starting in 2000, the phosphorus concentrations have been lower than those of preceding years. Although the phosphorus concentrations in Lake Taneycomo have decreased since 2000, the lake has continued to be in a mesotrophic to eutrophic state, as measured by phosphorus and nitrogen concentrations (http://www.lmvp.org/Data/2002/taneycomo.pdf and http://www.lmvp.org/Data/2003/Taneycomo2003.pdf).

Carroll County, Georgia

The Upper Little Tallapoosa River Watershed in Carroll County, Georgia, about 50 miles west of Atlanta, contains a series of small reservoirs that provide drinking water for over 30,000 residents. There has been a rapid shift in the watershed from agricultural land use to suburban land use as a result of increased development for people moving west from Atlanta. Between 1996 and 2001, the city issued between 83 and 105 single family home building permits per year. In 2002 and 2003, it issued 162 and 164 permits, respectively (http://www.city-data.com/city/Carrollton-Georgia.html). There is no public sewer system in much of the county, and therefore onsite septic systems are proliferating (Trust for Public Land, 2004). During heavy rain events, NPS runoff enters the water source. The first known outbreak of *Cryptosporidium* in the world occurred in the Upper Little Tallapoosa River Watershed in the City of Carrollton and Carroll County in 1987.

The City of Carrollton passed a watershed protection ordnance in June 2002 establishing a Recharge Area District, a Wetlands District, a Water Supply Watershed District, and a River Corridor Protection District to manage growth in the source watershed. New treatment processes, including the use of carbon filters, lime, and alum have been put in place to control threats from *Cryptosporidium* and other pathogens. Within two years the city plans to incorporate membrane treatment, with the possible addition of ultraviolet disinfection. The city will work to meet new regulations for unwanted disinfectant byproducts, although the level has not increased (North, 2004). Increasing sediment and organic loads in the watershed, most likely from cattle and increased development, has made treatment more difficult and expensive.

The Carroll County Water Authority was created to provide a new source of water to residents outside of the City of Carrollton. Previously, the Authority purchased water directly from the City of Carrollton. A 640-acre reservoir was developed along with a new treatment plant with an 8 MGD capacity. Currently, it treats approximately 4 MGD of raw water using alum as a primary treatment, along with some pre-chlorination treatment, and the use of a quick static mixer (Cook, 2004).

Arcadia Lake, Oklahoma

Arcadia Lake was constructed by the United States Army Corps of Engineers (USACE) to serve as the primary drinking water supply for the City of Edmond and some of the smaller surrounding communities and also to provide flood control. Arcadia Lake is also a source of recreation for the Oklahoma City metropolitan area, which includes Oklahoma, Canadian, Cleveland, McClain, Logan, and Pottawatomie counties.

The Oklahoma Water Resources Board (OWRB) completed a Phase I Diagnostic and Feasibility Study of Arcadia Lake in March 2000 (OWRB, 2000). The results of the study indicated that the lake is eutrophic with numerous water quality problems. Specific problems in Arcadia Lake include excess nutrients, sediment, pesticides, metals, fecal bacteria, and trash. The study reports that the significant water quality problems in the lake are a result of increasing development pressures in the watershed. The study identified a variety of general BMPs that were recommended for the watershed, however, implementation of such BMPs would have involved cooperation between numerous entities, such as Oklahoma City, the City of Edmond, other smaller municipalities, the State of Oklahoma, and individual landowners and businesses.

Approximately 60 percent of the Arcadia Lake watershed is designated as urban. Runoff from rainfall events accounts for 90 percent of the lake water recharge. Estimates of nutrient load indicate that about 60,000 pounds (27,200 kg) of total phosphorus and 21,000 pounds (95,000 kg) of total nitrogen are assimilated by the lake per year. These values translate into the sequestration of 84 percent of total phosphorus and 63 percent of total nitrogen from storm water by the lake. This runoff is heavily laden with solids and nutrients from the watershed. Although most of the material washed into the lake settles out in the upper end, the soluble nutrient portion stimulates algae growth.

Because point source discharges were diverted outside the Arcadia Lake watershed in an effort to alleviate some of the lake degradation, most of the pollutants in Arcadia Lake are from NPSs. The myriad of activities associated with urban land use (ranging from vehicular traffic to groundbreaking construction to aging sewerage systems or homeowner lawn fertilization) can account for most of the NPS pollutant loadings, including phosphorus and nitrogen, to Arcadia Lake.

Additional sampling that took place in Arcadia Lake from October 2002 through July 2003 indicated that the trophic state index (TSI), using Carlson's TSI (chlorophyll-*a*), was 59. This indicated that the lake continues to be eutrophic, with high levels of productivity and nutrient conditions (OWRB, 2004). This value is similar to the TSI value of 58 calculated in the 2000 study, indicating no significant change in productivity has occurred. The TSI for all sampling sites varied seasonally and ranged from mesotrophic in the spring to meso-eutrophic in the winter and hyper-eutrophic in both summer and fall.

According to data collected by OWRB (2004), the lake-wide total phosphorus average was 49 µg/L at the surface and 122 µg /L at the lake bottom. Surface total phosphorus ranged from 16 µg /L to 110 µg /L and was highest in the fall months. The lake-wide total nitrogen average was 730 µg /L at the surface and 830 µg /L at the lake bottom. Surface total nitrogen ranged from 410 µg /L to 960 µg /L with the highest values recorded in the spring quarter and lowest in the winter. The total nitrogen to total phosphorus ratio was 15:1 for sample year 2003. Lakes with a total nitrogen to total phosphorus ration greater than 7:1 (such as Arcadia Lake) are characterized as phosphorus limited (Wetzel, 1983).

Arcadia Lake continues to be eutrophic. This is indicative of high primary productivity and nutrient rich conditions. The 2003 sampling results are similar to those seen in the 2000 study, indicating that no significant change in productivity has occurred.

3.2 The Use of Land Acquisition to Protect Water Quality

Wetlands and forested land around reservoirs, if left undeveloped, can help slow and filter water before it gets to lakes and reservoirs, keeping these drinking water sources cleaner and making treatment cheaper (USDA, 2002). One management option available for preserving undeveloped land is land acquisition. Acquisition of private land can be critical to protecting drinking water in some cases. Significant benefits have been realized where local governments have chosen to purchase watershed land.

Many cities have seen fit to actively control threats to their reservoir water supplies by incorporating land acquisition as a major component of their drinking water supply management strategy. Many states, including Maine, Massachusetts, Virginia, Florida, California, Ohio, Vermont, New Hampshire, Texas, Washington, and Hawaii, are encouraging the use of land acquisition and other similar measures to protect source water. For example, the Maine Department of Environmental Protection (Maine DEP) is currently preparing new guidelines that would require stricter municipal zoning laws around drinking water sources. The new zoning policy is expected to go into effect in the spring of 2005 (Grard, 2004). The new policy would require all shorelands within 1,000 feet on either side of a drinking water intake to be zoned for resource protection. Development for residential or other uses would be prohibited in these areas. The following case studies illustrate land acquisition programs similar to the program under CAW’s Lake Maumelle Management Plan.

Portland, Maine

The Portland Water District has a policy that states that the first and most logical step to ensuring quality water at the tap is to prevent contamination from entering the source. The Portland Water District has been able to conserve nearly 2,500 acres of land around the Lower Bay of Sebago Lake, the source of drinking water supply for the Portland metropolitan area. Although it has eminent domain authority, the Portland Water District acquires properties at market value from willing sellers. The District is currently purchasing the remaining parcels located at least partly within 500 feet of the shore. The Portland Water District is also working to strengthen the no trespassing zone around the shoreline within a two-mile limit from the drinking water intake.

According to the Portland Water District 2004 Water Quality Report (http://www.pwd.org/pdf/Quality%20Report%204_21_04.pdf), the overall susceptibility of Lake Sebago to contamination is moderate. This characterization is based on a number of factors, including the density of development, current and anticipated future development pressure, and activities that involve materials that can lower water quality.

Boston, Massachusetts

The primary source of drinking water for the greater Boston metropolitan area is the Quabbin Reservoir. The Wachusett Reservoir also serves this area. The watershed of the Quabbin Reservoir is 186 square miles in area. Currently, the only treatment the water receives before being delivered to the consumer is chlorination, with the addition of chloramines as a secondary disinfectant. This is due to a waiver the system received from the U.S. Environmental Protection Agency (EPA) because of the high quality of the source water. Although the watershed of the Quabbin Reservoir is well protected (i.e., with 93 percent of the area forested and a population of approximately 3,000 at a density of 16 persons per square mile), the Wachusett Reservoir is much less protected (i.e., with 75 percent of the area forested and a population of 34,000 at 290 persons per square mile). Because of the detection of *Cryptosporidium* in recent years, the Massachusetts Water Resources Authority (MWRA) is in the process of building a water treatment plant outside of Boston, where the water will undergo ozonation before being delivered to Boston residents.

While improved treatment is a must for the next century, the first barrier to protecting water quality will always be watershed protection. MWRA is purchasing key parcels of land within the watersheds of the Quabbin and Wachusett Reservoirs in order to control land use to the extent possible. In 1992, a $135 million fund was established to purchase development rights to environmentally sensitive property in the Wachusett and Quabbin watersheds. A prioritization mechanism was established and used to identify the most important parcels of land to be purchased. Factors such as steep slopes, the type of development, and the proximity to tributaries have been used to rank every parcel in the two watersheds. A Watershed Land Sensitivity Model was developed by MWRA and its land management partner, the Metropolitan District Commission (MDC), for the specific conditions that exist at the Wachusett Reservoir watershed. The model takes into account site conditions such as slope, land use, availability of sewers, and the presence of aquifers. On the basis of the model results, targets for various types of land protection can be specified. MWRA's strategy is meant to eliminate significant threats from potential development and includes the following tools: acquisition of land or conservation restriction by MDC, acquisition of land or conservation restriction by a non-profit conservation organization, signing of protection agreements between MDC and land owners, and the passing of state and local laws and regulations that protect water and forest resources.

New York City, New York

New York City gets its drinking water from two sources: the Croton watershed, consisting of reservoirs in Westchester and Putnam counties; and the Catskill/Delaware watershed, consisting of reservoirs in a number of more rural counties further upstate. The SDWA requires systems like New York City's to be filtered, unless EPA finds a compelling reason why they may be allowed to avoid filtration. EPA recently granted an extension to the city to avoid filtering water from the Catskill/Delaware watershed, because the city has a successful watershed protection program in the upstate counties that house this system. The program includes land acquisition and public education.

The city's Land Acquisition and Stewardship Program (LASP) protects water quality through the purchase of sensitive, vacant lands within the eight counties of the city's water supply watershed. The Land Acquisition Program is based on a willing seller/buyer relationship. Landowner participation is completely voluntary and interested landowners are offered fair market value for their properties. These values are determined by independent appraisers hired by the city. Because most of the city's vast watershed is owned by private citizens and businesses, it is necessary to implement a systematic program of investing the city's land acquisition funds where they will have the most beneficial effect on long-term water quality. Areas in the watersheds are ranked according to their proximity to the reservoirs and the time it takes water to reach the city's distribution system. Property owners in the highest priority areas are being solicited first, and the entire 10-year program of solicitation is being conducted according to a clearly-defined timetable, organized by priority areas.

Through January 21, 2002, 477 purchase contracts representing 34,447 acres were signed by the city in the Catskill/Delaware system watershed, including 19,259 acres acquired and 15,188 acres under purchase contract. For the Croton watershed, 314 acres were acquired by the city, with an additional 137 acres under purchase contract. In addition, New York State had also secured several hundred acres in the Croton watershed, which were to be transferred to New York City during the next few years.

Salt Lake City, Utah

The Salt Lake City water system serves more than 400,000 customers, providing an average of 81.2 MGD. The source water for Salt Lake City comes from the canyon watersheds of the Wasatch Mountains, which encompass over 185 square miles, and from the watershed of the Provo River, which encompasses 500,000 square miles. With such large watersheds, it might be difficult for Salt Lake City to effectively protect its source water. However, in the late nineteenth to early twentieth centuries, the City Council of Salt Lake City began purchasing property from individuals and from the Union Pacific Railroad in City Creek Canyon, the first of the Wasatch Mountain canyons to serve as a watershed for Salt Lake City's drinking water supply.

By 1907, the city had acquired most of City Creek, and land in other canyon watersheds as well. The city continued to purchase watershed land over many years, and owns more than 23,000 acres or 18 percent of the seven-canyon watershed area (http://www.slcgov.com/Utilities/watersh.pdf). Furthermore, under a state law passed in 1935, the city's Metropolitan Water District (MWD) has extraterritorial jurisdiction to protect its watershed and its water supply. As incorporated, the MWD has the power of eminent domain, and may acquire water and water rights (with or without state assistance) as well as develop, store, and transport water for the city. Under this state authority, ordinances have been passed and enforced by the city to manage watershed lands that are not owned by the municipality.

Seattle, Washington

The upper basin of the Cedar River watershed (also referred to as the Upper Cedar River Municipal watershed) and the South Fork Tolt River watershed, along with Lake Washington, are the primary sources of drinking water for the City of Seattle. The Upper Cedar River Municipal watershed and the South Fork Tolt River watersheds are unpopulated mountainous areas protected from land use change and managed for water quality protection, long-term forestry, and wildlife habitat. The City of Seattle owns most of the land (100 percent of the Upper Cedar River Municipal watershed and 77 percent of the South Fork Tolt River watershed) and has a strong working relationship with the other major landowner in the South Fork Tolt River watershed, the United States Forest Service.

The Seattle Public Utilities (SPU) supplies drinking water to the City of Seattle and its regional customers. SPU has an aggressive watershed management and protection plan for the 91,000 acres of the Upper Cedar River Municipal watershed and the 13,300 acres of the South Fork Tolt River watershed. To protect water quality, this plan includes the elimination of timber harvesting for commercial purposes and the removal of approximately 40 percent of the forest roads. Agricultural, industrial, and recreational activities are not allowed in the watersheds. Access to these watersheds is restricted to appropriate staff and participants in educational programs conducted by SPU staff.

The Upper Cedar River Municipal watershed is located in southeast King County along the western slope of the Cascade Mountains, with headwaters located near the Cascade crest. Numerous rivers and streams (e.g., Cedar River and Rex River) drain into 1,680-acre Chester Morse Lake. Chester Morse Lake occupies a natural lake basin that was elevated and expanded in 1916 by construction of the Masonry Dam, originally built for hydroelectric power generation. Chester Morse Lake collects and impounds the drainage from the upper municipal watershed. The lake serves as the primary storage site for the city water supply. The Masonry Pool, immediately west of Chester Morse Lake, serves as an additional impoundment (USFWS *et al*., 1999).

Since Seattle identified the Cedar River as its primary drinking water supply in the mid 1900s, the city had taken steps to protect the upper two-thirds of the watershed from further development and to remove structures from already developed land. The city began acquiring land parcels in the mid 1900s and had consolidated ownership of the upper basin by 1996.

The lower Cedar River watershed is not protected in the same manner as the upper two-thirds of the watershed. In fact, the lower basin has a significant amount of residential and other development. SPU has embarked on an effort to correct problems that affect this part of the watershed, specifically flooding and water contamination.

The South Fork Tolt River watershed is nestled in the foothills of the Cascades east of Carnation, Washington. It supplies about 30 percent of the drinking water for the City of Seattle. The watershed became a drinking water supply source in 1964. In 1997, the City of Seattle successfully obtained lands within the South Fork Tolt River watershed from Weyerhaeuser Corporation, a timber company, through a land exchange deal. This exchange gave Seattle 70 percent ownership of the land in the South Fork Tolt River watershed (http://www.seattle.gov/util/services/).

Seattle is currently implementing a Habitat Conservation Plan (HCP) in the Upper Cedar River Municipal watershed to both protect source water quality and restore habitats for species that inhabit, or could inhabit, the municipal watershed. Under the HCP, Seattle has agreed to the following commitments:

- Eliminating timber harvest for commercial purposes to effectively create a watershed ecological reserve that provides long-term, comprehensive protection of the watershed ecosystem.

- Committing a total of about $27.2 million for a comprehensive program to restore fish and wildlife habitats in the watershed that have been degraded by past activities, such as logging and road construction.

- Committing to removing approximately 38 percent of the forest roads within the watershed in the first 20 years of the implementation and employ restoration thinning, planting, and other approaches to restore the natural ecological functions and processes in watershed forests that create and maintain habitats for at-risk species.

- Designing and conducting projects to restore habitats in streams and streamside areas and to improve water quality over the long term.

- Providing more than $6 million to design and conduct comprehensive research and monitoring studies that will provide the information needed to achieve the conservation objectives of the HCP over the long term.

Tacoma, Washington

Tacoma Water's supply operations provide municipal water to a large segment of the population (about 82,000 people) in the City of Tacoma, and Pierce and South King Counties. Tacoma Water currently owns approximately 10 percent of the Upper Green River watershed upstream of its diversion, with the ownership located in the valley floor and adjacent uplands around the mainstem and its major tributaries. Tacoma Water has developed agreements with landowners, including the Muckleshoot Indian Tribe, located upstream of Tacoma's Howard Hanson diversion dam to provide supplemental protection to water quality through conservation easements and agricultural easements, in addition to the protections required by state law and regulations (R2 Resource Consultants, 2001).

Tacoma Water has prepared an HCP as part of its application to the U.S. Fish and Wildlife Service and the National Marine Fisheries Service for a 50-year incidental take permit for its water supply operations on the Green River. The permit, although not required to operate its municipal water supply system, does reduce Tacoma Water's risk of violating the Endangered Species Act while operating its system. The HCP provides a number of benefits for fish and wildlife as well as water users in the Central Puget Sound region; in particular, it serves as an umbrella for a number of agreements for river operations, water supply operations, and forest and land management to ensure a consistent approach to fish and wildlife protection. The HCP also addresses Tacoma Water's proposed land management approaches for the upper Green River watershed. Two alternatives that Tacoma Water officials are considering are a "no timber harvest" alternative and an alternative that would allow timber harvesting only for the purpose of creating or enhancing fish and wildlife habitat (R2 Resource Consultants, 2001).

Tacoma Water officials have allied with a coalition of environmental conservation groups to buy 302 acres of forest in the Upper Green River watershed, the source of most of the city's drinking water. Tacoma Water will contribute $350,000 to the nearly $2 million purchase price of the Plum Creek Timber Company land. The property lies on a steep slope east of Sawmill Creek, a tiny Green River tributary. A permanent conservation easement will prevent logging on the site, which includes patches of virgin timber and old secondary growth. The transaction gives Tacoma title to the land, which is adjacent to other Tacoma-owned property surrounding the Green River. Tacoma Water Superintendent, Ken Merry, expects the acquisition will help protect the quality of city water (http://www.tribnet.com/news/local/story/4859294p-4795886c.html).

3.3 Cost-Benefit Analysis

Contamination of drinking water supplies leads to the need for either enhanced water treatment or development of a short-term or long-term alternative water supply. The cases described above and experience across the United States suggest that it is generally less costly to protect a water supply than to restore water quality after a water supply has been contaminated (Williams and Fenske, 2003; USEPA, 1995). Treatment costs include both capital costs for an enhanced water treatment system and the increased costs for operation and maintenance of such a system.

A 1997 study of Texas cities examined the costs of water treatment that became necessary due to deteriorating water quality. The study concluded that when raw water is contaminated, the cost of chemical treatment increases from a base of $75 per million gallons to $95 per million gallons (Eisen-Hecht and Kramer, 2002).

Water treatment costs have been correlated with the percentage of a watershed that is forested. Development is often associated with deforestation, and thus development can be directly linked to increased treatment costs. The impacts of development on water quality and treatment costs are usually felt over the long term – five to ten years and longer. However, the magnitude of these impacts is significantly higher than the short-term costs for protection of source waters and surrounding lands. In particular, according to a report by the TPL and the AWWA, many communities are learning that while land conservation is a significant investment, it is "a bargain" compared to the long-term costs of treatment or of remediating contaminated water (Trust for Public Land, 2004).

According to a 2002 study of 27 water suppliers conducted by the TPL and the AWWA, treatment costs increase when forest cover in a watershed is lost. Specifically, 50 to 55 percent of variation in chemical treatment costs can be attributed to variability in the percent forest cover in the watersheds (Figure 1). Other factors affecting the variation in treatment costs include varying treatment practices, the size of the facility (because larger facilities can take advantage of economies of scale), specific location of development in relation to source water, the presence of row crops, and other agricultural, urban, and forestry practices in the watershed. Chemical treatment and chemical costs increased by about 20 percent for every 10 percent decrease in watershed forest cover (for areas with 60 percent or less forest cover). Similarly, when combined chemical and capital treatment costs are analyzed, costs increased by 14 to 21 percent for every 10 percent decrease in forest cover in the watershed (Trust for Public Land, 2004).

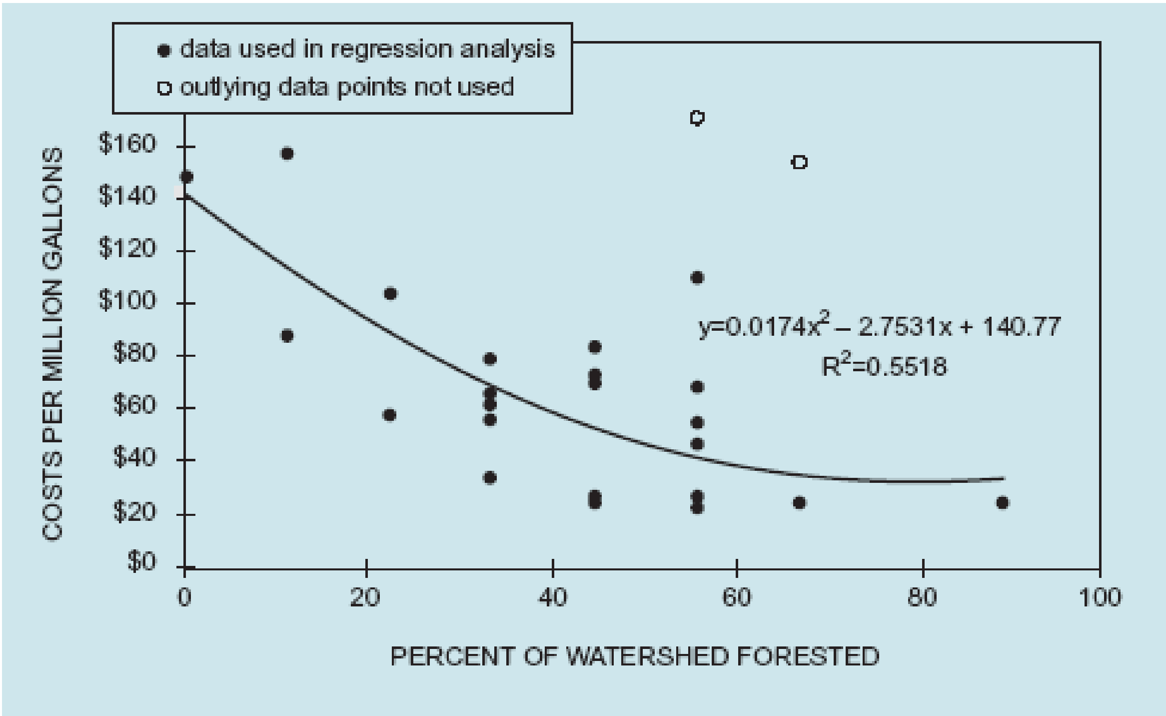

Figure 1. Increased Treatment Costs as Forested Percent Watershed Decreases (From The Trust for Public Land, 2004).

Cost savings resulting from source water protection go beyond the savings associated with avoiding enhanced treatment costs, remediation costs, and the cost of developing alternative water supplies. If source water is protected, regulatory agencies can provide waivers from monitoring. According to the National Center for Small Communities, waivers from monitoring requirements saved Massachusetts water systems approximately $22 million over three years and saved Texas water systems $49 million over two and one-half years (Eisen-Hecht and Kramer, 2002).

There is also inherent value in protecting water quality. A study of water quality protection in the Catawba Basin in North Carolina included a survey of residents to determine the value they placed on source water protection. Results of the survey indicated that protecting water quality in the Catawba basin is an important issue to area residents. When asked how much they would pay for supporting a water management plan ($5, 10, 25, 50, 100, 200, or 250), the mean “Willingness to Pay” (using the most conservative estimate) was $139 per person. Aggregating this mean figure across the population of the 16 counties in the basin provided an estimate of $75.4 million for the total inherent value in the Catawba Basin arising from water quality protection. This is a conservative number because it represents only the value accruing to individuals in the Catawba Basin. The study did not attempt to estimate the value of water quality protection for commercial, industrial, and recreational uses or for individuals downstream of the reservoir system (Eisen-Hecht and Kramer, 2002).

EPA has demonstrated that the cost savings resulting from source water protection are significant. A 1995 EPA report, *Benefits and Costs of Prevention: Case Studies of Community Wellhead Protection,* identified the relative costs of protection versus treatment in areas that use groundwater as a drinking water source. The combined average per well benefit-cost ratio for all seven communities was 27:1. That is, for every $27 spent on treatment in these communities, only $1 would have been spent on groundwater protection to avoid added treatment and finding a new water source. In five case study communities that experienced contamination and developed a Wellhead Protection Program (WHPP), the ratio of costs resulting from contamination to the costs of WHPP development and implementation ranged from 4:1 to 197:1, on a per-well basis. The report concludes that source water protection offers relatively inexpensive "insurance" compared to the rather significant cost of cleanup. The differences in cleanup and protection costs would be even greater if total projected remediation and long-term public health costs are included in the analysis.

One of the communities that is treating its contaminated water supply is Camden-Rockland, Maine (http://www.nsc.org/ehc/water/wbulle12.htm). The water authority of Camden-Rockland, Maine currently serves a population of about 18,000 and it expects to spend $6 million for advanced water treatment because of excess phosphorus in its water source, Lake Chickawaukie.

Preliminary estimates of the additional treatment costs to be faced by CAW and its over 310,000 customers, if Lake Maumelle becomes more eutrophic, include a price tag of $60 million to install a granular activated carbon treatment system. Conventional water treatment processes of surface water sources (i.e., filtration and chlorination) produce disinfection byproducts (a potential human health threat) when organic matter is present. Granular activated carbon treatment would be necessary to remove the higher concentrations of organic matter resulting from further eutrophication and increased biological activity in the lake.

In summary, effective source water protection programs reduce costs by reducing the need for:

- disinfection and filtration,
- treatment to remove disinfection by-products,
- monitoring, and
- other activities, treatments, or supply alternatives necessary to comply with SDWA regulations and ensure the safety of drinking water and public health.

3.4 Lessons Learned

Based on the experience of other municipal water suppliers and on long-term studies of watershed change, several lessons critical to the protection of Lake Maumelle can be discerned:

1. Proactive management of water quality can better protect public health and helps mitigate treatment costs.

2. All development, whether converting land to agricultural, residential, or commercial use, is associated with some level of water quality degradation. The disturbance of the natural land surface and the input of materials (e.g., fertilizers, pesticides, and road runoff), along with changes to the land surface (e.g., increased imperviousness resulting in greater runoff volumes from streets, roofs, and lawns), all contribute to greater runoff volumes and pollutant loads to water bodies.

3. Land acquisition and explicit prohibitions on watershed development provide a higher level of protection than the use of BMPs. While BMPs, such as low impact development practices, are preferable to "standard" development methods, no development is always the preferred alternative when development will pose risks to water quality and public health. Soil conditions, slopes, and proximity of proposed development to source water should all be taken into account when evaluating such risks, while balancing costs and benefits of development.

4. The costs associated with source water protection are significant, but the costs of treatment and remediation are generally much greater.

4.0 Status of Lake Maumelle Water Quality and Concerns

4.1 Overview of the Study Area

The Big Maumelle River Basin has a drainage area of 137 square miles at the Lake Maumelle dam and is part of the Arkansas River Basin (Figure 2). The average annual precipitation in the area is about 54 inches. Lake Maumelle contains 7.13×10^{10} cubic meters of water and has 6.10×10^{10} gallons of usable water. Besides being used as a drinking water supply, Lake Maumelle is also used for non-body contact recreation and provides habitat for fish and wildlife. The lake is 290 feet above sea level at the spillway. The surface area of Lake Maumelle at spillway elevation is 8,900 acres or 13.9 square miles and the maximum length of the reservoir is 11.8 miles. CAW reports a maximum as-built depth of 60 feet, while recent USGS studies have reported a maximum depth of 45 feet. The current average depth of Lake Maumelle is 24 feet. The relatively shallow morphology makes Lake Maumelle more sensitive to eutrophication (Stapleton, 1985).

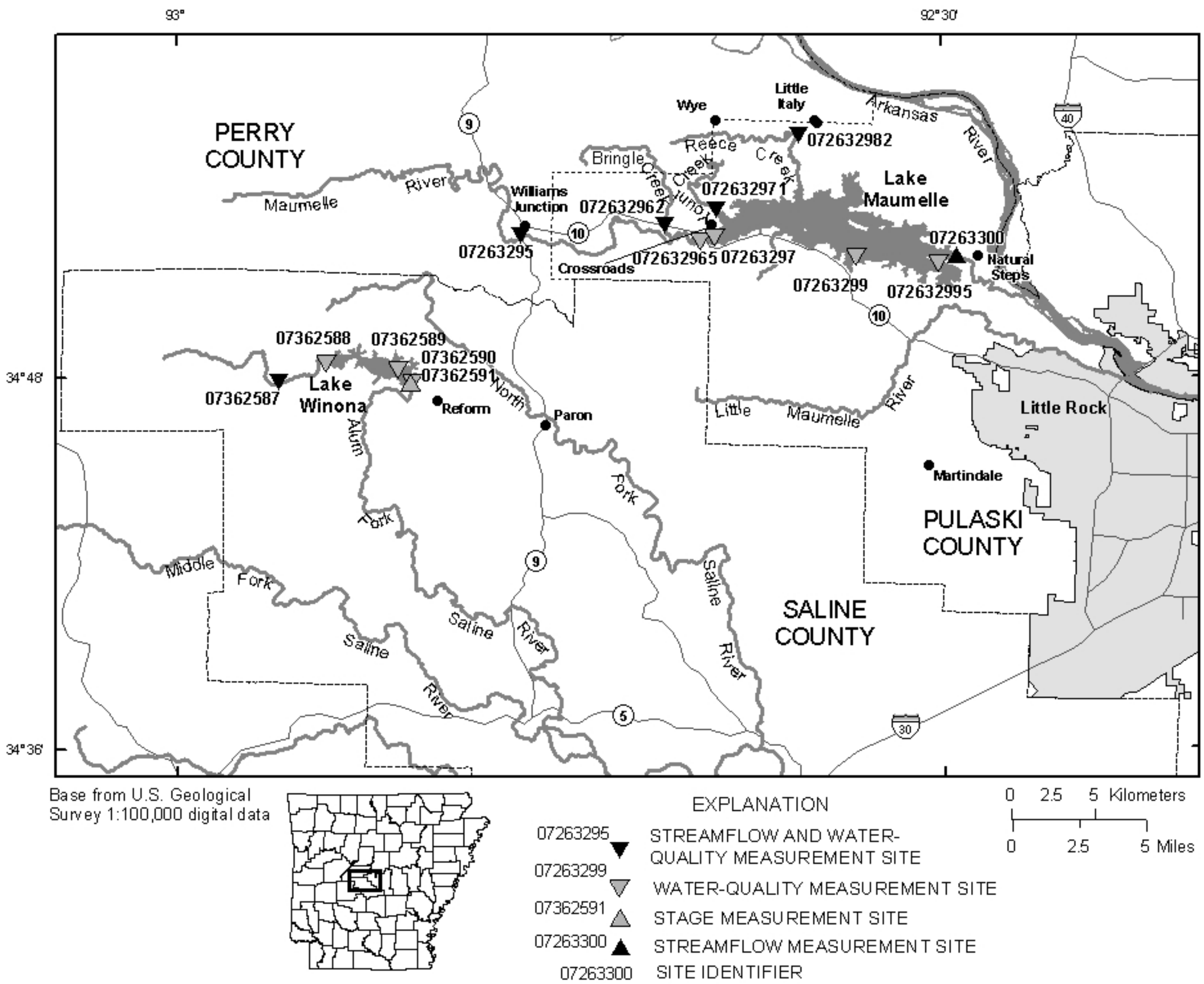

Figure 2. Location of Lake Maumelle

There are ten major soil series with twenty-one differing soil types in the Lake Maumelle watershed. The most predominant soil series is the Carnasaw Series that consists of well-drained, gentle-sloping to steep soils located on the top, sides, and foot slopes of mountains, on benches and on low ridges in the valleys (Stapleton, 1985). Carnasaw soils are low in natural fertility, slow in permeability, and have a moderate to very severe erosion potential (Haley, *et. al*., 1975; Townsend and Williams, 1982). The U.S. Department of Agriculture (USDA) Forest Service classifies the forest land as “moderate to low productive” land with a full range of site conditions that have been determined to be suitable for timber production (U.S. Department of Agriculture, 1989).

The general land use classification (Figure 3) for the Lake Maumelle watershed is forest and pasture. The Ouachita National Forest manages most of the upper one-third of the watershed as forest land. The remainder of the watershed is primarily forest with some pasture and agriculture existing in the lowland area of the Big Maumelle River above the lake. Turf (sod) farming is practiced in the flood plain of the basin. Many of the forest areas, apart from those that are protected by CAW and the Forest Service (such as wilderness areas), are subjected to timber harvesting on a periodic basis.

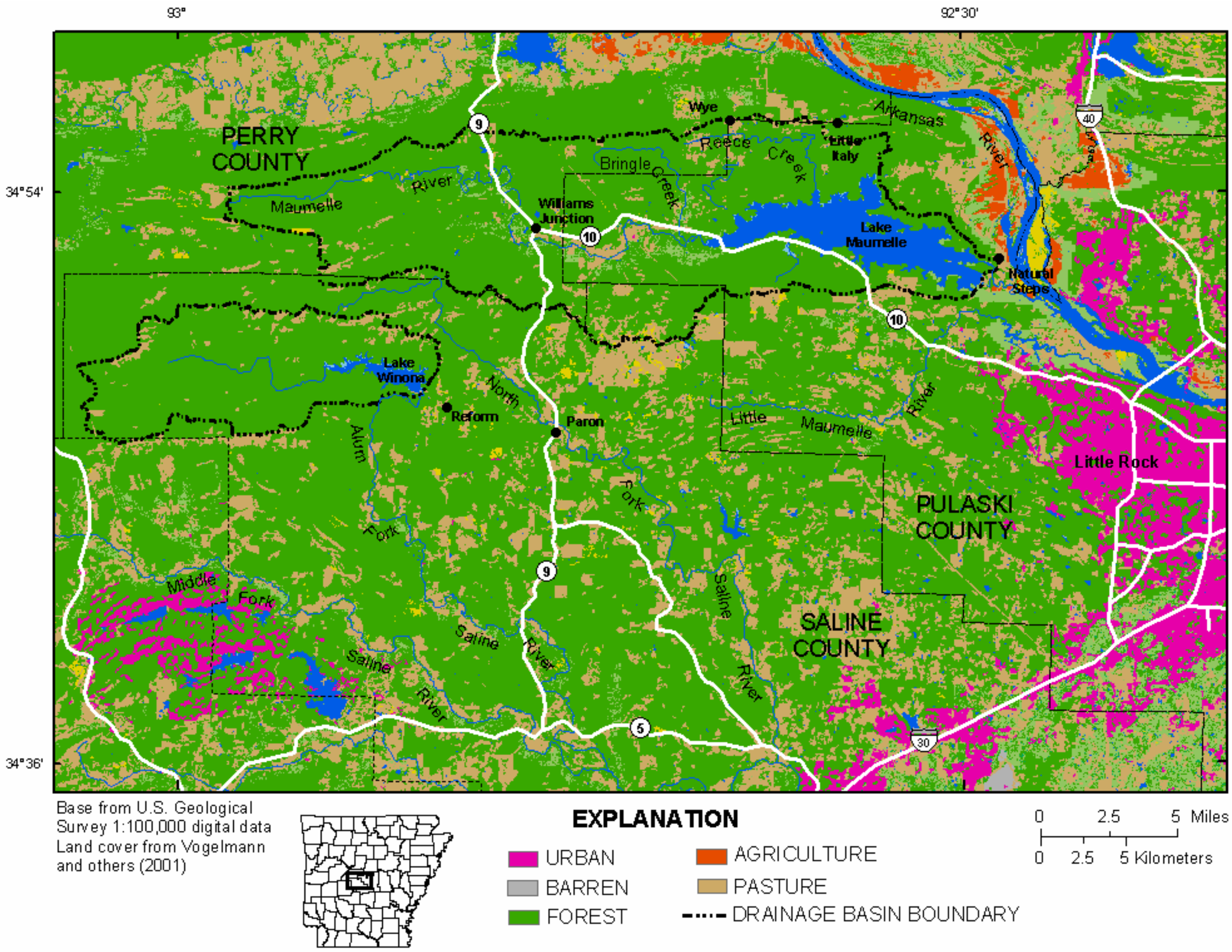

Figure 3. Land Use in the Lake Maumelle Watershed and Surrounding Area

In summary, Lake Maumelle is used for multiple purposes consistent with maintaining good water quality. The land in the watershed is subject to a variety of uses, and is primarily forested, with some areas subject to periodic timber harvesting.

4.2 Water Quality Status of Lake Maumelle

Hydrologic and water quality data have been collected from Lake Maumelle and its inflows since 1991 by the USGS and CAW. The USGS (1994) conducted monitoring of Lake Maumelle from 1989 to 1992, analyzed the nutrient load to Lake Maumelle, and predicted the response in lake productivity to nutrient input. They found the following:

> "…changes in influent phosphorus concentrations would increase expectant chlorophyll-*a* levels greater than would relative changes in nitrogen. However, as phosphorus level increase, the expectant changes in chlorophyll-*a* levels become more influenced by changes in nitrogen. With influent phosphorus concentrations greater than 0.06 mg/L as P, relative changes in influent nitrogen affect expectant chlorophyll-*a* levels as much as changes in phosphorus.
>
> What these data and hypotheses demonstrate, from a management perspective, is that control of phosphorus and nitrogen leading into Maumelle reservoir will be necessary to maintain the present water quality condition of Maumelle. If nutrient inputs can be maintained at present levels, the water quality within Maumelle reservoir should remain relatively stable. However, increases in phosphorus load will alter the water quality from its present oligo-mesotrophic condition to that of a more eutrophic condition, and this trophic response will be amplified with increases in nitrogen loading." (USGS, 1994)

This analysis by the USGS indicates that small changes in total phosphorus load to Lake Maumelle have long-term impacts on lake water quality. Controlling phosphorus loads is essential to the protection of the lake.

The USGS has continued to collect hydrologic and water quality data in cooperation with CAW (USGS, 2004). This latest effort includes monitoring conducted from 1991 to 2003. Information obtained through the monitoring effort has been used to develop a long-term water quality database to accurately assess present water quality conditions, trends, and sensitivity to changes. Water samples were collected at four locations in Lake Maumelle for this database. The samples were analyzed for several field parameters and constituents. These include specific conductance, pH, dissolved oxygen, nutrients, water temperature, organic carbon, chlorophyll-*a,* suspended sediment, Secchi depth, and fecal indicator bacteria. Seasonal and annual loads of nutrients, dissolved organic carbon, and suspended sediment were estimated for the main inflows into the lake. These data reveal the following trends:

- Dissolved oxygen concentrations remain uniform and near saturation levels during the winter because of complete mixing of the water column. As the temperature warms and the water temperature becomes more stratified, dissolved oxygen levels in the lower, colder layers of the lake decrease.
    - This decrease in dissolved oxygen is due in part to the destructive effects of siltation, which can smother bottom-dwelling oxygen-producing plants and prevent light from reaching them by making the lake water cloudy (i.e., increasing turbidity as measured using Secchi depth).
    - The added sediment carries unwanted nutrients, which increase algal growth, thus increasing the lake's biochemical oxygen demand.
- Total phosphorus concentrations measured in the epilimnion vary both spatially and temporally in Lake Maumelle, with higher concentrations in the western portion of the lake.

- Concentrations of chlorophyll-*a* vary seasonally, with the highest median concentrations (e.g., 3 to 6 µg/L in the eastern portion of the lake) generally during August through November, and the lowest concentrations (e.g., 0.5 to 2 µg/L in the eastern portion of the lake) during March through July.

- Water clarity is significantly greater at the eastern end of the lake than at the western end. Secchi depth varies seasonally, with the greatest depth in summer and the least depth in winter. [Note: Water clarity is measured by determining the maximum depth of visibility of a Secchi disk (painted black and white) submerged in the water.]

- Total phosphorus and chlorophyll-a concentrations measured west of the Highway 10 Bridge (i.e., with medians of 12 µg/L and 4.5 µg/L, respectively) are significantly higher than locations in the rest of the lake.

- Trophic state indices identify conditions ranging from oligotrophic to mesotrophic for three sites on Lake Maumelle, with the deeper eastern portion being in oligotrophic to mesotrophic states and the shallower western portion being more advanced in the eutrophication process.

Overall, based on the 2004 USGS study, it can be concluded that the shallower western portion of Lake Maumelle above the Highway 10 Bridge is exhibiting mesotrophic to early eutrophic conditions. The lake exhibits more oligotrophic conditions in the central and eastern portions of the lake. As depicted in Figure 4, concentrations of total phosphorus at the western end of Lake Maumelle in open water (i.e., Lake Maumelle East of Highway 10 Bridge) range up to above 30 µg/L, while concentrations in the middle and eastern parts of Lake Maumelle (i.e., near Little Italy and near Natural Steps) only range up to 20 µg/L (with one observation at about 30 µg/L in late 2003). This is consistent with the greater degree of eutrophication and higher concentration of chlorophyll-*a* observed at the western portion of the lake.

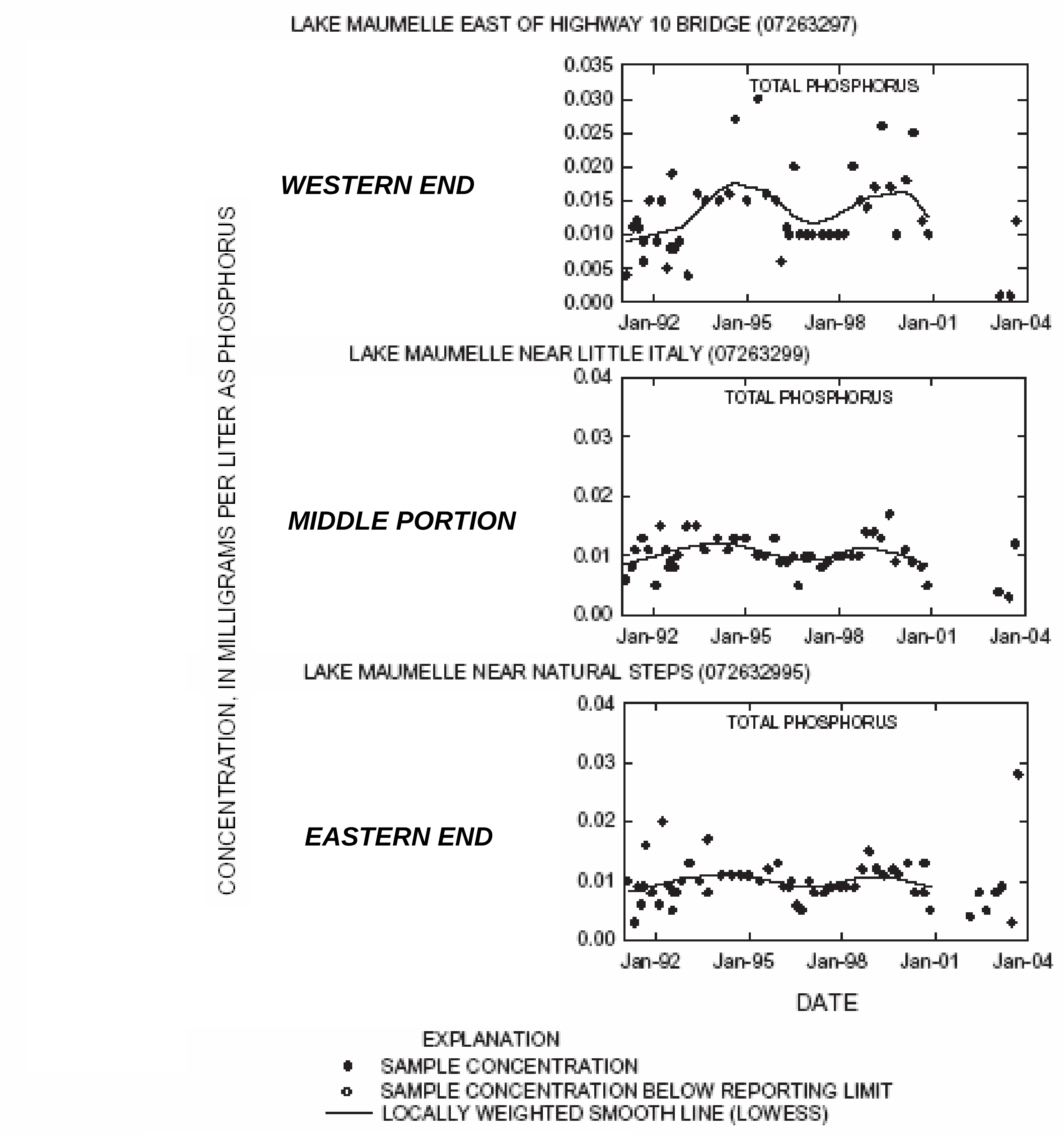

Figure 4. Time Series of Phosphorus Concentrations for Three Sites on Lake Maumelle, Arkansas, 1991 through 2003 (USGS, 2004)

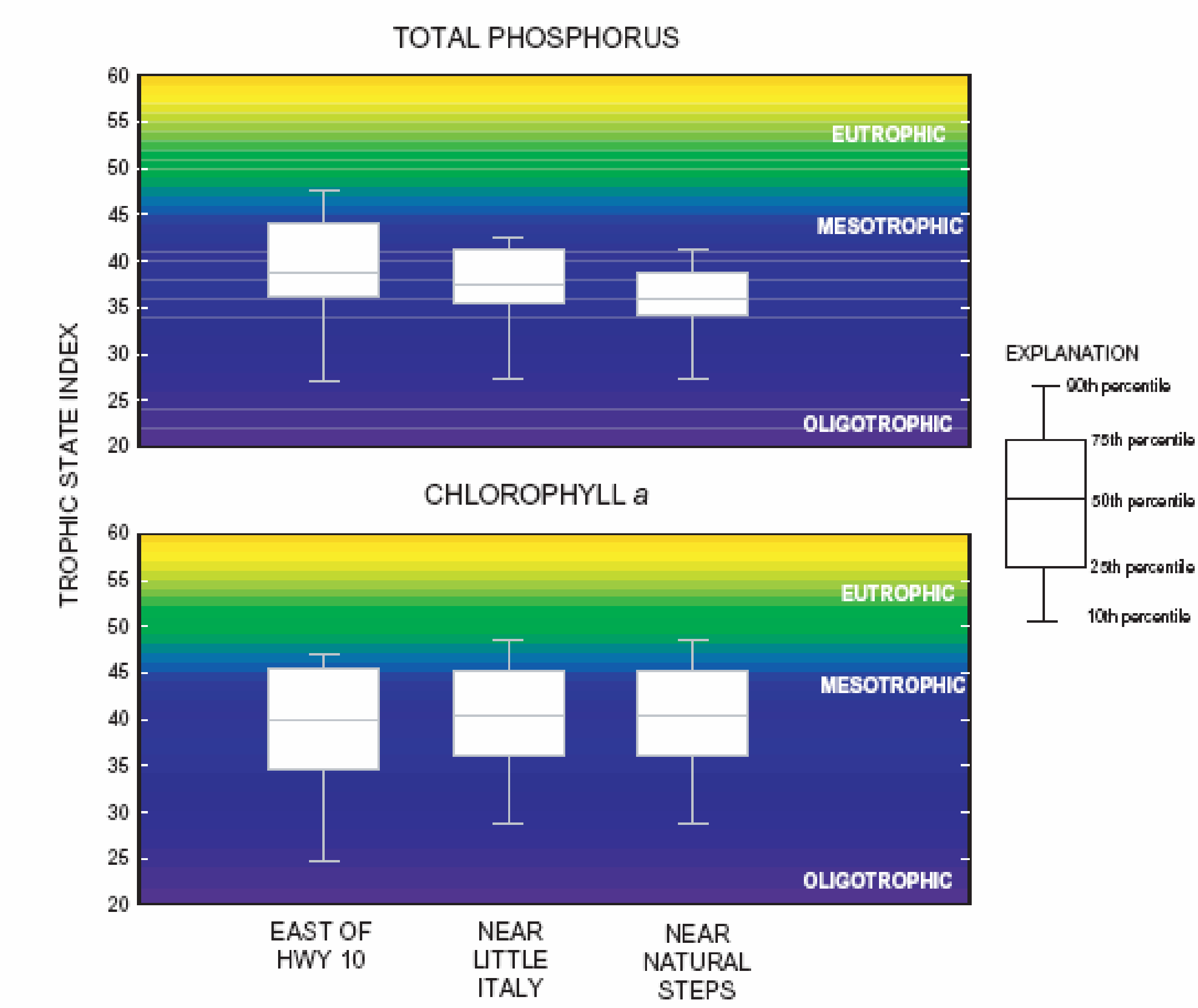

Figure 5. Trophic State Indices for Three Sites on Lake Maumelle, Arkansas (USGS, 2004)

In summary, as depicted in Figure 5, Lake Maumelle is generally characterized as oligotrophic to mesotrophic for three locations in the open water section of Lake Maumelle (USGS, 2004). Continued monitoring suggests that although the western end of the lake is becoming increasingly eutrophic, the eastern end of the lake—where the drinking water intake is located—remains relatively pristine (i.e., oligotrophic). These findings are consistent with earlier studies that pointed to phosphorus as the limiting factor for the trophic state of Lake Maumelle (USGS, 1994; Stapleton, 1985). If nutrient inputs can be maintained at the early 1990s levels, the water quality of Lake Maumelle should remain relatively stable. Nevertheless, increases in phosphorus loading will alter the trophic state of Lake Maumelle from the oligo-mesotrophic state to that of a more eutrophic state (USGS, 1994).

4.4 Concerns Regarding Land Development in Zone 1 of Lake Maumelle

Poor Quality Soils and High Erosion Potential Limit Land Development in Zone 1

According to information from the USDA's Soil Survey Report for Pulaski County, the soils in Zone 1 are poorly suited for development. One reason is that the soils and slopes within Zone 1 make the area prone to erosion during and after construction. The topography within Zone 1 is associated with medium to rapid runoff and the hazard of erosion is severe to very severe (USDA, 1975).

The soils in Zone 1 are identified as "Carnasaw-Mountainburg Association, undulating" (CMC) and "Carnasaw-Mountainburg Association, steep" (CMF). CMC soils are found on the top, sides, and foot slopes of mountains, on benches, and on low ridges in valleys. They are associated with slopes ranging from 3 to 12 percent. Runoff from CMC soils is medium to rapid, and the hazard of erosion is severe to very severe. CMF soils are found on the top and sides of mountains and on ridges. They are associated with slopes ranging from 12 to 40 percent. Runoff from CMF soils is very rapid, and the hazard of erosion is very severe. In addition, CMC and CMF soils are rated to pose severe limitations for town and country planning because of their low bearing capacity, high shrink-swell potential, low permeability due to their being composed of predominantly clayey materials, and high slope.

An examination of slope steepness data (see Figure 6) reveals that much of the land within Zone 1 is sloped at a gradient of 10 percent or more, and about 40 percent of the slopes are in the range of 15 percent to 25 percent gradient (i.e., strong slopes). In addition, about 14 percent of the land in Zone 1 is associated with slopes greater than 25 percent gradient. In general, slopes of 15 percent to 25 percent gradient are considered hazardous due to the potential for erosion and landslides, and site-specific hazards should be identified and addressed. Slopes of 25 percent gradient or higher are generally unsuitable for development because of high development and municipal service costs, along with severe erosion potential (Town of Chapel Hill, 2004; City of Norwood, 1999; Centre County, 2005; Ten Towns Committee, 2003; Van Buren County Community Center, 2004).

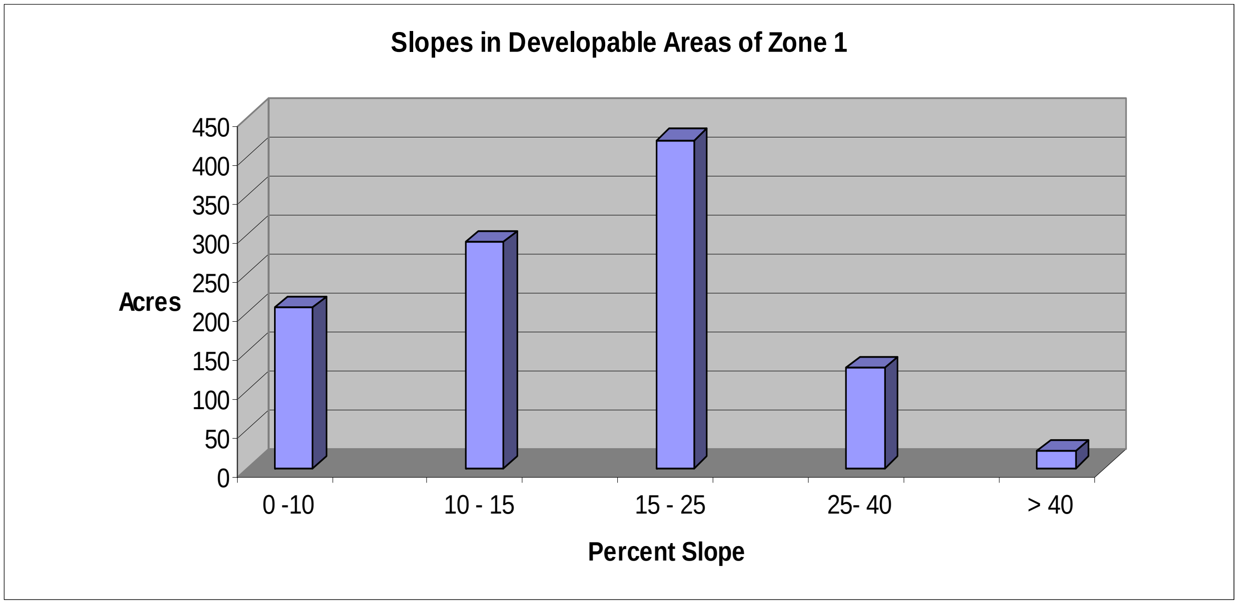

Figure 6. Distribution of Slopes in Developable Areas of Zone 1

The Trust for Public Land and the American Water Works Association (Trust for Public Land, 2004) state that identifying high-priority land for protection is critical to managing drinking water sources. Specifically, their 2004 report entitled "Protecting the Source" notes that parcels with steep slopes and erodible soils that are close to a drinking water source are the most important areas to protect, because development on these sites is most likely to degrade water quality. These are the conditions present in Zone 1, which make it a particularly important for CAW to protect this area from development.

Close Proximity of Zone 1 to CAW's Water Intake

The proximity of Zone 1 to the water intake of CAW greatly increases the threat of contamination. Any pollutant input from Zone 1, for example, from accidental gasoline spills, debris and fire-suppressants from fire-fighting, and chemicals used for landscape maintenance and pest control, can potentially reach the lake - and the water intake - in a short time. The water treatment processes currently in place do not address many of these potential pollutants. The steep topography and thin soils in Zone 1 contribute to a shortened travel time for any released pollutants to the water intake, thus limiting CAW's ability to respond to these events. An examination of the elevation and watershed boundary (i.e., ridge line) indicates that the runoff from Zone 1 only has to traverse a short distance before reaching the lake (see Figure 7 and 8). In addition, the steep topography in the southern section of Zone 1 would further increase the potential for erosion caused by the runoff. Because of the proximity of Zone 1 to the water intake, it is unlikely that dilution or attenuation can provide a safety margin when pollutants are released in Zone 1. Although it is possible to retrofit CAW's treatment processes to deal with a wide range of pollutants, such a practice is very expensive and is likely to be cost ineffective. Prevention is the better and typically more cost effective strategy for safeguarding drinking water from such pollutants.

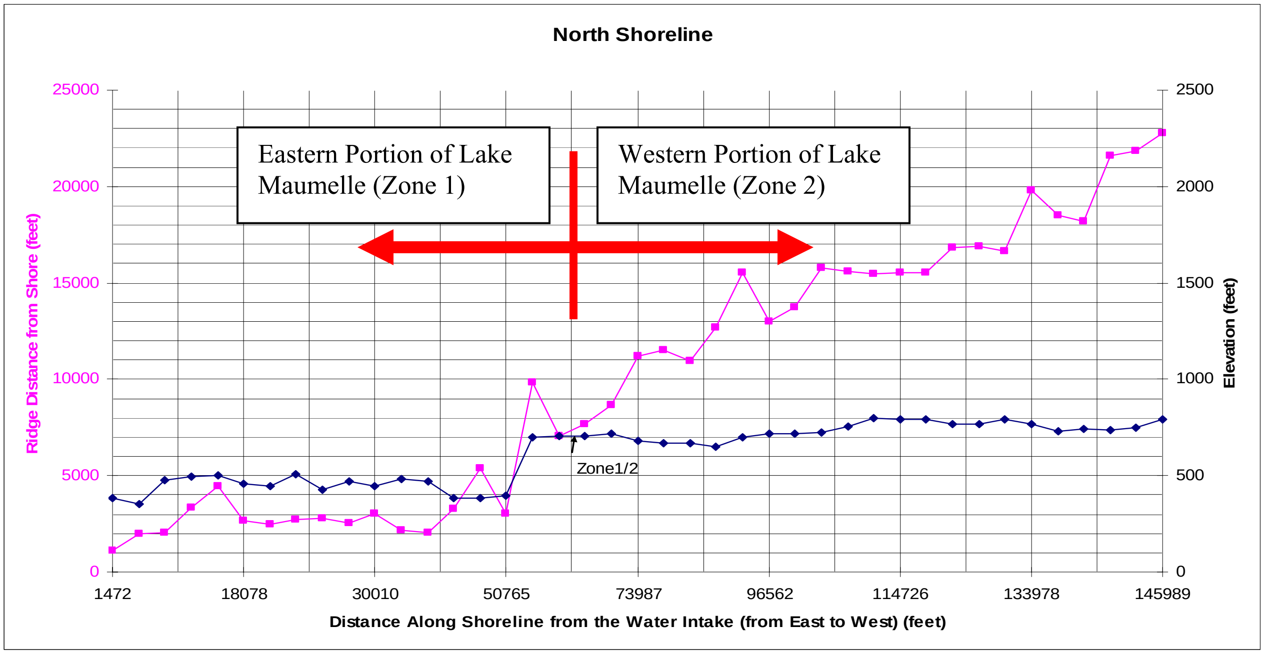

Figure 7. Position and Elevation of Ridge Line from Lake Maumelle – North Side

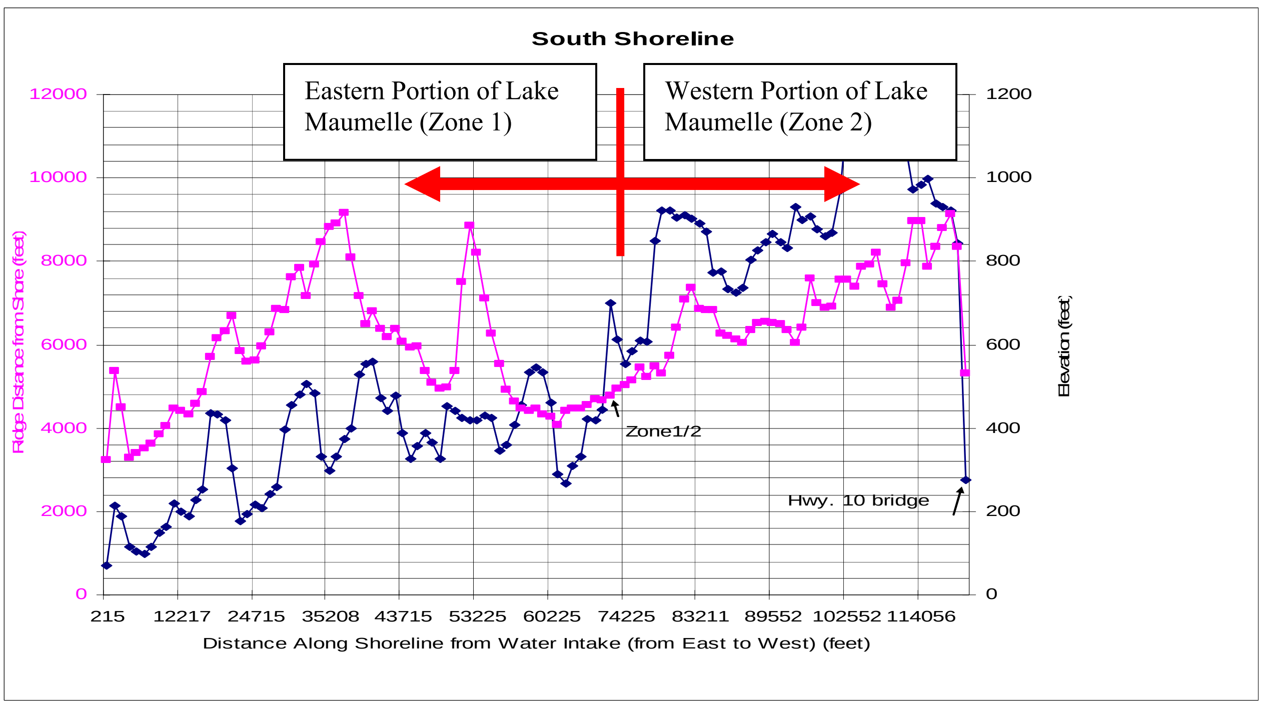

Figure 8. Position and Elevation of Ridge Line from Lake Maumelle – South Side

Zone 1 is poorly suited for development due to steep slopes and soils with low bearing capacity and high shrink-swell potential. The development of Zone 1 is even less advisable when the protection of Lake Maumelle's water quality is considered. ***First, the poor soil and steep slope conditions would result in erosion and the release of sediments and nutrients into the lake – a significant problem that will accelerate the eutrophication process of Lake Maumelle. Second, the close proximity of Zone 1 to the water intake at the eastern end of the lake increases the risk of accidental contamination by common development-related chemicals. There would be little opportunity for natural attenuation and dispersion of contaminants before they reach the water intake, and CAW would have very little time to respond in a manner sufficiently protective of public health.***

4.5 Impacts to Lake Maumelle from Land Development

Impacts of construction activities

In general, the construction activities necessary for creating residential developments result in stormwater discharges that may have significant impacts on the water quality of nearby water bodies. This is because as stormwater flows over a construction site, it gathers and transports pollutants, such as sediment, debris, and chemical contaminants. When such stormwater flow to a source of drinking water, such as Lake Maumelle, it will degrade water quality and increase human health hazards. Furthermore, polluted stormwater runoff can harm or kill fish and other wildlife. Sedimentation can destroy aquatic habitat, have a harmful effect on the trophic state of the lake, and shorten the life of the reservoir.

Given the steep slopes in Zone 1, it is likely that stormwater polluted during construction would flow directly to Lake Maumelle. BMPs for erosion and sediment control (such as land grading, temporary diversion dikes, and brush barriers) can have some effect on mitigating stormwater problems during construction. If all stormwater is captured on-site and allowed to evaporate or infiltrate into the ground on-site, some of the potential harmful effects on Lake Maumelle's water quality may be mitigated. However, the soils in Zone 1 are associated with very low permeability, so infiltration of all stormwater after a heavy rain is unlikely. It will be difficult to implement BMPs in a manner effective enough to ensure that at least some stormwater, and perhaps even large quantities of stormwater, will not flow to Lake Maumelle, carrying sediment and contaminants.

Maps of Zone 1 indicate that there are areas of channeled flow through which stormwater can flow quickly and directly to Lake Maumelle. Given the soil properties in Zone 1, it is likely that rills and gullies would develop if the soil were disturbed by construction activities and traffic. The development of rills and gullies promotes rapid erosion of hill slopes, which would contribute additional sediment and nutrients to Lake Maumelle.

Post-construction impacts to Lake Maumelle

Continuous use of the land in Zone 1 following any residential development would provide a continuing source of pollutants to Lake Maumelle. Nutrients, pathogens, pesticides, and other chemicals used for lawn and garden care all would present a significant threat to Lake Maumelle given the soil type and slope of the land in Zone 1.

Even attempts to design residential development carefully, and to implement practices such as permeable pavements and green roofs, are unlikely to mitigate impacts to Lake Maumelle sufficiently to eliminate significant risks. This type of development is known as Low Impact Development (LID), and it attempts to reproduce or maintain as closely as possible the original hydrology of a developed site. Site design elements of LID include minimizing impervious surfaces such as roads, clustering buildings together, and leaving areas with the most sensitive and important soils and vegetation untouched. LID also can include bioretention cells (vegetated depressions where water can infiltrate to the soil and be taken up by hardy plants), green roofs, permeable pavements, rain barrels, and the amendment of soils with compost or lime to improve permeability (Jones, 2004).

Even assuming some implementation of post-construction BMPs (such as detention ponds, grassy swales, or porous pavements) and instituting LID, the chemicals and pathogens from residential activities could infiltrate through soil and contaminate groundwater, which is likely to flow into Lake Maumelle and deteriorate its water quality over somewhat longer time periods (because the flow of groundwater into the lake generally will take longer than flow directly over the land surface to the lake). Leaking storage tanks for wastewater and leaking sewer lines are also possible subsurface sources of nutrients and other contaminants that could impair lake water quality.

Although post-construction impacts to Lake Maumelle from continuous activities in a residential development may be anticipated, and possibly mitigated somewhat through LID, it is especially difficult to plan for protecting the lake from accidental releases of contaminants. Such releases include those resulting from car accidents, house fires, and chemical spills. The probability of such releases can be expected to increase along with increased activity and traffic in the area following any development.

Limitations of BMPs

BMPs and LID can reduce the risks posed by development near drinking water sources, but cannot completely eliminate risk to human health and the environment. BMPs are limited in that they are generally designed for a specific capacity, and may be overloaded during extreme storm events. Furthermore, BMPs require proper maintenance, and they will fail if not continually monitored and repaired.

Many states and municipalities require BMPs for stormwater runoff associated with developed land. These required BMPs often include onsite detention and retention basins (USEPA, 2002). Stormwater detention ponds, or dry ponds, are basins designed to detain stormwater temporarily so that sediments and pollutants have time to settle out.

Stormwater retention ponds, or wet ponds, are intended to retain stormwater for an extended period of time; many such ponds never completely dry up. Wet ponds treat water in two ways: settling separates out sediments, and biological activity is intended to decrease concentrations of nutrients in the water. Stormwater wetlands are shallow pools populated with wetland plants; these artificial wetlands treat water in much the same way as wet ponds (i.e., by settling and biological activity). A variety of filtering techniques are practiced; most use sand as the filtration medium. Some filters incorporate a settling basin to remove large particles, or organic media to consume nutrients. Infiltration basins or trenches impound water long enough for it to be absorbed into the soil; the soil filters the water as it recharges the underground aquifer (i.e., groundwater). Swales are enhanced drainage ditches; open, grassy channels that treat stormwater through a combination of filtering by the vegetation and soil, infiltration into the soil, and nutrient uptake.

However, even the most effective BMPs have been shown to be only partially successful at removing pollutants from stormwater (Brown and Schuler, 1997). Table 3 below, developed using data from the EPA and American Society of Civil Engineers' National BMP Database (http://www.bmpdatabase.org/) illustrates the limitations of BMPs at removing various typical stormwater pollutants. Negative values in the table indicate that some BMPs can even serve to increase concentrations of some pollutants in stormwater.

Table 3: Median Pollutant Removal of Stormwater Treatment Practices (Brown and Schueler, 1997).

Treatment BMP	Median Pollutant Removal Efficiency (percent)						
	TSS	**TP**	**Sol P**	**TN**	**NOx**	**Cu**	**Zn**
Stormwater Detention Ponds	47	19	-6.0	25	4	26(1)	26
Stormwater Retention Ponds	80	51	66	33	43	57	66
Stormwater Wetlands	76	49	35	30	67	40	44
Filtering Practices(2)	86	59	3	38	-14	49	88
Infiltration Practices	95(1)	70	85(1)	51	82(1)	N/A	99(1)
Water Quality Swales(3)	81	34	38	8	31	51	71

(1) Data based on fewer than five data points.
(2) Excludes vertical sand filters and filter strips.
(3) Refers to open channel practices designed for water quality.

Notes: N/A = data are not available; TSS = Total Suspended Solids; TP = Total Phosphorous; Sol P = Soluble Phosphorous; TN = Total Nitrogen; NOx = Nitrate and Nitrite; Cu = Copper; Zn = Zinc.

A combination of steep slopes and poor soil conditions would make the implementation of BMPs an extremely challenging task in Zone 1 and these same conditions make it impossible to predict the effectiveness of any such measures. Even assuming that LID techniques can reduce stormwater runoff, the possibility of groundwater contamination (which may subsequently enter Lake Maumelle) and on-site stormwater treatment system failures (which would allow sediment and nutrients to enter Lake Maumelle via channeled flows) would still pose a threat to Lake Maumelle's water quality.

Furthermore, even under the best LID scenarios, it is unclear who would monitor stormwater and groundwater, and who would maintain physical structures associated with BMPs. If structures were damaged or needed upgrading, it is unclear who would undertake (or enforce) the activities necessary to protect Lake Maumelle (e.g., serve as a regulator and/or pay for the costs associated with monitoring and remediation). Furthermore, land owners in a residential development would need to restrict their usage of the land (e.g., no extensive lawn areas) and minimize the use of potential contaminants (e.g., limited or no use of pesticides and fertilizers for landscaping) to prevent further lake water quality degradation. It is unclear who would enforce such restrictions, and if restrictions were violated, who would remediate problems created or prevent further violations. Covenants and deed restrictions can be used to place restrictions on future land uses or to maintain BMPs, but a governmental entity is needed to ensure that the restrictions are enforced and BMPs are maintained. In the cases where the ability to enforce covenants and restrictions is highly questionable or speculative, and where such covenants and restrictions are not legally binding or are revocable, development of sensitive land areas such as those in Zone 1 would increase the threat to Lake Maumelle's water quality.

In summary, although BMPs can be effective, to some extent, in preserving water quality and reducing impacts from development, they cannot completely eliminate the impacts and risks of development. Given the inappropriate site characteristics in Zone 1 and Zone 1's close proximity to CAW's water intake, it is unsuitable for large-scale residential development.

Setting a Precedent for Future Development

The risks to the water quality of Lake Maumelle from the development of Zone 1 should not be underestimated. It is also important to consider the setting of precedent by allowing development in areas with steep slopes and poor soils. If development is permitted in such an inappropriate area, it may be difficult to prevent further development of the area around the lake.

Additional residential and commercial developments and associated infrastructure can be anticipated to bring additional sediment, nutrient, and contaminant loads to the lake, even if BMPs are used. It is unlikely that Lake Maumelle could sustain its current water quality under such conditions, and costly treatment alternatives would be required if the lake were to continue to be used as a drinking water source.

4.6 Relative Pollutant Loads from Different Land Use Practices

A variety of pollutant sources have been introduced in the Lake Maumelle watershed over the past 50 years. In addition, new development is being proposed. This section reviews the status of the predominant current and potential future land uses in the watershed and the relative impact they may have on nutrient, silt, and other pollutant load to the lake. Studies have demonstrated that the productivity of Lake Maumelle is phosphorus limited. As a result, increases in total phosphorus load (even small increases) are likely to result in increasing eutrophication. Therefore, the discussion below emphasizes phosphorus loading related to the various land uses.

Forestry Management and Timber Harvest

The majority of the Lake Maumelle watershed is currently forested. Using mid-1990's National Land Cover Data from the USGS, forested land was estimated to be about 96 percent of the total watershed land area. A visual reconnaissance overflight of the watershed conducted on May 19, 2004 indicated that much of the timber stand in Zone 1 remained, although selective harvesting and clear-cutting was also observed.

The export of total phosphorus from forested land is estimated to range from 0.025 to 0.464 pounds per acre per year (lbs/ac/yr) (0.028 to 0.520 kilograms per hectare per year or kg/ha/yr) (Stapleton, 1985; Reckhow *et al.*, 1980; Reckhow and Chapra, 1983; and Likens, 1970; Endreny, 2002; Kellogg *et al.*, 2000; Prezsonik *et al*., 2002; Morrison County, 2002; North Carolina Division of Water Quality, 1998; Schloss, 2000). Clear-cuts are associated with the highest levels of phosphorus export from forest soil; whereas undisturbed forests are associated with minimal phosphorus export. The range of export coefficients (0.025, 0.123, and 0.464 lbs/ac/yr or 0.028, 0.138, and 0.520 kg/ha/yr) used in the analyses in Section 4.7 is based on the variety of land uses in the Lake Maumelle watershed. This includes "forest with high disturbances" (see Table 4), because clear cuts have been observed in the watershed.

Existing Residential Development

The Lake Maumelle watershed currently has sparse and dispersed residential development. On the basis of the most recent aerial photographs of the watershed, a total of 609 structures are currently located in the watershed (CAW, 2004). The large majority of the structures are not inhabited (e.g., storage buildings). Most of these structures are in Zone 2, but some structures are present in Zone 1. Those structures that are occupied rely on on-site septic systems for wastewater disposal. Because the wastewater is disposed of in the subsurface, and because so few structures are located in Zone 1, the contribution of the existing residents in Zone 1 to contamination of the lake is expected to be very limited.

The May 2004 reconnaissance flight taken over the watershed revealed that home sites in the watershed typically remain heavily forested, although some roads were constructed for these home sites. According to the mid-1990's National Land Cover Data from the

USGS, the area under residential use and other urban usages is less than 0.1 percent of the total watershed land area. Although the export of phosphorus from residential developments is higher than that from disturbed forested land, the low percentage of Lake Maumelle watershed that is currently developed has kept the impact by phosphorus from these residential developments to a minimum.

Future residential development

Currently, much of the land outside the one-quarter mile buffer around Lake Maumelle is privately owned. There is now pressure to develop high-value lake-view homes in Zone 1. Plans for developing lands in Zone 1 have been drafted and submitted to the county for review and approval. While these developments have not been fully platted, informational meetings sponsored by the developers have been held to provide information regarding these proposed developments.

The conservation design practices that have been explicitly incorporated into one of these development plans include:

- Minimizing site disturbance during and after construction, to preserve the native landscape.
- Restoring disturbed areas using a diverse mix of native species.
- Strictly limiting impervious cover.
- Maintaining wide buffer zones around all water bodies.

The effectiveness of these proposed practices in Zone 1 cannot be fully evaluated because the design specifications have not been presented. The phosphorus export coefficient generally associated with low density residential development is 0.829 lbs/ac/yr (0.929 kg/ha/yr), which is more than 30 times that of well-preserved forested areas and almost seven times that of partially-disturbed forested areas. In addition, the construction activities are likely to increase silt load to the lake. Jennings *et al*. (2002) have measured total suspended solids loading from construction sites at five to eight times those measured from wooded sites. The implementation of BMPs, including the design practices listed above, will reduce the phosphorus and sediment loads somewhat, but it is unlikely that there will be no increases.

More importantly, the soils and slopes in Zone 1 make the area prone to erosion during and after construction. The effectiveness of any BMPs will be greatly reduced under these soil and slope conditions.

Internal Nutrient Cycling

Lake Maumelle stratifies in the summer months, when anoxic conditions occur in the lower portion of the lake or hypolimnion (i.e., bottom water). The hypolimnion is isolated from the surface during periods of thermal stratification and reaeration from surface mixing is eliminated. Furthermore, sediment input and biochemical oxygen demand serve to decrease dissolved oxygen concentrations in the hypolimnion. Very little, if any, oxygen input from algal photosynthetic activity occurs below the metalimnion. Because of this combination of factors, anoxic conditions are achieved and phosphorus is released from the lake sediments. When the lake waters turn over in the fall, the released phosphorus becomes available for biological uptake, thereby enhancing productivity. While the released phosphorus is available, it is not considered a “new” source of nutrient load to the lake. Instead, it is an internal source to the lake and is not considered as part of the analysis in Section 4.7.

Summary of Current Phosphorus Loads to Lake Maumelle

Phosphorus is currently the pollutant of the greatest concern for Lake Maumelle, because small increases in phosphorus load can change the trophic state of the lake. Most of the Lake Maumelle watershed is forested, and phosphorus releases from forests vary: undisturbed areas produce the least, and clear-cut areas produce the most. In contrast, the most benign residential development releases considerably more phosphorus than disturbed forested lands. Because development in the Lake Maumelle watershed is minimal at present, especially in Zone 1, where soil and slope conditions are generally severe, development contributes relatively little to the current phosphorus loading. In addition, because development is minimal, the water supply is not threatened by a wide variety of other chemicals that are associated with human activities. The following subsection investigates the impact that changing land use in the Lake Maumelle watershed would have on water quality over the long-term.

4.7 Predicting Lake Maumelle Response to Increases in Phosphorus Load

Phosphorus Loading Scenarios

Typical export coefficients for phosphorus, based on scientific and land use planning literature (Stapleton, 1985; Reckhow *et al*., 1980; Reckhow and Chapra, 1983; Likens, 1970; Endreny, 2002; Kellogg *et al*., 2000; Prezsonik *et al*., 2002; Morrison County, 2002; North Carolina Division of Water Quality, 1998; Schloss, 2000) are presented in Table 4 below.

Table 4. Phosphorus Export Coefficients – Averages from Scientific and Land Use Planning Literature

Land Use	Phosphorus Load (pound/acre/year)
Forest with no or low disturbances	0.025
Forest with moderate disturbances	0.123
Forest with high disturbances	0.464
Low Intensity Residential	0.829
Medium Intensity Residential	1.515
High Intensity Residential	3.242
Commercial/Industrial	2.299
Urban/Recreational Grasses	1.297
Pasture	0.465
Row Crop	1.264
Golf Course (under grass)	0.895
Open Water	0.204

It should be noted that the phosphorus export coefficients are based on scientific and land use planning literature and are not based on site-specific factors such as soil type, terrain, and landscape position (e.g., proximity to the lake and tributaries). Depending on the site-specific conditions, these export coefficients might be too conservative for areas with highly erodible soil and steep slopes. Conversely, these export coefficients could be high for more favorable locations with stable soils and gentle slopes. Nevertheless, the use of these export coefficients allows some insight into the relative impacts of varying land uses on Lake Maumelle.

Table 5 presents the current land use and land ownership percentages in the Lake Maumelle watershed. Spatial data maintained by CAW staff, along with the National Land Cover Data from the USGS, were used to derive the land use and land ownership acreages.

Table 5. Land Use in the Lake Maumelle Watershed

Ownership and Land Use	Acres	Percent of Watershed Land
CAW Lands	7,998	10.07%
Arkansas State Park	64	0.08%
US Forest Service Wilderness Area	42	0.05%
US Forest Service National Forest	18,245	22.97%
Low Intensity Residential	1	0.00%
Commercial/Industrial	42	0.05%
Urban/Recreational Grasses	3	0.00%
Pasture	1,454	1.83%
Row Crop	50	0.06%
Golf Course (under grass)	150	0.19%
Golf Course (under forest)	725	0.91%
Privately Owned with Restrictions	379	0.48%
Other Privately Owned	50,272	63.29%
Total Land Area	**79,425**	**100.00%**
Open Water	8,579	
Total Land & Water Area	**88,004**	

The phosphorus export coefficient (Table 4) and land use data (Table 5) indicate that an estimated 12,140 pounds of phosphorus are entering Lake Maumelle on an annual basis (see Appendix B).

Trophic Status from Phosphorus Input to Lake Maumelle

Vollenweider (1980) developed a lake trophic status predictive model for the Organization for Economic Cooperation and Development (OECD) to assist governments with their lake management efforts. The model is based on earlier work by Vollenweider (1976) involving data collected from lakes around the world. Vollenweider developed the following predictive relationship, which uses critical concentrations of phosphorus, lake water residence time, and lake mean depth to determine critical annual loading rates of phosphorus:

$$L_c = P_c\,(z/t_w + 10)$$

where:

L_c is the critical annual loading rate of phosphorus (in milligram per square meter per year or $mg/m^2 \cdot yr$),
P_c is the critical concentration of total phosphorus defining the trophic category of the lake (in milligram per cubic meter or mg/m^3),
z is the lake mean depth (in meter or m), and
t_w is the water residence time (in year or yr).

Vollenweider and Kerkes (1982) used the critical total phosphorus concentrations given in Table 6 to define the various lake trophic states.

Table 6. Relationship Between Trophic State and Phosphorus Concentration

Trophic Category	**P_c = Critical Total Phosphorus Concentration (mg/m^3)**
Ultra-oligotrophic	≤ 2.5
Oligotrophic	2.5 – 8
Mesotrophic	8 – 25
Eutrophic	25 – 80
Hyper-eutrophic	≥ 80

In the case of Lake Maumelle, the mean lake depth is 7.5 meters and residence time is approximately 1.72 years. Based on the relationship described above, the critical annual loading rate of phosphorus (L_c) necessary to characterize Lake Maumelle as mesotrophic rather than oligotrophic is approximately 115 $mg/m^2 \cdot yr$. Taking into account current land use conditions (Table 5), the critical annual loading rate of phosphorus (L_c) is 153 $mg/m^2 \cdot yr$, which means Lake Maumelle is currently in a mesotrophic state. This finding is consistent with the phosphorus and chlorophyll-*a* levels observed in the lake and the lake trophic state reported by the USGS (2004).

To estimate the impact of potential land use changes on phosphorus loading to Lake Maumelle, two additional land use scenarios (2 and 3) have been developed. Typical phosphorus export coefficients were used for this analysis. Scenario 2 assumes that areas in Zone 1 currently in unrestricted private ownership (approximately 1,320 acres of commercially managed timber land) are condemned and managed to provide maximum protection for the lake. Scenario 3 assumes that these same lands will not be condemned but instead will be converted to low density residential use. The baseline loadings and the two additional scenarios' loading estimates are presented in Table 7.

Table 7. Phosphorus Loads From the Lake Maumelle Watershed Under Different Development Scenarios

Scenario		Annual Phosphorus Load		Critical Annual Loading Rate (L_c)
		(pounds/yr)	(gram/year)	(gram/square meter·year)
1	Current land use conditions (baseline)	12,139	5,505,215	0.153
2	Current conditions for Zone 2 and giving all developable lands in Zone 1 (1,320 acres) protected forest status (i.e., no timber harvesting)	11,997	5,440,816	0.151
3	Current conditions for Zone 2 and allowing low density residential development of 1,320 acres in Zone 1	13,058	5,921,995	0.164

Table 7 shows that the conversion of the 1,320 acres of privately-owned, commercially-managed forested land in Zone 1 to low density residential use would increase the phosphorus load by about 920 pounds per year. On the other hand, if these 1,320 acres were allowed to return to natural conditions (i.e., no timber harvesting), there would be a reduction of phosphorus load to Lake Maumelle by about 140 pounds per year. Therefore, incremental developments in the watershed will contribute additional phosphorus to Lake Maumelle. As discussed earlier, an increase of phosphorus load to Lake Maumelle will lead to an increase in production of organic matter in the lake, which will increase the technical challenges to treating Lake Maumelle's water and raise the cost of treatment.

Table 8 provides a summary of the impact of land use changes associated with these 1,320 acres in Zone 1. Currently phosphorus loads from these areas could be decreased by 81 percent or increased by a factor of five (i.e., 500 percent), depending on how this land is protected or developed. Looking at the watershed as a whole, the increase in phosphorus loading from switching the land use from undisturbed forest to low density residential development in Zone 1, without knowing specific site conditions and BMP implementation, would be about 9 percent of the current annual 12,140 pounds of phosphorus load to Lake Maumelle.

Table 8. Phosphorus Loads From Different Development Scenarios of the Currently Unrestricted Developable Lands in Zone 1

	Area	Phosphorus Load Under Current Forest Conditions	Phosphorus Load Under Low Density Residential Development	Phosphorus Load With Full Protection of Forests
Unrestricted privately-owned developable lands in Zone 1	1,320 acres	175 pounds per year*	1,094 pounds per year	33 pound per year

* Assumes periodic timber harvesting on lands not owned by CAW or the State.

It is important to emphasize that the phosphorus export coefficients used in the above analysis were based on literature values for the various land uses, and that development in Zone 1 can be expected to contribute phosphorus (and other contaminants) to Lake Maumelle at rates greater than those predicted by the analysis. This is because these export coefficients do not take into account the steep slope and poor soil conditions in Zone 1, which would serve to increase phosphorus releases from Zone 1 and thus hasten the degradation of water quality of Lake Maumelle. Nevertheless, even the conservative analysis summarized in Tables 7 and 8 indicates that development in Zone 1 will have a negative effect on Lake Maumelle's water quality.

As can be seen from Table 5, over 60 percent of the Lake Maumelle watershed (about 50,000 acres) is privately-owned timber land. Transforming all the timber land in Zone 2 from partially disturbed forested conditions to low density residential use and associated supporting uses, even with the implementation of BMPs (assuming an overall 50 percent removal efficiency), could double the total phosphorus load to Lake Maumelle (i.e., from 12,140 pounds per year to 25,800 pounds per year) (see Scenario 4 in Appendix B). If such development were to take place without control or offset, the resulting increase in phosphorus would severely undermine Lake Maumelle's value as a drinking water reservoir. Obviously, a more detailed analysis is needed to determine the suitability of particular areas in Zone 2 for development. If they have adverse site conditions such as steep slopes and erodible soils, many of the areas in Zone 2 could pose significant risks to Lake Maumelle, if developed. BMPs may not be effective in reducing phosphorus load from every area in Zone 2, and thus development of inappropriate sites in Zone 2 could cause further increases of phosphorus concentrations in Lake Maumelle.

To reiterate, geography (e.g., site conditions and proximity to the lake) plays an important role in determining the impacts of various land uses throughout the Lake Maumelle watershed. Proximity to the lake and streams, soil properties, and steepness of the terrain all contribute to the suitability of a site for development. Areas that are near the lake and tributaries to the lake, with highly erodible soils and poor infiltration capacity, and on steep terrain, are not suitable for residential development and other activities (e.g., farming and clear-cutting), because any disturbances in these areas would mobilize high levels of phosphorus that could enter Lake Maumelle. In addition, adverse site conditions would severely restrict the effectiveness of BMPs at controlling phosphorus loading to Lake Maumelle. Therefore, areas with adverse site conditions, in both Zone 1 and Zone 2, must be managed properly to restrict their impacts on Lake Maumelle.

In summary, the above analysis illustrates the following: if all 1,320 acres of currently unprotected forested land in Zone 1 were placed under protected forested status, phosphorus loading from these acres would diminish by 81 percent. If the same 1,320 acres were developed residentially, the phosphorus loading from these acres would increase by 500 percent. This estimate is conservative, in that it does not take into account the poor soil and steep slope conditions that would exacerbate the adverse effects of accelerated phosphorus releases from the development sites in Zone 1 on Lake Maumelle.

4.8 Health Effects Expected if Water Quality of Lake Maumelle is Impaired

The additional nutrient loading to Lake Maumelle due to runoff from development, and possibly to groundwater contamination associated with that development, would result in an increase in organic matter in the lake. Higher levels of organic matter in drinking water sources lead to a greater demand for chlorine and lead to an increase in the formation of chlorination DBPs, such as trihalomethanes, during treatment (Graham *et al*., 1998). Trihalomethanes have been shown to be carcinogenic in laboratory animals (Singer, 1999) and may also be associated with early term miscarriages (Waller *et al.*, 1998). Because of these public health risks, EPA's regulations require water utilities to take steps to reduce regulated DBPs (Cooke and Kennedy, 2001).

Pathogens and chemical contaminants introduced into stormwater from residential activities pose additional health threats. Some of the pollutants commonly found in stormwater from developed sites include coliform bacteria, copper, lead, zinc, oil and grease, in addition to phosphorus and nitrogen (USEPA, 2002). Adverse health effects due to such pollutants include gastrointestinal, liver, kidney, and central nervous system effects, high blood pressure, and reproductive effects.

Increasing biological productivity increases the potential for algal blooms that can produce toxins that are harmful (to human and other animals) in the lake water (http://www.chbr.noaa.gov/CoastalResearch/DiversityEssay.htm). Moreover, increased nutrient inputs and biological productivity can create taste and odor problems in the water.

The various adverse effects mentioned above will become more common and frequent if Lake Maumelle's water quality is allowed to degrade. More importantly, these public health and aesthetic problems would severely undermine CAW's customers' confidence in the finished product.

5.0 Lake Maumelle Source Water Protection Plan and Activities

CAW has taken a proactive approach toward the protection of Lake Maumelle and its other source waters. Source water protection programs for surface drinking water sources were initiated as national policy with the 1996 amendments to the federal SDWA. CAW's focus on source water protection pre-dates the national program.

In 1985, LRMWW (predecessor to CAW) contracted for a Phase I Diagnostic Feasibility Study with University of Arkansas at Little Rock (Stapleton, 1985). The study found that Lake Maumelle was going through a nutrient/productivity transition period, and becoming more nutrient-enriched. Based on these findings, Lake Maumelle's trophic classification was changed from low mesotrophic to more advanced mesotrophic and possibly hypermesotrophic. Furthermore, the study found that Lake Maumelle is vulnerable to pollutant loading and eutrophication processes due to the lake's shallow morphometric characteristics.

A subsequent report by the Benham Group, Inc. in 1988 found that Lake Maumelle's intake site is sensitive to nutrient loading and algal blooms. Manganese problems had also been observed near the water intake structure. The report (Benham Group, 1988) noted that the key to control of excessive fertilization in waters such as Lake Maumelle, in which phosphorus is the limiting aquatic plant nutrient, is control of available phosphorus from external sources. The sources of increased phosphorus loading include the conversion of land-use from forest to agriculture and agriculture to residential, which cause several-fold increases in the potential quantity of phosphorus exported per unit area of land surface. The Benham study also concluded that Lake Maumelle's morphology makes it highly vulnerable to increased nutrient loading.

Based on the University of Arkansas at Little Rock and Benham studies, LRMWW began investigating the development of a watershed protection plan for the Lake Maumelle watershed and the implementation of a monitoring program to assess trends in water quality. LRMWW collaborated with the USGS in 1989 to conduct a water quality assessment and to institute a monitoring program. The USGS study (USGS, 1994) reported that Lake Maumelle can be considered in a state of oligo-mesotrophic transition in its open water near the intake. If nutrient inputs are maintained at current levels, the water quality of Lake Maumelle should remain relatively stable. However, increases in phosphorus load would alter water quality from its present oligo-mesotrophic condition to that of a more eutrophic condition (e.g., mesotrophic). This trophic response would be amplified by increases in nitrogen, although the lake productivity is currently phosphorus limited.

These studies confirmed the need for watershed management activities to limit the introduction of additional sources of phosphorus to the lake. On July 31, 1992, the LRMWW passed a resolution to institute a Lake Maumelle watershed protection program. The resolution authorized the utility manager to purchase Lake Maumelle watershed lands that were necessary for the proper operation and management of LRMWW. Based on this authority, a one-quarter-mile buffer was established around Lake Maumelle and any lands not owned by LRMWW were purchased or condemned (see Figure 9). This phase of the watershed protection program resulted in the purchase of 1,005.35 acres of land.

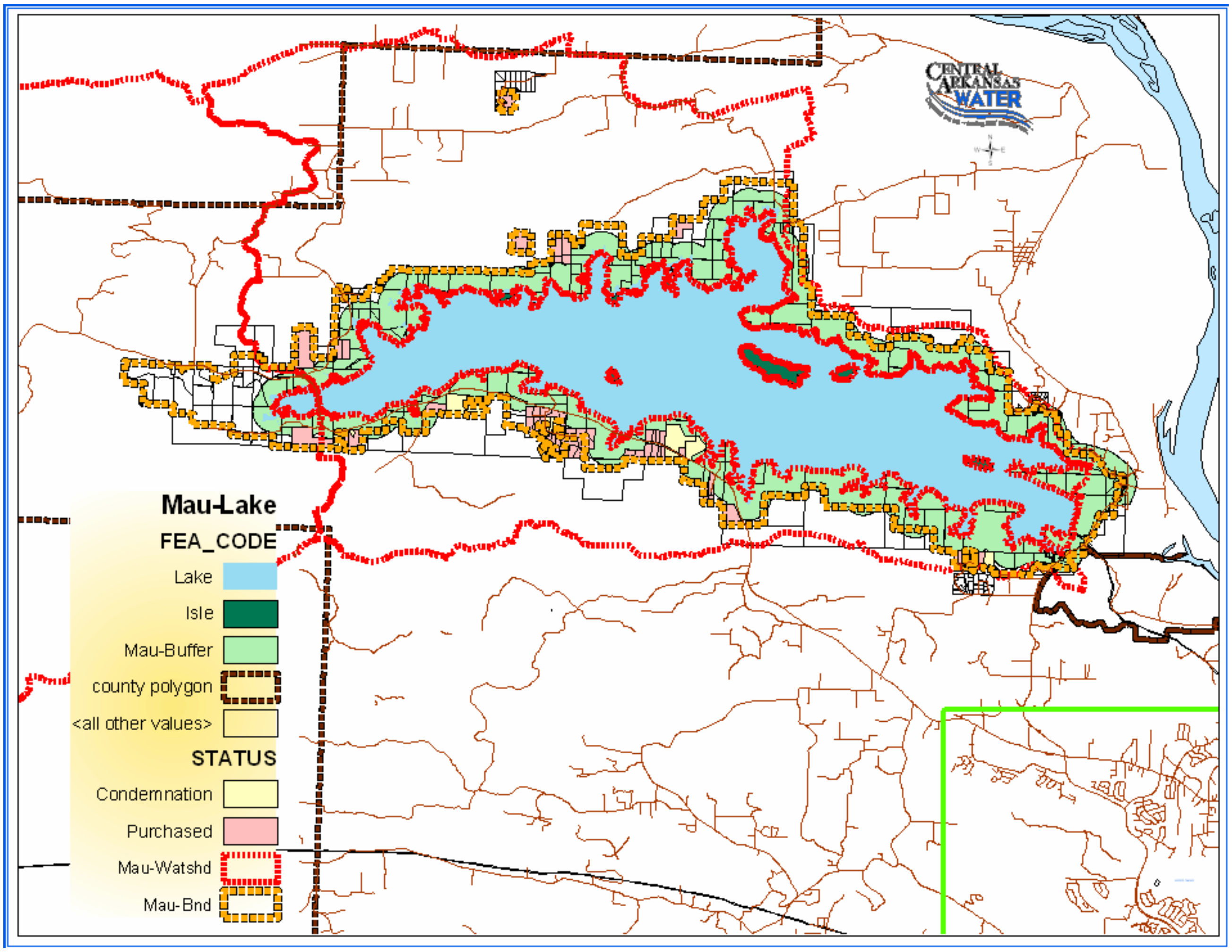

Figure 9. First Phase of the Lake Maumelle Source Water Protection Plan

A second phase of watershed protection activities was authorized by the LRMWW Commission on October 16, 1998. This resolution established watershed zones, which are depicted in Figure 10. Any undeveloped property east of the line depicted in Figure 10 was to be acquired. Critical property west of the line could also be acquired as it became available, as well as property within a 300-foot buffer around critical tributary streams to the lake.

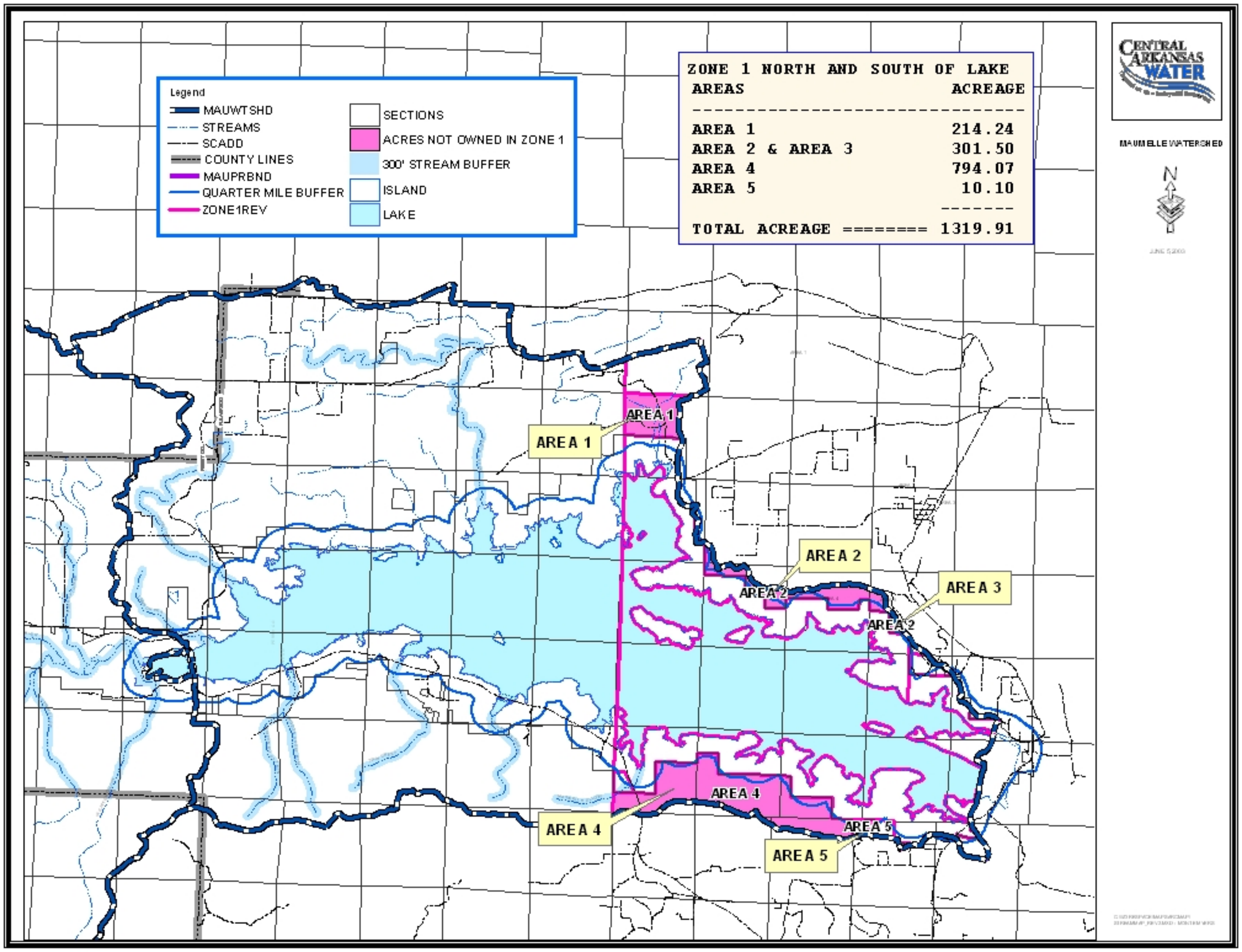

Figure 10. Second Phase of the Lake Maumelle Source Water Protection Plan

On September 4, 2003, the CAW Commission adopted a revised version of the 1998 resolution by establishing two major zones for land acquisition and various protective activities. Similar to the 1998 resolution, any undeveloped properties in Zone 1 (i.e., land surrounding the eastern portion of the lake) are to be acquired. In addition, critical property to the west of Zone 1 in the watershed of Lake Maumelle should also be acquired as it became available, including property within the 300-foot buffer around critical tributary streams to the lake.

CAW is prepared to acquire all critical lands (e.g., all lands east of the demarcation line depicted in Figure 9 and selected lands and buffers around critical tributaries). CAW is aware of a number of problems associated with existing land use in the watershed (e.g., an aquaculture pond, a golf course, turf farms, and pasture lands) and it is prepared to amend its watershed protection plan to address these concerns. CAW is also developing a comprehensive emergency response plan and the implementation of various BMPs on various existing activities (e.g., cleanup along roadways, modification or elimination of the Arkansas Fish and Game aquaculture pond, and outreach to watershed residents).

Conclusions Regarding the Lake Maumelle Watershed Protection Plan

Land acquisition in Zone 1 is a sound approach to source water protection. As demonstrated above, land acquisition has been adopted as a source water protection tool by many water suppliers across the country and is recommended as effective by AWWA and EPA. It is the only way to guarantee that incompatible land uses will not threaten water supplies.

Given the cost of buying all the land in the Lake Maumelle watershed is prohibitively high, setting land acquisition priorities in light of an affordable budget and water rate (for CAW's customers) is realistic and necessary. While land acquisition in Zone 1 is CAW's highest priority, CAW is also continuing its effort to acquire land of high priorities in Zone 2.

The history of CAW's watershed management plan demonstrates the evolving nature of its approach to source water protection. A central goal of source water protection is that, while water utilities such as CAW are legally accountable for the delivery of safe drinking water to its consumers, they should not have to provide more treatment than that which is necessary to address naturally occurring pollutant concentrations (e.g., wildlife contamination unrelated to human activities, minerals leaching from rock formations, and siltation from natural erosion). CAW has made its source water protection plan dynamic in addressing emerging issues to protect the public health of the citizens of central Arkansas (i.e., ensuring the highest quality drinking water), and at the same time, ensuring the affordability of the water service (i.e., avoiding unnecessary and costly treatments).

6.0 Conclusions and Recommendations

Based on the analysis outlined above, Cadmus has developed a number of conclusions and recommendations, detailed below, regarding (1) any development in Zone 1 of the Lake Maumelle watershed, and (2) the efficacy of CAW's source water protection plan to preserve the water quality of Lake Maumelle as a drinking water supply.

6.1 Impact of Development in Zone 1

Since the mid-1980s, CAW has demonstrated concern for and taken action to protect Lake Maumelle as a sustainable source of raw drinking water. Analyses by the USGS demonstrate that additional phosphorus loading to Lake Maumelle would increase the trophic state and organic matter in the lake and shorten its life as a drinking water source. Cadmus concludes that land development in close proximity to the lake shore and major tributaries would most likely result in additional nutrient loads that would pose a threat to Lake Maumelle's source water quality. The conversion of forest land to residential use will increase the nutrient, pathogens, sediment, and other chemical loads to the lake. Residential development can also increase the likelihood of unpredictable impairments from spills and other unintentional releases.

In particular, the conversion of privately-owned developable lands in Zone 1 to low density residential housing use will cause an increase in phosphorus load to Lake Maumelle. Under current forest conditions (i.e., with some timber harvesting), the estimated phosphorus load from Zone 1 is about 294 pound per year (with 175 pounds from the 1,320 acres of developable lands). Low density residential housing on the 1,320 acres of privately-owned developable lands will add about 920 pounds of phosphorus per year, according to the analysis presented in Section 4.7. This estimated increase in phosphorus load from the conversion of forest to residential use is conservative in that is does not take into account the poor soil conditions and steep slopes in Zone 1. Nutrient loading increases due to such a land use change in Zone 1 are expected to be significantly higher.

The pollutant removal efficiencies of BMPs are very difficult to evaluate without specific site plans and long-term implementation and maintenance plans. Even under the best site conditions, the effectiveness of BMPs is often limited. The poor soil and steep slope conditions in Zone 1 make effective use of BMPs unlikely and impracticable. In addition, the full impact on the reservoir by pathogens and other chemicals from the development in Zone 1 is difficult to quantify without specific site development plans and mathematical modeling that addresses these particular threats. Nevertheless, it is clear that the steep slopes and poor soil characteristics in Zone 1, combined with the proximity of Zone 1 to CAW's intake, increase the risk of contamination that would result from development in this area. Cadmus finds that CAW's action to prevent additional residential development in Zone 1 of the Lake Maumelle watershed is warranted.

6.2 CAW's Source Water Protection Plan

Cadmus concludes that CAW's Lake Maumelle source water protection program is reasonable but can be improved upon (e.g., by carrying out additional monitoring on the nutrient loads from the Arkansas Fish and Game Commission aquaculture pond, the Alotian Club (golf course), turf farms, and pasture lands). In addition, a comprehensive emergency response plan should be finalized and implemented. Also, an implementation and enforcement plan, along with all proper mechanisms, to ensure all BMPs on developed lands are properly operated and maintained should be developed.

The current source water protection plan, which uses a phased approach to protect the watershed via land acquisition, is a rational approach, given financial constraints and the need to protect the high water quality currently found at the eastern end of the lake. The location of the line dividing the watershed areas targeted for total acquisition (Zone 1) from those considered a less immediate priority (e.g., designated buffer areas within Zone 2) is a component of the source water protection program. As with many decisions made within a complex framework, economics, public trust, science, and politics are often involved in developing a solution. As illustrated in Section 3.2, it is very common for water systems to employ a phased approach to prioritizing land for acquisition and implementing other land use control strategies. Ultimately, the goal is to limit opportunities for pollutants to enter the source water. As examples, both Boston and New York are using decision support tools to systematically acquire lands when they become available in their watersheds.

Cadmus recommends that the land acquisition program be continued in the eastern portion of the reservoir to prevent development in Zone 1. Furthermore, Cadmus recommends that CAW continue to acquire lands as buffers along the major tributaries to the reservoir, including along the Big Maumelle River, and other critical areas with unfavorable site conditions (e.g., steep slopes and poor soils).

Finally, Cadmus recommends that CAW's planning and protection efforts should be formalized in a comprehensive watershed management plan. Using the watershed management plan, CAW can systematically conduct assessments of pollutant loads to the lake and the relationships between pollutant loads and water quality. Cadmus also recommends the development of a more detailed watershed load and lake response model based on HSPF or other well-accepted modeling software. Such a model would allow CAW to set priorities for additional land purchases and BMP implementation in areas of more favorable site conditions (e.g., lands in Zone 2 with gentle slopes and good soils, and that are set-back from the lake and tributaries).

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http://www.epa.gov/region02/water/nycshed/protprs.htm (summary of New York's watershed protection programs)

http://h2o.enr.state.nc.us/basinwide/documents/CTB_B4.pdf (North Carolina, Catawba)

http://www.mwra.state.ma.us/04water/html/watshed.htm (Massachusetts Water Resources Authority)

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http://www.pwd.org/pdf/Quality%20Report%204_21_04.pdf (A Vision of Your Source. Portland Water District 2004 Annual Water Quality Report)

http://www.rand.org/scitech/stpi/ourfuture/NaturesServices/sec1_watershed.html (summary of the New York Watershed Agreement process and its progress)

Appendix A

Abbreviations and Acronyms/Glossary

Abbreviations and Acronyms

ADOH	Arkansas Department of Health
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
BMPs	Best management practices
BOD	Biological oxygen demand
CAW	Central Arkansas Water
CMC	Carnasaw-Mountainburg Association, undulating (soil reference)
CMF	Carnasaw-Mountainburg Association, steep (soil reference)
DEQ	Department of Environmental Quality (Utah)
DBPs	Disinfection by-products
DWM	Division of Watershed Management (Massachusetts)
FEMA	Federal Emergency Management Agency
HBEF	Hubbard Brook Experimental Forest
HBES	Hubbard Brook Ecosystem Study
LID	Low Impact Development
LRMWW	Little Rock Municipal Water Works
MGD	Million gallons per day
MIL	Mountain Island Lake
MOA	Memorandum of Agreement
MWD	Metropolitan Water District (Salt Lake City)
MWRA	Massachusetts Water Resources Authority
NPS	Nonpoint Source Pollution
OWRB	Oklahoma Water Resources Board
NRCS	Natural Resources Conservation Service
SCMP	Stream Corridor Management Plan
SDWA	Safe Drinking Water Act
SPU	Seattle Public Utilities
TDS	Total dissolved solids
TN	Total Nitrogen
TP	Total Phosphorus
TPL	Trust for Public Land
TSI	Trophic State Index
UARL	University of Arkansas – Little Rock
UMBS	University of Michigan Biological Station
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WHPP	Wellhead Protection Program
WPA	Watershed Protection Act (Massachusetts)

Glossary

Algae: Small aquatic plants that occur as single cells, colonies, or filaments. They contain chlorophyll but lack specific water-carrying tissues. Through the process of photosynthesis, algae produce most of the food and oxygen in water environments.

Anoxia: A condition of no oxygen in the water. This often occurs near the bottom of fertile, stratified lakes in the summer and under ice in late winter.

Aquifer: An underground, water-bearing bed of permeable rock, sand, or gravel. Aquifers contain large amounts of groundwater that feed into wells and springs.

Bathymetric map: A map showing the bottom elevation contours and depth of a lake.

Best management practices (BMPs): A combination of nonstructural (i.e., management and/or cultural) and structural methods that prevent or reduce the movement of sediment, nutrients, pesticides and other pollutants from the land to surface or groundwater, or which otherwise protect water quality from the potential adverse effects of stormwater and nonpoint source pollution.

Biochemical oxygen demand (BOD): The measure of the amount of oxygen used by microorganisms, such as bacteria, to decompose organic waste, such as sewage, manure, and dead plant material that may be present in a water supply source. If there is a large quantity of organic waste in the water supply, there will also be a lot of bacteria present working to decompose this waste. In this case, the demand for oxygen will be high (due to the bacteria) so the BOD level will be high. When BOD levels are high, dissolved oxygen (DO) levels decrease because the oxygen that is available in the water is being consumed by the bacteria. Because less DO is available in the water, fish and other aquatic organisms may not survive.

Chlorophyll-*a*: A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae.

Dissolved organic carbon (DOC): Organic materials from plants and animals broken down and dissolved into water. DOC in marine and freshwater ecosystems is one of the Earth's largest actively cycled reservoirs of organic matter.

Epilimnion: The uppermost, warmest, well mixed layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.

Epiphytes: Small plants or animals that grow attached to larger plants.

Eutrophic: The condition of high biological activity and low transparency of water when a lake is well-nourished – associated with degraded water quality in a lake.

Eutrophication: The natural process of physical, chemical, and biological changes that cause a water body to age. This process is associated with nutrient, organic matter, and silt enrichment and sedimentation of a lake or reservoir. If the process is accelerated by human influences, it is termed cultural eutrophication.

Fecal indicator bacteria: Natural inhabitants of the gastrointestinal tracts of humans and other warm-blooded animals. Their presence in water is used to measure the sanitary quality of water for recreational, industrial, agricultural, and water supply purposes.

Fall overturn: The autumn mixing, top to bottom, of lake water caused by cooling and wind-derived energy.

Food chain: The general progression of feeding levels from primary producers, to herbivores, to predators.

Hypolimnion: The lower, cooler layer of a lake during summertime thermal stratification.

Internal nutrient cycling: The transformation of nutrients such as nitrogen or phosphorus from biological to inorganic forms through decomposition, occurring within the lake itself.

Limnology: The scientific study of the physical, chemical, geological, and biological factors that affect aquatic productivity and water quality in freshwater ecosystems – lakes, reservoirs, rivers, and streams.

Limnologist: A person who practices limnology.

Loading: The total amount of material (sediment, nutrients, oxygen-demanding materials) brought into the lake by inflowing streams, runoff, direct discharge through pipes, groundwater, the air and other sources over a specific period of time (often annually).

Mesotrophic: The condition of clear water lakes and ponds with beds of submerged aquatic plants and medium levels of nutrients. Mesotrophic lies between obliotrophic and eutrophic.

Metalimnion: The layer of water with rapid temperature and density change in a thermally stratified lake; lies between epilimnion and hypolimnion.

Nonpoint source (NPS): Pollution that cannot be traced to a specific origin or starting point, but seems to flow from many different sources. Nonpoint source pollutants are generally carried off the land by stormwater (or melting snow) runoff. The commonly used categories for nonpoint sources are agriculture, forestry, urban, mining, construction, and land disposal.

Nutrient: An element or chemical essential to life, such as carbon, oxygen, nitrogen, and phosphorus.

Oligotrophic: The condition of clear waters with little organic matter or sediment and minimum biological activity – due to very low nutrient input.

Organic matter: Molecules generated by plants and animals and containing linked carbon atoms and elements such as hydrogen, oxygen, nitrogen, and phosphorus.

Pathogens: Microorganisms capable of producing diseases. They are of great concern to human health relative to drinking water.

pH: The scale of measurement of acidity or alkalinity in aqueous (water based) solutions. A neutral solution such as pure water has a pH of 7. Solutions with a lower pH are termed acidic and solutions with a higher pH are termed alkaline.

Photosynthesis: A chemical reaction that occurs only in plants. Plants use chlorophyll to convert water and carbon dioxide into cellular material and oxygen in the presence of light.

Phytoplankton: Microscopic algae and microbes that float freely in open water of lakes and oceans.

Residence Time: Commonly called the hydraulic residence time – the amount of time required to completely replace the lake's current volume of water with an equal volume of "new" water.

Secchi depth: A measure of transparency of water or water clarity (the ability of light to penetrate water) obtained by lowering a black and white disk (Secchi disk, 20 centimeters in diameter) into water until it is no longer visible. Higher Secchi readings indicate clearer water and lower readings indicate turbid or colored water.

Sediment: Bottom material in a lake that has been deposited after the formation of a lake basin. It originates from remains of aquatic organisms, chemical precipitation of dissolved minerals, and erosion of surrounding lands.

Stratification: The process by which several horizontal water layers of different density may form in some lakes. During stratification, the bottom mass (hypolimnion) is cool, high in nutrients, low in light, low in productivity, and low in dissolved oxygen. The top mass (epilimnion) is warm, higher in dissolved oxygen, light, and production, but lower in nutrients. The sharp boundary between the two masses is called a thermocline. The metalimnion exists in this area.

Specific conductivity: A measure of a body of water's ability to conduct electricity, and therefore a measure of the water's ionic activity and content. The higher the concentration of ionic (dissolved) constituents in the water, the higher the specific conductivity. Specific conductivity is generally found to be a good measure of the concentration of total dissolved solids (TDS) and salinity.

Thermocline: A horizontal plane across a stratified lake at the depth of the most rapid vertical change in temperature and density.

Trophic state: The degree of eutrophication of a lake. Transparency, chlorophyll-a levels, phosphorus concentrations, and quantity of dissolved oxygen in the hypolimnion can be used to assess trophic state.

Trophic state Index (TSI): A number used to categorize lakes as oligo-, meso-, or eutrophic, on a scale generally from 1 to 100; the higher the number, the more eutrophic. It is calculated in a variety of ways, using chlorophyll (a measure of algae abundance), Secchi depth (an indirect measure of algae abundance by measuring water clarity), or nutrients. Lakes of TSI with a 60 or more are considered eutrophic.

Turbidity: The cloudiness of water – characterized by obscurity.

Water column: The water in the lake between the interface with the atmosphere at the surface and the interface with the sediment layer at the bottom.

Appendix B

Phosphorus Loadings from Various Development Scenarios

				Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Land Use	*Ownership (acre)*	*Percent of Watershed Land*	*Protection*	*Current Conditions*	*Percent of Watershed Load*	*Current Condition with Protected Forest in Zone 1*	*Percent of Watershed Load*	*Current Conditions with Low Density Development in Zone 1*	*Percent of Watershed Load*	*Current Conditions with Low Density Development (with BMPs*) in Zone 2*	*Percent of Watershed Load*
CAW -owned	7998	10.07%	Yes	200	1.92%	200	1.95%	200	1.77%	200	0.83%
Arkansas State Park	64	0.08%	Yes	2	0.02%	2	0.02%	2	0.01%	2	0.01%
US Forest Service Wilderness Areas	42	0.05%	Yes	1	0.01%	1	0.01%	1	0.01%	1	0.00%
US Forest Service National Forest	18245	22.97%	Partly	2416	23.25%	2416	23.57%	2416	21.36%	2416	10.04%
Low Intensity Residential	1	0.00%	No	1	0.01%	1	0.01%	1	0.01%	1	0.00%
Commercial/Industrial	42	0.05%	No	97	0.93%	97	0.94%	97	0.85%	97	0.40%
Urban/Recreational Grasses	3	0.00%	No	4	0.04%	4	0.04%	4	0.03%	4	0.02%
Pasture	1454	1.83%	No	676	6.51%	676	6.60%	676	5.98%	676	2.81%
Row Crop	50	0.06%	No	63	0.61%	63	0.62%	63	0.56%	63	0.26%
Golf Course under Grass	150	0.19%	No	134	1.29%	134	1.31%	134	1.19%	134	0.56%
Golf Course under Forest	725	0.91%	Yes	89	0.86%	89	0.87%	89	0.79%	89	0.37%
Privately Owned Land with Restrictions	379	0.48%	Partly	50	0.48%	50	0.49%	50	0.44%	50	0.21%
Other Privately Owned	50272	63.29%	No	6656	64.07%	6514	63.57%	7576	66.99%	20324	84.48%
Total Land	**79425**	**100.00%**		**10388**	**100.00%**	**10247**	**100.00%**	**11308**	**100.00%**	**24056**	**100.00%**
Open Water	8579			1750		1750		1750		1750	
Total Land & Water	**88004**			**12139**		**11997**		**13058**		**25806**	

* Best Management Practices with 50% phosphorus removal efficiency