SUMMARY REPORT: HEALTH AND MANAGEMENT OF THE EDINBORO LAKE ECOSYSTEM

Prepared for
Edinboro Regional Community Services, Inc.
by
Western Pennsylvania Conservancy
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MISSION

Western Pennsylvania Conservancy's mission is to enrich the human relationship with the natural world by saving the places we care about.

HOW WE ACHIEVE OUR MISSION

We accomplish our mission by:

- Conserving the region's places of exceptional ecological, recreational and scenic value;
- Preserving Fallingwater® as a symbol of human activity in harmony with nature;
- Engaging others in cooperative partnerships to promote the linkages of ecological protection with social and economic values of communities;
- Connecting people of all ages with the natural world through experience, education and responsible stewardship; and
- Working with communities to enhance livability and reduce pressure on undeveloped areas.

Saving the Places We Care About®

Natural Resource Stewardship • Preservation of Fallingwater • Attractive Neighborhoods
Sustainable Countrysides • Community Engagement

Dear Friend:

Since its inception in 1932, Western Pennsylvania Conservancy, working together to save the places we care about, protects natural lands, promotes healthy and attractive communities and preserves Fallingwater. WPC has protected more than 204,000 acres of natural lands in Pennsylvania. We continue to work to secure lands of ecological significance that frequently offer recreational and scenic values.

Working in identified protection areas, Western Pennsylvania Conservancy fosters the integration of ecological protection with economic and social needs while building on the core values of the community.

Through community conservation efforts, Western Pennsylvania Conservancy works to help make neighborhoods healthier and more attractive through its urban flower and vegetable garden programs and other greening projects. By helping to encourage reinvestment in communities, we can help reduce development pressures on undeveloped countrysides.

Western Pennsylvania Conservancy maintains and operates Fallingwater, Frank Lloyd Wright's masterwork, in Mill Run, which was entrusted to WPC in 1963. We are dedicated to preserving Fallingwater as a symbol of living in harmony with nature.

We trust that you will find the information contained within this publication to be accurate, timely, and an effective tool to learn about Edinboro Lake, the western Pennsylvania environment, and how you can help us save the places we care about. WPC is honored to have been selected by Edinboro Regional Community Services for involvement in this study and looks forward to future involvement in the conservation of our important lakes.

We hope you enjoy this report and, as always, please feel free to contact us with your comments.

Sincerely,

Larry J. Schweiger
President
Western Pennsylvania Conservancy

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ACKNOWLEDGEMENTS

Summary Report: Health and Management of the Edinboro Lake Ecosystem is prepared for Edinboro Regional Community Services by Western Pennsylvania Conservancy (WPC). The study is funded by a grant from Community Revitalization Assistance Program through Pennsylvania Department of Community and Economic Development, with additional funding from WPC.

Citizens of the Edinboro Lake community are concerned about the condition and future health of the lake, thus prompting this study. This concerned was addressed through the efforts of Edinboro Regional Community Services, Inc. (ERCS), the recipients of the grant which supported this project. Guiding various aspects of the project from ERCS were Dr. Alfred W. Stone, Daniel A. Austin and Richard Bain.

Literature research, source compilation and the vast majority of the report's writing of this report was done by consulting ecologist Norma L. Kline. Dr. Julie A. Wolin, consulting limnologist, Indiana University of Pennsylvania, reviewed the compiled literature and data in order to analyze the condition of the lake and provide recommendations related to lake health issues. Dr. Eric Randall, Dr. Brian Zimmerman and Dr. Henry Lawrence of Edinboro University of Pennsylvania facilitated the study by making library resources available and discussing ideas about the project; they are also initiating their own field studies related to questions about Edinboro Lake. Dr. Steven Tonsor made references available at the University of Pittsburgh's Pymatuning Laboratory of Ecology. Robert J. Wellington, Erie County Department of Health, provided several references. Mr. Raymond Hasse, Pennsylvania Department of Environmental Protection, provided water quality data related to several lake issues.

Several additional colleges and state resource agencies were queried and responded to information requests. Although they are too numerous to mention here, their assistance was valuable, and these additional institutions are noted at the beginning of the Annotated Bibliography, which was also a product of this study.

Report cover photograph by Paul G. Wiegman, Western Pennsylvania Conservancy.

Major Findings and Recommendations: Edinboro Lake

Several environmental problems and associated management recommendations comprise the core of the Western Pennsylvania Conservancy's report on Edinboro Lake.

- ✓ **Excessive Nutrients.** Too many nutrients, especially phosphorous, are entering the lake, causing eutrophication, excessive plant growth and depleted oxygen supplies.
  Recommendation: Reduce nutrient inputs to the lake by improving agricultural practices, upgrading or eliminating sewage treatment plant discharges and reestablishing wetlands. Conduct further study on nutrient issues, including other potential sources and amounts (e.g. waterfowl, septic systems). Study the collateral impacts of aquatic weed control to endangered species, etc. Study the pros and cons of sediment removal.

- ✓ **Erosion and Sedimentation**. Edinboro Lake suffers from an excessive amount of past and present sedimentation. The depth of the lake is reported to be 10 feet less than it was originally. Sediments lower water quality and aggravate the problem of excess phosphorous.
  Recommendation: Best Management Practices should be adhered to for all activities in the watershed that cause soil erosion, including agriculture and road building. Wetlands should be reestablished around the lake and new ones created in the watershed to control sediment runoff. Lake bottom sediment removal should be carefully studied before proposed.

- ✓ **Wetland and Shoreline Loss**. Lakeshore and wetland habitats have been lost, which impacts wildlife, natural diversity and water quality. Habitat degradation encourages exotic species that further impact the natural ecosystem.
  Recommendation: Reestablish previously dredged or filled wetlands, protect remaining wetlands and undeveloped shoreline areas while restoring damaged shoreline where possible. Control or eliminate aggressive invasive species.

- ✓ **Water Pollution and Toxins**. Unacceptable levels of pathogens have been recorded, and albeit partially corrected, at times are still above standards. PCBs and mercury are toxic and are present in the lake bottom and possibly in fish and other wildlife.
  Recommendation: Further investigate potential sources of pathogens, including livestock waste, high numbers of Canada geese, and malfunctioning on-lot and sewage treatment plant operations. Encourage Best Management Practices in agricultural areas. Eliminate near-lake septic and sewage plant overflow discharges into lake. Test lake sediments and fish for PCBs, mercury and other toxic compounds. Advise the public.

- ✓ **Future Stewardship**. The management of Edinboro Lake should be well orchestrated and must involve many people and agencies in order to be successful.
  Recommendation: Construct an Edinboro Lake Conservation and Management Plan, to include mapping, baseline information, summary of lake stressors, Best Management Practices to be used within the watershed, monitoring programs, and future research needs. To implement the plan, convene a lake management group consisting of interested citizens and stakeholders.

EXECUTIVE SUMMARY

Health and Management of the Edinboro Lake Ecosystem

This study of Edinboro Lake, located in Erie County, Pennsylvania, is a summary of the lake ecosystem, major stresses to that ecosystem, and recommendations for the protection and management of the lake and its watershed, as related to the stresses revealed.

Western Pennsylvania Conservancy completed the study for the Edinboro Regional Community Services, Inc. A Pennsylvania Department of Community and Economic Development grant from the Community Revitalization Assistance Program provided funding. The grant was provided because citizens of the Edinboro Lake community are concerned about the condition and future health of the lake. As reported herein, the environmental condition of the lake is somewhat degraded. This study reports on the factors resulting in this condition and makes recommendations to remedy the present situation.

Background

All natural environments have natural stresses that affect the quality of the environment and the organisms within. Due to various adaptations, most freshwater organisms are well able to cope with the natural stresses that their environment places upon them. Imposed stresses, such as human land and water use, or environmental manipulation, are activities that are either damaging or have the potential to damage the aquatic system.

Characteristics of Lake Ecosystems

In order to effectively understand the potential damage of stresses, it's important to understand the characteristics of a lake's ecosystem. All lakes have well-defined physical boundaries and are semi-closed systems, meaning the water stays within a lake's boundaries long enough to develop distinctive biological and chemical characteristics. Lakes also have annual or seasonal variations in water levels, based mainly on changes in precipitation and runoff. They also receive inputs of ground and surface water, solar energy and chemical substances from the lake's drainage basin. This is important because when nutrients or other pollutants enter still waters, they tend to be retained within the system for long periods of time.

It is important to note that a pollutant in a natural lake, which is a relatively static water system, may persist for considerable periods after the pollution stops. This happens because the exit pathways tend to be much more restricted and certain pollutants also become trapped in bottom sediments.

Generally, in deep lakes in temperate zones, water divides into upper and lower layers. The upper layer is well lit and oxygenated, and sufficiently high temperatures promote algal productivity to support zooplankton and fish. By contrast, the lower layer is cold, dark and becomes progressively de-oxygenated as the decaying remains of organisms descend. Lakes of significant depth, such as Edinboro Lake, experience two seasonal periods of free circulation, when the layers actually switch, or mix. This is known as lake turn-over. At these times, upper and lower water layers circulate, making nutrients more widely available.

Overview of the Edinboro Lake Ecosystem

Edinboro Lake is a calcareous glacial lake; such lakes are critically imperiled in Pennsylvania due to their unique characteristics and rarity. Such lakes are of natural origin and only eight exist in northwestern Pa. These lakes are termed "calcareous" due to the presence of calcium and other minerals that groundwater carries to the lake from surrounding soils. This results in water chemistry that includes high pH. The drainage basin is in northwestern Pennsylvania, about 15 miles south of Erie. The climate is characterized by more moderate temperatures and higher annual precipitation levels than is normal for this latitude due to the moderating effects of Lake Erie.

The lake has four main tributaries: Conneauttee Creek, Shenango Creek, Whipple Creek (local name), and Lakeside Run (local name). The drainage basin of the lake is 16.2 square miles in size. All of the soils in the watershed have low permeability close to the surface. Poor soil conditions and high water tables impose limits on the suitability for standard, on-lot septic systems as functional wastewater treatment in this basin.

Biologically Significant Resources

The Edinboro Lake drainage basin harbors both rare natural communities and species of concern in Pennsylvania. The rare natural communities are Edinboro Lake, a calcareous glacial lake, and unusual types of wetlands adjacent to the lake. In particular, one of the wetlands is locally known as Edinboro Lake Fen and is of particular interest because it is habitat for special concern species, and in itself is an unusual type of wetland. The lake provides habitat for six plant species of special concern. All but one of the species is classified as endangered, threatened, or rare in Pennsylvania. Twenty-three plant species of special concern are known to occur in the watershed; 11 of the plants are listed as endangered species in Pennsylvania, eight of the plant species are listed as threatened, and four are protected as rare plant species. Most of these plants are wetland species residing in the fen.

Land Use

Human communities affect the lake and the land around it by four generic categories of inputs to the lake: agricultural runoff and wastewaters, non-agricultural/non-urban runoff, urban runoff, and municipal/domestic wastewaters. In 1994, land use in Washington Township was catalogued as 53% agriculture, 37% open space, 5% residential, 2% roads, less than 1% industrial, less than 1% recreation, and less than 1% game lands. Most of the lake's shoreline has been developed, with only the northeastern shoreline remaining free of development.

Overview of Ecosystem Health, Stressors and Sources of Stressors

The chemical, physical and biological nature of Edinboro Lake and its drainage basin requires addressing the stressors and sources of stressors that threaten the ecosystem.

Stresses imposed on natural ecosystems by human activities or environmental manipulation affect the chemical, biological and physical components of lake ecosystems. Key chemical stressors are toxic contamination and excess nutrients. Key biological stressors consist of excess competition, pathogens, exotic species, genetic loss, and population disruption of native species. Key physical stressors involve land use and are identified as sedimentation, habitat access loss, habitat degradation or loss, and hydrological modification.

Sources of key chemical, biological and physical stressors to lake ecosystems are:

- filling of wetlands and lake, or shore modification
- dams or dikes
- dredging and draining
- navigation
- exotic species introduction
- excess harvest or stocking
- development, erosion, and runoff (sediments and pollutants)
- air, emission or deposition
- point source discharges (pipe effluent)
- contaminated sediment

Chemical Environment Stressor – Excess Nutrients

Eutrophication

Lakes with ample nutrients supporting rich algal blooms and profuse growths of aquatic plants are termed eutrophic, or "well-fed." Key nutrients responsible for eutrophication are nitrogen and phosphorus, which have natural origins within a drainage basin and within lake ecosystems. But, in addition to natural origins, nitrogen and phosphorus can be delivered to surface waters at an elevated rate as a result of human activities. Excess nutrient input from human activities is commonly referred to as "cultural eutrophication". Cultural eutrophication ultimately results in loss of water clarity, loss of oxygen in bottom waters, excessive plant and algal growth and a shift in the food web from valuable game fish to less desirable species. Prior to human inputs, phosphorous supplied to lakes in northwestern Pennsylvania was relatively low and this nutrient was a limiting factor for plant growth.

Edinboro Lake is in the advanced state of eutrophication. Researchers estimate that approximately 80% of the phosphorus and 95% of the nitrogen that reaches the lake is from non-point sources such as surface runoff. Other significant sources for phosphorous are sewage treatment plant discharges. Control measures are available, including the use of Best Management Practices on agricultural lands, wetland creation and restoration, and the use of tertiary sewage treatment systems, or diverting treatment plant discharges away from the lake.

Overall, the water quality of Edinboro Lake is poor-fair. A U.S. Environmental Protection Agency survey report indicates that any further increase in nutrient loading should be avoided. The report reveals that strong thermal stratification is occurring in the lake. Temperatures were found to range from 81 degrees Fahrenheit at the surface to 54 degrees in bottom waters. Dissolved oxygen levels also showed a strong variation from surface to bottom -- an indication of eutrophication -- although the levels were in compliance with the present Pennsylvania water quality criteria.

Nutrient (total phosphorus and nitrogen) inputs remain high and indicative of eutrophic to hyper-eutrophic conditions. These high nutrient loadings accelerate algal growth, contribute to lower water quality, and continue to accelerate the eutrophication process of Edinboro Lake.

Evidence identifies six confirmed or suspected sources of nutrients to Edinboro Lake are:

Primary Sources

- inflow from Shenango, Conneauttee and other creeks carrying nutrients from land use practices

- septic systems near lake and sewage treatment plant discharges

- internal release of phosphorus from sediments

Secondary Sources

- resident waterfowl populations (investigation needed)

- the damaged wetland (marsh) at the northern end of the lake

- climate effects on lake nutrients

In addition to categorization as Primary or Secondary Sources, nutrient sources are also considered to be point or non-point in their origin. Point sources originate from specific identifiable locations, e.g. discharge pipe, while non-point sources are those that originate over a wide area and often from generalized locations, e.g. cropland. The point and non-point nutrient sources for Edinboro Lake are summarized below.

Non-Point Sources

Phosphorus loading has likely declined since the lakeside community was connected to the sewage treatment plant in the 1970s. Still, half of the lake shoreline was not served by the sewage treatment facility.

Minimal nutrients are contributed by streambank and roadside erosion, while approximately 1.6 tons of phosphorus from manure spread on farm fields in the lake watershed during winter is delivered to the lake during spring thaw. In fact, animal manure and erosion are the source of 60 % of the total phosphorus and bacteria to the lake.

Non-point source runoff delivers 95 % of the total nitrogen and 80 % of the total phosphorus entering the lake.

Golf courses in the drainage basin and dredging activities in the lake's wetland are possible sources of nutrients.

Annual atmospheric deposition of nitrogen in the French Creek drainage basin, which includes Edinboro Lake and its watershed, has been estimated as 36 %.

Agriculture

There are up to eight farms in the drainage basin at the time of this report. Without implementing agricultural best management practices in the Shenango and Conneauttee creek watersheds, agriculture will probably remain the primary source of sediment and nutrients. Up-to-date water quality information would be useful.

Urban and Development

Nutrient input to the lake comes from sources such as fertilizer from golf courses, lawns and farms, as well as sediment from eroding construction sites, roads and agriculture. Housing in the watershed is increasing the amount of hard surface in the drainage basin, which increases the rate of stormwater runoff. Wastewater from auto repair garages, laundromats and car washes is treated by the borough wastewater treatment plant, which appears to eliminate a source of urban non-point source pollution to the lake.

Internal Loading of Nutrients

Release of phosphorus from the lake sediments is a likely major source of nutrient loading. The dredged lagoon wetland area located at the north end of the lake is probably releasing nutrients into Edinboro Lake.

Point Sources

In 1980, phosphorus and nitrogen loading to the lake was calculated. Point sources were shown to contribute 20 % of the phosphorus loading and 3 % of the nitrogen to the lake from tributary streams. The discharges were attributed to the Washington Township Sewage Treatment Plant, General McLane School Treatment Plant, Boron Oil Company and Humble Oil Refining Company.

During the 1990s, Washington Township and General McLane High School treatment plants were the known permitted point source discharges.

Hydraulic overloading at the Washington Township plant because of rain events, results in exceeding the permitted flow of 0.2 million gallons per day. Material entering the lake is not completely treated and contributes nutrients and organic matter to the system. It is expected to be under control within two years.

It is unclear if the Washington Township and General McLane High School treatment plants are in compliance. Either tertiary treatment or connecting the township plant to the Borough plant would help reduce phosphorus input.

In general, up-to-date information about the loading of nutrients into the Edinboro Lake ecosystem is an area of major information needs. It is believed that no additional information is needed to know that the system is overloaded, especially with phosphorous, and enough information is available to take corrective action. However, for the long-term informed management of the lake, more recent information should be acquired.

Chemical Environment Stressor – Toxic Contaminants

Polychlorinated biphenyls (PCBs) were detected at 22.0 micrograms per kilogram during a 1980 sediment analysis of pesticides in Edinboro Lake. PCBs are among the most aggressive mutagenic compounds known and can be responsible for certain malformations in offspring when present at higher levels. PCBs also accumulate in foodchains and are very persistent in the environment. The levels of PCBs in Edinboro Lake fish and wildlife are unknown.

Mercury, a naturally occurring element as well as one present as an atmospheric pollutant, is a concern in all inland lakes, because in muddy anoxic conditions this metal enters the food chains and accumulates in tissue. Mercury is a very toxic heavy metal and can impact the health of humans and wildlife. Mercury has been found to cause neurological problems and at high levels even death. The amount of mercury in Edinboro Lake sediments and wildlife should be determined in order to educate the public and lake managers. One management option is for government agencies to publish fish consumption advisory notices to warn the public if levels are high in fish inhabiting certain water bodies. Although this is an option, it is not known whether such a step is necessary at Edinboro Lake until the fish are tested for mercury levels.

Physical Environment Stressor – Sedimentation

Soil dredged to create channels at the northern end of the lake, subsequently washed into the lake, where it filled wetlands and added sediments to the lake bottom. In recent years, siltation entered Edinboro Lake from development activities in the watershed, such as construction of Interstate 79, golf courses, schools and year-round residences. Non-point source runoff is water that originates from many locations. For example, runoff from agricultural activities that surround the lake contain sediments that are carried into the lake by rain and snow-melt. Based on current and past bottom contour maps of the lake, there may be up to 10 feet of additional recently deposited sediment on the bottom.

It must be pointed out that the sediments entering the lake are associated with another stress factor: phosphorous loading. Phosphorous is often a limiting nutrient for plant life in lakes, however Edinboro Lake has excessive amounts. Phosphorous has an affinity for sediment particles and binds to them in the lake, or as both are transported to the lake by surface waters flowing over the surrounding landscape. The sediments on the bottom of the lake are thereby loaded with excess phosphorous that can be later released to the waters creating accelerated plant growth.

Physical Environment Stressor – Habitat Degradation, Including Loss And Exotic Species

Nearshore Development

In the 1930s and 1940s, the western shore of the lake was developed as a summer community. By 1980, approximately 600 nearshore homes existed. By the late 1990s, most of the lake's shoreline has been developed; only the northeastern shoreline remains free of development.

Habitat Degradation – Littoral Zone Modification

In the 1940s, numerous channels were developed in the headwaters of the lake to provide boating access to lakeside residences. Between 1955 and 1960, channels were created in the marshy area in the northeast section of the lake, converting the continuous marsh into a group of island marshes and peninsulas. A portion of the marsh at the north end was filled for subdivision development. To eliminate aquatic vascular plant and algae growth, strategies including herbicide treatments, mechanical weed harvesting and winter drawdown of the lake water level were implemented.

Habitat Degradation – Exotic Species

Common carp (*Cyprinus carpio*) have been reported from Edinboro Lake since 1938. Excessive carp populations result in a loss of submerged aquatic vegetation because this fish uproots plants. The damage to these habitats then potentially threatens other lake biota, including juvenile fish seeking cover. Invasive exotic plant species in the lake, the adjacent marsh or along the shoreline include purple loosestrife and Eurasian water-milfoil.

It must be noted that in the future there is real potential for the introduction of additional exotic species. The modes and control measures for such introductions among the pest species.

Physical Environment Stressor – Hydrologic Modification

Around 1800, a dam built for a gristmill flooded the valley and lake, covering a bog or fen which may have existed. It also drowned wetlands, trees and other vegetation. Since then, Edinboro Lake was enlarged each time a new and higher dam was built. By 1950, the lake may have become relatively stabilized, following construction of the current dam, built in 1922.

As a result of the dam, new or expanded wetlands developed in some areas, with shrubs, emergent and floating herbaceous plants. The marsh was believed to have substantially reduced the potential for algal blooms in much of the lake.

Periodic winter drawdowns of lake waters have been implemented to control aquatic vegetation in the lake.

Biological Environment Stressor – Pathogens

In the early 1970s, septic systems associated with lakeside area residences were recognized as being responsible for the input of coliform to the lake. Installation of sewers in the lakeside area in 1973 resolved the situation. However, runoff from improper handling of animal wastes in the watershed remained a source of coliform input. Other sources, including incomplete sterilization of sewage treatment plant effluent (related to hydraulic overloading) and feces from the growing Canada goose population are still suspect. Fecal coliform and fecal streptococci bacteria levels exceeded state water quality criteria in 1981. From that time to the present, apparently this problem has continued sporadically. The outdated Washington Township sewage treatment plant has been relied upon to handle an increasing load as the number of clients has increased. Most recently, heavy rains have resulted in excess inflows to the plant, and plant capacity for proper treatment of effluent has been exceeded. In order for chlorine sterilization treatment to effectively kill pathogens, the necessary Contact Time at the appropriate chlorine concentration must be allowed. However, this is not possible when a treatment facility experiences hydraulic overloading and is functioning essentially as a pass through system.

Recommendations Related to the Health and Management of the Edinboro Lake Ecosystem

Introduction to Recommendations: A Strategy for Edinboro Lake

In order to bring about and maintain improved conditions at Edinboro Lake, a set of recommendations are provided that address problems identified within the lake ecosystem. If these recommendations are to be successfully implemented, a strategy is needed that should involve the development of a plan and a community group that will guide the process.

I. An Edinboro Lake Conservation Plan should be constructed based on scientific insight and it should be widely disseminated within the watershed of the lake. The plan should include:

- Creating a map of the boundary of the Edinboro Lake watershed. This should be superimposed upon base maps (topographic, highway, land use, zoning, etc.) used by municipal and resources managers. Watershed boundary mapping will assist in understanding lake issues in a variety of decision making-processes. The boundaries along with other information should be interrelated through the creation of a Geographic Information System for the lake and its watershed.

- Create a summary of the characteristics, stressors or threats to Edinboro Lake, including much of the information in this report. Nutrient and water budgets should be included in addition to determination of the key ecological processes of the lake ecosystem, and a comprehensive assessment of biological diversity significance associated with the lake and drainage basin.

- A list and description of Best Management Practices related to a variety of land use activities that potentially result in the creation of stressors to the lake ecosystem. The practices would function as guidelines that are referred to in making decisions about sedimentation control, storm water management, wastewater management, agricultural practices, restoration, mitigation and various development activities.

- Restoration of certain aspects of the lake ecosystem and watershed should be a focus of lake management. Included is the restoration of wetlands at the northern end of the lake so these might once again function as sediment and nutrient traps. The creation of additional wetlands relative to this same function should be considered within the watershed where sources of sediment, nutrients (phosphorous, etc.) and toxic compounds could be intercepted.

- Implement lake, wetland and watershed monitoring practices. A program should be developed to monitor the stressors and quality parameters of the lake. This should be an informed program that is aware of potential problems with lake health and how to identify symptoms.

- Form a group of interested citizens, municipal managers, academics, and other stakeholders to function as an implementation body for the conservation/management plan. Involve the Edinboro Lake Preservation and Restoration Foundation in this effort.

II. It is also recommended that the following studies be done in order to obtain a more complete understanding of the ecosystem and in order to develop the recommended conservation plan. It is recommended that lake managers engage Edinboro University and other appropriate colleges to provide the necessary scientific inquiry.

- A comprehensive study that includes a comprehensive water budget, a complete study of stratification and mixing, a trophic study, preparation of a bathymetric map, determination of sedimentation rates, and an assessment of the lake's biotic community. This study should include an evaluation of the fish community and identification of fish indicator species for management and monitoring purposes.

- An evaluation of the tributaries to Edinboro Lake, especially Shenango and Conneauttee creeks and the lake's outlet, using the current U.S. Environmental Protection Agency Rapid Bioassessment protocols.

- A monitoring of water quality for Edinboro Lake that includes chemical and biological parameters.

The following is a series of recommendations that if adopted will improve the environmental quality of Edinboro Lake, or, will address information gaps and the ultimate development of additional recommendations for action.

Recommendations Regarding Excess Nutrients As Stressors Resulting in Eutrophication

- Develop phosphorus and nitrogen nutrient budgets for the lake that details each nutrient source. A detailed nutrient budget is recommended rather than determination of phosphorus and nitrogen Total Daily Maximum Loads, as the latter has more to do with state regulations and water quality standards than long term ecosystem integrity and health. A detailed nutrient budget should include:

    - the entire drainage basin to determine point and non-point sources of phosphorus and nitrogen inputs to the lake including but not limited to sewage treatment systems, septic systems, agricultural fields, golf courses, atmospheric input, streams entering the lake, lagoons at the north end of the lake, and internal loading

    - systematic in-stream and in-lake sampling

    - phosphorous levels in bottom sediments and the release rate

    - mean total phosphorus for the lake

- phosphorus inputs from specific point sources and specific non-point sources
- the extent of internal loading
- input from waterfowl
- phosphorus and nitrogen outputs from the lake

- Connect the Washington Township Sewage Treatment Plant to Edinboro Borough's facility, so the effluent from the township plant will not be discharged into the lake. This is being considered by the Erie County Department of Health and Pennsylvania Department of Environmental Protection. If this linkage can not be made, the Washington Township plant should be upgraded to tertiary treatment in order to reduce the phosphorous content (and other pollutants) of the effluent. However, it must be noted that if the present effluent is simply diverted to the borough's facility, the excessive phosphorous will be thereby discharged into Conneauttee Creek and flow to French Creek. This plan is really only successful if the borough plant has the capacity to supply comprehensive tertiary treatment for the combined total township/borough load.

- The prior recommendation is the first order of attention. Continuation of existing inputs of phosphorous to the lake should be significantly reduced. Consider extensive sediment removal, should internal loading (from existing phosphorous in bottom sediments) prove to be a major contributor to the Edinboro Lake system. Extensive dredging of sediment is a possible method of addressing phosphorus loading, but cultural inputs of phosphorus must be cut-off for this method to work. Should extensive dredging be pursued, sediment sampling should be conducted prior to dredging in order to determine sediment characteristics, e.g. heavy metals, etc. Again, the dredging alternative is recommended only if severely limiting input sources does not first eliminate excessive eutrophication.

- Work with interested farmers, golf course owners, etc., within the lake watershed to install Best Management Practices that will reduce the amount of nutrients and sediments flowing to the lake.

- Wetlands should be used to improve the quality of Edinboro Lake. Restore wetlands at the northern end of the lake and at other locations where nutrients entering the lake from upland sources would be intercepted before entering the lake. Restore or create wetlands further upstream at specific locations, e.g. below barnyards, where nutrient laden surface water can be intercepted and biologically treated before it reaches the lake. Note, the recommendation above is the most important as it relates to prevention.

Recommendations Regarding Cultural Eutrophication

Undertake a study of the existing cultural eutrophication to determine when it started, and to provide greater insight and baseline information for assessing management endeavors and for management monitoring purposes. Engage state universities to study the history of Edinboro Lake cultural eutrophication, potentially using paleolimnological (fossil diatoms) methods. Conduct a related study of bottom sediments and a timeline of sedimentation rates.

Recommendations Regarding Toxic Contaminants As Stressors

- Sample lake sediments for PCBs, mercury and other toxic contaminants to determine at what levels these toxic contaminants are present.

- Investigate the sources and control measures for the most important contaminants.

- Sample fish tissue for PCBs, mercury and other toxic contaminants to determine at what levels these toxic contaminants are present.

Recommendations Regarding Sedimentation Stressors

- Work with interested farmers, managers of earth disturbance projects, etc., within the lake watershed to install best management practices that will reduce the amount of sediments flowing to the lake.

- Wetlands should be used to improve the quality of Edinboro Lake. Restore wetlands at the northern end of the lake and at other locations where sediments entering the lake from upland sources would be intercepted before entering the lake. Restore or create wetlands or other sediment trap basins further upstream at specific locations, e.g. below row cropland, where sediment laden surface water can be intercepted before it reaches the lake. Note, the first recommendation related to prevention is the most important.

- Prepare a current bathymetric map for Edinboro Lake.

- Conduct a sediment core analysis, in part to determine the past and present sedimentation rate for Edinboro Lake.

- Determine the original basin depth and conduct sediment analysis to aid in pinpointing when cultural eutrophication began.

Recommendations Regarding Habitat Degradation Stressors

- Target the last remaining undeveloped shoreline and near-shore areas for protection as parks or natural areas by municipal governments or conservation organizations.

- Consider the effects of methods to control aquatic vegetation on shoreline and aquatic habitats. Do not use weed harvesters, since this method does not distinguish between exotic and beneficial plants (including endangered species), and spreads nuisance species such as Eurasian water-milfoil. Do not use grass carp to control aquatic plants, because of the damage they do to beneficial plants and aquatic habitats, and because they are prohibited under Pennsylvania law. Consider hand-pulling plants or limited dumping of sand in beach areas to reduce plant growth.

- Undertake a comprehensive program to identify and control invasive exotic species in the lake, and to prevent additional introductions of such species.

Recommendations Regarding Hydrologic Modification Stressors

- The lake level and the implications of the present dam require more study. Consideration should be given to permanently lowering the lake level to control aquatic vegetation to in order reduce phosphorus input. This would reduce the extent of the lake's littoral zone and re-establish a naturally vegetated buffer zone that could also reduce non-point source runoff into the lake.

Recommendations Regarding Pathogens As Stressors

- Investigate any suspected malfunctioning on-lot sewage treatment systems and take appropriate corrective measures.

- Identify dairy farms and/or other agricultural livestock in the drainage basin to determine whether individual farms could still be sources of pathogens. Encourage farmers to implement best management practices.

- Address the problem of hydraulic overloading and subsequent overflow of the Washington Township sewage treatment plant as a potential source of pathogens. Correct the present situation whereby combined inflow sources exceed the plant's capacity and do not allow adherence to proper sterilization procedures. Ultimately, the sewage treatment plant discharge to Edinboro Lake should either cease, or a major upgrade of the plant and entire sewage system should be undertaken in order to bring the total operations into compliance.

- Assess the growing Canada goose population as a source, and if it is, propose a remedy.

Recommendations Regarding Information Gaps and Additional Research

- Initiate research projects in order to fill information gaps about the lake ecosystem, including:

  - water quality monitoring focused on chemical and biological parameters, including plankton

  - ecological issues of water budget, lake stratification, trophic analysis (nutrients), bathymetric mapping, sedimentation rates, biotic community and appropriate monitoring targets (fish, etc.) relative to lake health

  - implications of present dam and its removal on water quality, etc.

- Determine the original natural levels of nutrients in the lake and when cultural pollution initially elevated eutrophication in order to better understand the present eutrophication problems. Consider diatom and sediment studies to acquire these data.

This concludes the Executive Summary portion of the <u>Summary Report: Health and Management of the Edinboro Lake Ecosystem.</u>

SUMMARY REPORT: HEALTH AND MANAGEMENT OF THE EDINBORO LAKE ECOSYSTEM

Intent of the Summary Report

The intent of this report is to provide a summary of perceived stressors to the Edinboro Lake ecosystem and to provide initial recommendations regarding such stress as related to the health of the lake ecosystem. The summary and recommendations are based upon the information and data compiled during the preparation of the "Edinboro Lake Study Project Annotated Bibliography with Appendices." As appropriate, information provided by the project's consulting limnologist has been incorporated into the potential stressors summary.

While stressors to natural ecosystems are addressed in detail later in the summary report, as a way of introduction to the topic it is worth briefly noting the difference between natural and imposed stresses. All natural environments have natural stresses that affect the organisms within them. Due to various adaptations, "…most freshwater organisms are well able to cope with the natural stresses which their environment places on them" (Hellawell, 1986). Stresses are also imposed on ecosystems. Human activities and environmental manipulation can be the source of stressors which are similar to the natural kind, although not in degree, or represent stressors of a type that may be completely alien to the normal environment (Hellawell, 1986). Imposed stressors are activities that are either damaging or have the potential to damage the aquatic system (McAlpine, 1993). Imposed stresses are the focus of this summary report.

This summary of potential stressors is intended to provide insight into the Edinboro Lake ecosystem. The summary can also function as the first step of a formal stress analysis. A stress analysis consists of the identification, evaluation and ranking of stresses and sources of stresses to populations, species, ecological communities or ecosystems. When stresses and sources of stresses have been identified, evaluated and ranked, conservation strategies for a natural ecosystem can be identified to eliminate or minimize stresses. A formal stress analysis would determine if the potential stresses to Edinboro Lake are significant threats to the ecosystem as well as pinpoint the sources of those stresses.

Note that except to identify potential stresses to the Edinboro Lake ecosystem, the information and data cited from the annotated bibliography and contained in this report represents the views and findings of the respective authors. In other words, the information/data was accepted as presented by its authors. Re-analysis of any studies or data is outside the scope of this project.

Characteristics of Lake Ecosystems

All lakes have well-defined physical boundaries and are semi-closed systems in the sense that water stays within a lake's boundaries long enough to develop distinctive biological and chemical characteristics compared to the water that flows into it (National Research Council, 1996). Lakes also have annual or seasonal variations in water levels based mainly on changes in precipitation and runoff (Fuller, Shear and Wittig, 1995). Lakes receive inputs of water, solar energy and chemical substances from outside the system, primarily from the lake's drainage basin.

"Lakes…are…virtually closed systems although they do have inflows and outflows and a notional renewal time of many weeks, month or even years…When nutrients or other pollutants enter still waters they tend to be retained within the system, although their biological significance varies with the nutrient or pollutants." Lakes have a "…tendency for materials to accumulate within static waters, eventually reaching a threshold after which marked and perhaps irreversible changes occur…Lakes…thus have a 'history' or sequence of development…" (Hellawell, 1986).

"…[A] pollutant…in static water…may persist for considerable periods after the pollution stops, since the exit pathways tend to be much more restricted. Reduced intensity of algal blooms in static waters may not be concomitant with lowered nutrient inputs although…it could help avoid future exacerbation of the problems. This apparent hysteresis is attributable to the former input of nutrients which have accumulated in the benthic sediments and which continue to be available through diffusion and circulation through the lake. The movement of nutrients between various components of the lake ecosystem, i.e. the water column, sediments and biota, is complex, being influenced by such factors as the dimensions and physical properties of the lake, including its propensity to stratify,…its overall productivity and the chemical characteristics of the chemicals involved" (Hellawell, 1986).

"Primary productivity is intrinsic (autochthonous) within lakes and secondary production depends on the availability of an algal phytoplankton or, in shallow lakes, the contribution from benthic or marginal macrophytes…Mineral input into lakes tends to stimulate primary productivity, with other production increasing consequentially… Nutrient induced enhancement of primary productivity in static water bodies has become such a well known phenomenon that it has passed into everyday environmental terminology as 'eutrophication'…" (Hellawell, 1986).

One way to classify lakes is according to stratification patterns. Stratification, the development of temperature layers in lakes, determines physical and chemical aspects of water quality. Generally, in deep lakes in temperate zones "…during the warmer, summer, months the upper part of temperate lakes is heated by solar radiation…" (Hellawell, 1986). "The upper warm region, mixed thoroughly by wind to a more or less uniform temperature, is the epilimnion. At the bottom lies a colder region of heavier water little affected by wind action and, therefore, traditionally considered stagnant. Separating the lake temperature regions is an intermediate zone where the temperature drops rapidly with depth…" (Cole, 1983). The colder, lower layer is the hypolimnion, and the zone temperature change is the thermocline. "…The warmer surface water is less dense than the general mass of water beneath and the greater the difference in density the more stable will be stratification since it will not be easily displaced by wind action across the lake surface…” (Hellawell, 1986).

The division of a lake into upper and lower layers affects the biology of the lake. “…The epilimnion is well lit and oxygenated with sufficiently high temperatures to promote algal productivity and hence to support zooplankton and fish. When nutrients are in ample supply, algal growth is accelerated and excessive blooms may occur. By contrast, the hypolimnion is cold, dark and becomes progressively de-oxygenated as the decaying remains of organisms rain down from the epilimnion. Conditions may become so extreme that anoxia ensues whereupon biological productivity becomes minimal. Under less extreme circumstances, the epilimnetic material provides an energy source for benthic invertebrates. Anoxic sediments may promote the release of certain elements, especially iron and manganese… The sinking of dead algae and zooplankton through the thermocline not only contributes to the potential de-oxygenation of the hypolimnion but also prevents immediate recycling of nutrients…” (Hellawell, 1986).

The type of lake stratification measured at Edinboro Lake is labeled dimictic (Hartman, n.d.). This term applies to a lake in which two seasonal periods of free circulation. In summer, thermal stratification occurs as surface waters are warmed and cease to mix with the denser, colder, deep waters. In winter, when they cool to below 4 degrees C, surface waters expand, so becoming less dense than the warmer waters beneath them, giving a reverse stratification. Free circulation through the depth of the lake is possible only in spring and fall. In spring, free circulation, or mixing occurs when the surface temperature rises to 4 degrees Celsius and the water becomes heavier than that beneath and so sinks and mixes. In autumn, mixing takes place when the surface waters cool to below the temperature of the deep waters (Allaby, 1994). At these times, the water strata circulate, recycling nutrients, and in the fall, possibly returning oxygen to the hypolimnion. In both seasons, the water temperature in the lake is more uniform after waters mix during spring and fall overturn. Unless ice forms for a considerable period of time winter winds keep the lake mixed. In autumn, lower temperatures and reduced light intensity ensure that algal blooms are less pronounced, although there are more nutrients available in the epilimnion than in the spring. During spring “…light and temperature increase, plant nutrients are high (both from redistribution by mixing and from external sources, primarily surface run-off via the lake feeder streams) and these factors contribute to a peak of biological activity as a prelude to summer stratification when the cycle…is repeated” (Hellawell, 1986).

Overview of the Edinboro Lake Ecosystem

A review of the lake ecosystem and human influences on the system is necessary to understand Edinboro Lake's current state.

Edinboro Lake Ecosystem – The Watershed

Watersheds are ecosystems composed of myriad terrestrial areas drained by a network of streams of a single, larger drainage. A large proportion of the materials and energy that flow through stream systems is derived from the surrounding terrestrial system. As addressed earlier, lakes are, more or less, closed ecosystems. Yet, lakes are certainly influenced by the materials that enter them via streams. As a consequence, aquatic systems such as rivers and lakes must be understood in a watershed context for aquatic system management to be productive, effective, and beneficial.

Location and Environment

The drainage basin is in northwestern Pennsylvania about 15 miles south of the City of Erie. The climate is characterized by more moderate temperatures and higher annual precipitation levels than is normal for this latitude, due to the moderating effects of Lake Erie (U.S. Environmental Protection Agency, 1981).

Geology and Soils

The Pennsylvania Department of Environmental Resources (1981) summarized the basin's characteristics as 16.2 sq. mi. (41.9 sq. km) in size with a Devonian Age red, grey, and brown shale and sandstone surface bedrock geology. Between 6,000 and 7,500 feet of bedrock formations underlie the drainage basin. Bedrock formations are comprised of limestone, dolomites, shales, salt beds, and some sandstones. The surficial geology of the drainage basin has been significantly affected by glaciation. Tills of several different glacial advances are found in the area. The variety of glacial deposits has resulted in very different soils found adjacent to each other. The position of the different glacial deposits has produced high water tables in the Shenango and Conneauttee Creek valleys and at the northern end of the lake. Alluvial deposits in the floodplains of these creeks also exhibit high water tables (U.S. Environmental Protection Agency, 1981).

"The watershed is characterized by a gently rolling terrain with a maximum elevation of about 1,500 feet…The maximum relief above the lake's surface is about 300 feet…Slope varies generally from zero to 8 %. The upland areas have deep, medium textured soils, of moderately limey till (Erie silt loam) of the Erie Series…These soils are somewhat poorly drained. They are typically high in plant nutrients. A slowly permeable layer at 12 to 18 inches restricts the movement of air and water and the penetration of roots…" (Hartman, n.d.).

"The geology and soils of the…[Edinboro Lake watershed]…are a major concern because they may limit the types of on-lot systems that can be used for wastewater treatment in Washington Township. In many locations, impermeable soils, high groundwater tables and erratically placed boulders exist. In stream valleys, gravelly and highly permeable strata comprise productive groundwater aquifers used for drinking water supplies. Due to these features, standard septic-tank type on-lot systems are not appropriate and alternative technologies such as mound systems must be used for on-lot treatment and disposal" (U.S. Environmental Protection Agency, 1982).

"Most of the soils in the study area have limitations such as impermeable fragipans which render them suitable or probably unsuitable as locations for standard septic-type systems. Poor soil conditions and high water tables are presently limiting development to those areas with localized soil conditions suitable for on-lot wastewater disposal." Because of soil characteristics, the underlying bedrock formations, and the consistently high water table (generally 0-2 feet), groundwater in some areas …may be susceptible to contamination from various sources including dumps, landfill, and failing septic tanks" (U.S. Environmental Protection Agency, 1981).

Hartman (n.d.) notes that in 1972 the USDA Soil Conservation Service described the erodibility of the dominant soils in the watershed. Erodibility was described as follows:

Erie silt loam – low erodibility
Howard gravely silt loam – low erodibility
Fredon loam – medium erodibility
Phelps gravely silt loam – low erodibility
Wayland silt loam – high erodibility
Sloan silty clay loam – medium erodibility.

With stream corridor areas containing Fredon loam soil, stream floodplains composed of Howard gravely silt loam soil, and the Sloan silty clay loam along the north and east shoreline of the lake, these medium erodibility soils have the potential to contribute sediment and nutrients to the lake. As a consequence, edaphic (soil) conditions may make the lake prone to eutrophication.

Vegetation

A 1978 study provided information on post glacial and pre-European settlement vegetation in the drainage basin as well as associated with Edinboro Lake. When the drainage basin was still influenced by a glacier-related climate, a boreal forest likely occurred in the basin and the rest of the region (Boker and Hallenburg, 1978). As glaciers retreated and the climate became more temperate, the forest changed accordingly. Yet, the relatively northern Erie County climate provides conditions for the relict boreal communities to continue to exist. Isolated areas harbor boreal vegetation. "…These peatmoss-tamarack (*Sphagnum* spp. – *Larix laracina*) relict bog communities are associated with the undrained or poorly drained kettle lake holes and other depressions…The present climate of Erie County provides conditions for the relict bogs to succeed to more southern mesotrophic vegetation stages tending toward a beech-sugar maple climax forest…" (Kline, Wiegman, and Bier, 1993).

Boker and Hallenburg (1978) use evidence of present-day secondary forest in northwest Pennsylvania and various reference sites to deduce that prior to European settlement (ca. 1800 A.D.), the drainage basin was vegetated by a hemlock (*Tsuga canadensis*)-white pine (*Pinus strobus*)-northern hardwoods forest. Boker and Hallenburg describe this forest type to characteristically consist of hemlock and a mixture of broadleaf tree species, including sugar maple (*Acer saccharum*), red maple (*A. rubrum*), beech (*Fagus grandifolia*), black cherry (*Prunus serotina*), yellow birch (*Betula allegheniensis*), white ash (*Fraxinus americana*), tulip tree (*Liriodendron tulipfera*), northern red oak (*Quercus borealis*), white oak (*Q. alba*), and several less common tree species. They also noted that white birch (*Betula papyrifera*) was frequent in Erie County and in the Edinboro Lake basin specifically, but that white pine is generally absent from the basin.

Shrub species commonly found in the pre-European settlement hemlock-white pine-northern hardwoods forest were spicebush (*Lindera benzoin*), several species of arrowwood (*Viburnum* spp.), and blueberries (*Vaccinium* spp.). Canada yew (*Taxus canadensis*) was mentioned, too. Herbaceous plants characteristic of the hemlock-white pine-northern hardwood forest observed were Canada may-flower (*Maianthemum canadense*), goldthread (*Coptis groenlandica*), common wood-sorrel (*Oxalis montana*), and several species of club mosses (*Lycopodium* spp.). These species are still common to forest remnants in Erie County.

Boker and Hallenburg (1978) described vegetation of the Edinboro Lake drainage basin during the late 1970s, noting the changes since pre-European settlement. They reported that "…much of the lake basin…has some protection against soil erosion because of some kind of perennial plant cover…" Christmas tree farms, old field vegetation, several seral stages of woody vegetation ranging from young seedlings and saplings to relatively mature stands of forest were cited as present. "…It is apparent that the original vegetation on moist, to moderately well-drained sites was the hemlock-white pine-northern hardwoods forest…", although it is noted that few white pine were observed. The scarcity of white pine was attributed to extensive harvesting of the species after European settlement. Hemlock was not observed on drier sites in the drainage basin. Boker and Hallenburg recognize this vegetation assemblage as a mixed hardwood community with the same species as the hemlock-white pine-northern hardwoods forest without the hemlock.

Biologically Significant Resources

The Edinboro Lake drainage basin harbors both rare natural communities and species. The three rare natural communities, identified to date, are a calcareous glacial lake, (i.e., Edinboro Lake), a shrub fen and a basin graminoid-forb fen. The shrub fen is locally known as Edinboro Lake Fen. Such lakes are of natural origin and only eight exist in northwestern PA. These lakes are termed "calcareous" due to the presence of calcium and other minerals that groundwater carries to the lake from surrounding soils. This results in water chemistry that includes high pH. Calcareous glacial lakes are recognized as critically imperiled in Pennsylvania due to extreme rarity and human threats. The critically imperiled status means that typically there are five or fewer occurrences or very few remaining acres. The shrub fen is a natural community of global and state significance. On a global scale, these ecosystems are considered imperiled/vulnerable. That is, there are typically six to 100 occurrences known to exist. From a state viewpoint, shrub fens are deemed critically imperiled. Adjacent to the shrub fen is a basin graminoid-forb fen, a critically imperiled natural community in Pennsylvania.

Edinboro Lake provides habitat for six plant species of special concern in the state. All but one of the species is classified as Endangered, Threatened or Rare in the Pennsylvania. The shallowness of the lake promotes the occurrence of extensive areas of aquatic vegetation, including emergent, submerged and floating vegetation. The extensive emergent marsh located on the northeastern lake shoreline is characterized by arrowhead (*Sagittaria* sp.), cow lily (*Nuphar* sp.), cattails (*Typha* spp.) and purple loosestrife (*Lythrum salicaria*), with scattered and sometimes dense shrub thickets dominated by buttonbush (*Cephalanthus occidentalis*) and willow (*Salix* sp.) (Kline, Wiegman and Bier et al., 1993).

The shrub fen that borders Edinboro Lake receives water from groundwater seepages along the shoreline that form watercourses within the fen. These watercourses are vegetated by cow lily, spikerushes (*Eleocharis* spp.), bur-reed (*Sparganium* sp.), arrowhead and water-milfoil (*Myriophyllum* sp.). The shrub fen contains a mosaic of shrub thickets dominated by willow, red-osier dogwood (*Cornus stolonifera*), alder (*Alnus* sp.) and scattered red maple (*Acer rubrum*). Openings in the shrub thickets are dominated by sedges (*Carex* spp.), and royal fern (*Osmunda regalis*). Cattail, marsh cinquefoil (*Potentilla palustris*) and marsh St. John's-wort (*Hypericum virginicum*) are local dominants in these openings (Kline, Wiegman, and Bier et al., 1993).

Twenty-three plant species of special concern are known to occur in the lake watershed. Eleven of the plants are listed as Endangered species in Pennsylvania. Eight of the plant species are listed as Threatened species, and four plants are protected as Rare species. These plant species are located within the lake, the lakeside fen (i.e., Edinboro Lake Fen), along the perimeter of the lake in adjacent wetland habitats, and north of the lake within the watershed. Following is a list of the rare plant species as well as the general location of each:

<u>Within the Lake</u>
Northern water-milfoil (*Myriophyllum exalbescens*)
Whorled water-milfoil (*M. verticillatum*)
White-stem pondweed (*Potamogeton praelongus*) – historic only, now missing
Vasey's pondweed (*P. vaseyi*)
Eastern white water-crowfoot (*Ranunculus longirostris*)
Lesser bladderwort (*Utricularia minor*)

<u>Lakeside Fen</u>
Rush aster (*Aster borealis*)
Cuckooflower (*Cardamine pratensis* var *palustris*)
Broad-winged sedge (*Carex alata*)

Lesser-panicled sedge (*C. diandra*)
Soft-leaved sedge (*C. disperma*)
Prairie sedge (*C. prairea*)
Slender spikerush (*Eleocharis elliptica*)
Slender cotton-grass (*Eriophorum gracile*)
Small-headed rush (*Juncus brachycephalus*)
Swamp fly-honeysuckle (*Lonicera oblongifolia*)
Leafy northern green orchid (*Platanthera hyperborea*)
Autumn willow (*Salix serissima*)
River bullrush (*Scirpus fluviatilis*)

<u>Along the Perimeter of Edinboro Lake in Adjacent Wetland Habitats</u>
A swamp smartweed (*Polygonum setaceum* var *interjectum*)
Bog willow (*Salix pedicellaris*)
Bog-mat (*Wolffiella gladiata*)

<u>North of the Lake within the Watershed</u>
Red current (*Ribes triste*)

All but one of these 23 rare plants is associated with Edinboro Lake, Edinboro Fen or are in wetland habitats along the perimeter of Edinboro Lake. One rare plant, red current (*Ribes triste*), is located north of Edinboro Lake adjacent to the riparian zone of Conneauttee Creek. All of the rare plants and their habitats are hyrdologically connected to the aquatic system that contains Edinboro Lake.

In addition to the extant rare plants and natural communities within the lake's drainage basin, three rare plants with historic records have been known to occur in the watershed. White-stemmed pondweed (*Potamogeton praelongus*) was last observed within Edinboro Lake in 1958. The species is currently believed to be extirpated from Pennsylvania. The state endangered plant, spreading globe flower (*Trollius laxus* spp *laxus*), was last observed in 1884 in wetlands adjacent to the perimeter of the lake. Queen-of-the-prairie (*Filipendula rubra*) was last observed in the watershed north of the lake in 1962 (Boyd, 1999).

Edinboro Lake is an exceptional ecological resource, which is seriously threatened by development and agriculture. With the exception of the northeastern shoreline, nearly the entire lake shoreline has been developed. Only narrow strips of natural vegetation occur along most of the shoreline. Consequently, an adequate buffer needed to protect the lake ecosystem's ecological resources it is not present. Accelerated eutrophication and water quality degradation, from heavy sediment loads and excess nutrient input, degrades fishery habitats, natural community biodiversity, and the aesthetic qualities of Edinboro Lake (Kline, Wiegman, and Bier, 1993).

Tributaries to Edinboro Lake

Edinboro Lake has four main tributaries: Conneauttee Creek, Shenango Creek, Whipple Creek and Lakeside Run (Hartman, n.d.). The principal inflows to Edinboro Lake were identified as Shenango Creek and Conneauttee Creek (Pennsylvania Department of Environmental Resources, 1981). "…Shenango Creek, with a drainage area of 15.85 square kilometers (6.13 square miles), and Conneauttee Creek, with a drainage area of 17.02 square kilometers (6.58 square miles). Whipple Creek has a drainage area of 4.23 square kilometers (1.86 square miles) and Lakeside Run has a drainage basin 2.12 square kilometers (0.82 square miles) in size. The total area of the drainage basin has been reported as 41.94 square kilometers (16.2 square miles)…" and as 61.36 square kilometers (23.7 square miles), respectively (Hartman, n.d.). The lake outflows into Conneauttee Creek (Pennsylvania Department of Environmental Resources, 1981), which is a tributary of French Creek.

Just over 20 years ago, tributaries to Edinboro Lake were sampled by the Erie County Department of Health (Wellington, 1979). Tributaries sampled consisted of Shenango Creek, Conneauttee Creek, Unnamed tributary to Shenango Creek, Tributary to Conneauttee Creek, Unnamed tributary above and below the Washington Township Sewage Treatment Plant, Edinboro Lake outlet, and Darrow's Creek. Wellington (1979) reported that "generally, the tribs sampled above Edinboro Lake could be considered good with the exception of…[the unnamed tributary to Shenango Creek]…which had evidence of some siltation. Overall, however, due to the size of the stream, it seems quite likely that this would not have any significant long-term effect on Edinboro Lake…". Also, Wellington (1979) commented that the general water quality in the stream above and below the Washington Township Sewage Treatment Plant seemed better in 1975 than 1979.

Fish surveys were conducted in Shenango and Conneauttee Creeks in 1978 during an U.S. Environmental Protection Agency (EPA) survey. Fish collected in Shenango Creek experiencing low summer flow were creek chub, fantail darter, rainbow darter, largescale stoneroller, and blacknose dace. "…Fish collected in Conneauttee Creek included johnny darter, white sucker, bluegill, and bluntnose minnow."

Since the late 1970s, no further data has been collected on the tributaries to Edinboro Lake, except on Whipple Creek in connection with monitoring discharges from the Washington Township Sewage Treatment Plant.

Land Use

Information compiled for the annotated bibliography provides information on land use in the Edinboro Lake drainage basin for periods during the 1980s and 1990s.

Land and water problems cannot be considered separately. Lake problems such as over-fertilization and high bacteria concentrations are largely land use problems. Lake communities affect the lake and the land around it by such non-point source pollution. Based on an inventory of the Edinboro Lake watershed, there are four generic categories of inputs to the lake. Circa 1984, the input categories were: agricultural runoff and wastewaters, non-agricultural/non-urban run-off, urban run-off, and municipal/domestic industrial wastewaters. Given the nature of the land use patterns for lands surrounding the lake, it appears that non-point source pollution has a greater detrimental effect on Edinboro Lake than those from point sources (n.a., 1984).

In the early to mid 1980s land use in the watershed was 6-12% urban, suburban or developed, 50-57% agricultural, 34-36% woodland or undeveloped, with 3% lake surface and 2% recreation (Department of Environmental Resources, 1981; Hartman, n.d.; Wellington, n.d.). While a considerable portion of the drainage basin was considered woodland or undeveloped much of the land use was agricultural land (U.S. Environmental Protection Agency, 1982). Land use in the watersheds of Shenango and Conneauttee Creeks was mostly agricultural and forest land with some residential development along roads. However, the drainage area of Whipple Creek was mostly developed (U.S. Environmental Protection Agency, 1982).

During the mid to late 1990s, land use within the lake's watershed remains much the same as during the 1980s. In 1994, Washington Township, which occupies a significant percentage of lake watershed, was described as 53% agriculture, 37% open space, 5% residential, 2% roads, less than 1% industrial, less than 1% recreation, and less than 1% game lands (n.a., 1995). "Most of the lake's shoreline has been developed, with only the northeastern shoreline remaining free of development. Residential uses, especially along the west shore, and commercial uses make up most of this development…"(Borough of Edinboro, 1997).

Edinboro Lake Ecosystem – The Lake

The Pennsylvania Department of Environmental Resources (1981) provides the location of Edinboro Lake as the Borough of Edinboro, Washington Township, Erie County. The department describes the origin of the lake as natural and attributes ownership to the Borough of Edinboro, although in 1993, the Pennsylvania Fish and Boat Commission recognized ownership to be 12% municipal, 65% private open and 23% private closed (Lee, 1993).

Edinboro Lake, formerly known as Conneauttee Lake, is of glacial origin "…formed during the Lavery Advance in middle Cary time of Wisconsin glaciation. Two tongues of ice approached Edinboro, one down the Shenango Creek Valley and the other moving south from the site of the present village of McLane depositing a low kame moraine. Behind the kame an ice block depression was formed. This filled with water as the ice melted, creating the lake basin…The original kettlehole lake was enlarged by a dam constructed across the outlet…in 1802…Through the years, dams on the outlet stream have been rebuilt with resulting alterations to the lake surface. The existing dam, an 11-foot high, 106-foot long stone and concrete structure with removable boards, was built in 1922. Elevation of the water surface is normally maintained at…1,197 feet… providing a surface area of about …245 acres. Removal of boards permits a drawdown of five feet. A gate permits additional drawdown…" (Hartman, n.d.). The mean depth is 10 feet with a maximum depth of 30 feet, and shoreline length of 3.3 miles (Pennsylvania Department of Environmental Resources, 1981).

The original depth of the lake's basin is uncertain. Circa 1980 Hartman (n.d.) observed that an "accurate and reliable" bathymetric map of the lake prior to the dredging and channeling activities from 1955 to 1960 is not available. "…However early descriptions of the lake (Warner, Beers & Co., 1884) report the deepest water to be about 50 feet. A map by Terry Higgins prepared in 1960 showed a maximum depth of 44 feet (Wittuhun, 1974) and an earlier map by J. Labesky from about 1950 shows a maximum depth of 40 to 50 feet (Wise, 1975)…". The Ganzemuller and West (1973) map shows a maximum depth of 30 feet.

Total volume of water in the lake has been estimated at …728 million gallons by the Institute for Community Services (1974) and at 1.04 billion gallons by the Pennsylvania Fish and Boat Commission (Hartman, n.d.). Mean hydraulic retention time has been calculated to range from 35 days (Hartman, n.d.) to 58 days (Pennsylvania Department of Environmental Resources, 1981). A Commonwealth of Pennsylvania water quality inventory in the 1980s noted that the relatively shallow Edinboro Lake has a small (estimated) flow-through which indicates the lake is "…highly subject to pollution by dischargers within [the drainage basin]."(n.a., 1984).

Edinboro Lake has a water layer/circulation pattern known as dimictic with a well-defined thermal stratification during summer months. The lower depths (below 5 meters) of the hypolimnion are typically devoid of oxygen during the summer period. "…Heterograde oxygen curves have not been observed in Edinboro Lake. An ice cover…6 to 8 inches…thick commonly forms on the lake during the winter…" (Hartman, n.d.).

Wohler (1978) studied the aquatic ecosystem within the two main inlet streams of Edinboro Lake, Conneauttee and Shenango Creeks, and the adjacent north area of the lake (an area referred to by Wohler and some subsequent documents as the sensitivity area). Wohler's research focused on assessment of macronutrients (nitrogen and phosphorus) within the system, major aquatic plant communities (phytoplankton and vascular hydrophytes), bacterial populations indicative of fecal pollution, and sources of pollution. Wohler concluded that the sensitivity area was "…experiencing high nutrient loading…" and that the "…vascular hydrophyte biomass and the blue-green algae communities in the lake and inlet streams…reflect the eutrophic state of the lake system and enrichment by the inlet streams…".

Circa 1980 research data on the lake was variable in terms of sources and usefulness per Hartman (n.d.). Hartman also noted that no biological data appeared to be available prior to 1969. Yet, he was able to conclude from plankton data reviewed from 1969, 1970, 1972, 1974, and 1980-1981 that "… the summer phytoplankton community continues to be dominated by blue-green algae…".

"…Little quantitative sampling has been carried out on the vascular plants of this lake but species lists of plants collected by classes from the Pymatuning Laboratory of Ecology are available from July collections in the years 1951, 1955, 1958, 1974, and 1978…Few qualitative differences are apparent over this 27-year period except for the disappearance of several species of *Potamogeton* collected in 1958. *Myriophyllum spicatum* has developed as the dominant weed species in this lake."(Hartman, n.d.). (Copies of the species listed by the Pymatuning Laboratory of Ecology classes are provided.) Circa 1980, the only quantitative estimates on the standing are from Wohler (1977) (Hartman, n.d.) and this data solely addresses the inlet area of the lake. The shallow water marsh community in the sensitivity area contained narrow-leaved cattail (*Typha angustifolia*) and wide-leaved cattail (*T. latifolia*), pickerel weed (*Pontederia cordata*), water smartweed (*Polygonum amphibium*), spatter dock (*Nuphar advena*), and water lily (*Nymphaea odorata*). Northern blue flag (*Iris versicolor*) was common along lake shorelines. The two cattail species occurred in a nearly pure stand in some areas of the marsh (Boker and Hallenburg, 1978).

Along the shore at the north end of Edinboro Lake in 1978 was a shrub community characterized by red osier dogwood (*Cornus stolonifera*), silky dogwood (*C. amomum*), speckled alder (*Alnus rugosa*), willows (*Salix* spp.), American elm (*Ulmus americana*), common elderberry (*Sambucus canadensis*), buttonbush (*Cephalanthus occidentalis*), blueberries (*Vaccinium* spp.), and arrowwood etc. (*Viburnum* sp.) (Boker and Hallenburg, 1978).

In 1991, at least 26 taxa of aquatic vegetation were identified in Edinboro Lake by the Pennsylvania Fish and Boat Commission. This was deemed a significant increase over the 14 species observed in 1986. Shoreline congestion from vegetation had decreased significantly, from 37% in 1986 to 13% in 1991. Surface congestion had remained constant with 13% in 1986 and 15% in 1991…", according to Lee (1993).

Based on a July 1998 survey of the lake by the Pennsylvania Fish and Boat Commission (Pennsylvania Fish and Boat Commission, n.d.), 23 aquatic and emergent wetland plants were reported down three genera from a vegetation list compiled in 1991. Vegetation reported for Edinboro Lake were categorized by genera and consisted of willow (*Salix*), smartweed (*Polygonum*), coontail (*Ceratophyllum*), white water lily (*Nymphaea*), spatterdock (*Nuphar*), water shield (*Brasenia*), swamp loosestrife (*Decadon*), water milfoil (*Myriophyllum*), purple loosestrife (*Lythrum salicaria*), buttonbush (*Cephalanthus*), cattail (*Typha*), bur reed (*Sparganium*), flag (*Iris*), pondweed (*Potamogeton*), watered (*Elodea*), wild celery (*Vallisneria*), pickerelweed (*Pontederia*), spike rush (*Eleocharis*), arrow arum (*Peltandra*), greater duckweed (*Spirodela*), duckweed (*Lemna*), and watermeal (*Wolffia*). Genera missing that were observed in 1991 were waternet (*Hydrodictyon*, *Spirogyra*), hornwort (*Ceratophyllum*), fanwort (*Caboma*), rush (*Juncus*), bushy pondweed (*Najas*), arrowhead (*Sagittarius*), and bulrush (*Scirpus*).

Information compiled for the annotated bibliography includes research on Edinboro Lake's fish community. As fish communities are recognized as "…excellent indicators of overall ecosystem integrity and health," (Koonce, Minns, and Morrison, 1998) that information is provided for consideration.

Historically in Edinboro Lake, water quality has been suitable for warm and coolwater species. The lake has had a self-sustaining fishery for many years for centrarchids, brown bullhead (*Ameiurus nebulosus*), and yellow perch (*Perca flavescens*). Centrarchids are sunfishes and basses. "Included in this family of fishes are some of the popular sport fishes, such as crappies, basses, and bluegill…" (Page and Burr, 1991). Among the sport fishes reported to occur naturally in Edinboro Lake are largemouth bass, smallmouth bass, black crappie (*Pomoxis nirgomaculatus*), and bluegill (*Lepomis macrochirus*). Once naturally occurring, muskellunge (*Esox masquinongy*) and walleye (*S. vitreum vitreum*) have been maintained through regular stocking. Yellow perch have steadily declined since 1981. Golden shiner was the major non-panfish-forage fish present. Other species were common carp (*Cyprinus carpio*) and white sucker (*Catostomus commersoni*) (Lee, 1993).

In 1991 and 1998, fish species diversity data was collected by the Pennsylvania Fish and Boat Commission (Lee, 1993). In 1998, the fish species occurrence in Edinboro Lake was reported as follows: black crappie, bluegill, pumpkinseed (*L. gibbosus*) brook trout hatchery (*Salvelinus fontinalis*), brown bullhead, yellow bullhead (*A. natalis*), common carp, golden shiner (*Notemigonus crysoleucas*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*), muskellunge, walleye, white perch (*Morone americana*), white sucker, and yellow perch. A species reported in 1991 but missing from the 1998 data is white crappie (*Pomoxis annularis*). The walleye population is still maintained by stocking and Edinboro Lake is used as a brood lake for stocked muskellunge (Lee, 1993; Pennsylvania Fish and Boat Commission, n.d.).

Edinboro Lake has a self-sustaining largemouth bass population. Walleye in the lake are "…totally dependent on stocking to maintain a population…The panfish fishery consists of two major species, bluegill and black crappie which are both present in good numbers and quality size individuals." In addition to the stocking of walleye, Lee and Woomer recommend annual stocking of muskellunge, as Edinboro Lake is a muskellunge brood lake (Lee and Woomer, 1993). Thus, per Pennsylvania Fish and Boat Commission sampling, the lake's fish community appears to be primarily composed of Centrichids.

Lakes and Eutrophication

Algal populations are dependent upon light and nutrients for growth. Photosynthesis requires light and nutrients are needed for the anabolic activities of algal cells. "… In lakes with a natural scarcity of essential plant nutrients, phytoplankton densities are low, the water remains relatively clear and marginal macrophytes (vascular plants) are also rare. Such lakes are said to be oligotrophic, that is 'underfed.' By contrast, lakes with ample nutrients supporting rich algal blooms and profuse growths of macrophytes are eutrophic, or 'well-fed'…" (Hellawell, 1986). Per Hellawell and Cole (1983), other characteristic features of eutrophic lakes are:

> *Physical features* – Usually low altitude, wide but shallow basin, organically enriched mud substrate, poor light penetration and low transparency, green to yellow or brownish green color
>
> *Chemical water quality* – High nutrient values, especially nitrogen and phosphorus, water hardness, high suspended solids, variable, high in epilimnion but hypolimnion anoxic on stratification
>
> *Biology*
>
>> Phytoplankton – Low diversity (few abundantly represented species), high biomass, blue-green algae (*Cyanophycae*) typically present (e.g. *Annabaena, Aphanizomenon*), diatoms (e.g. *Asterionella, Fragilaria, Melosira*, and *Stephanodiscus*) occur

Macrophytes – many species of aquatic plants, abundant in shallow margins and along shoreline

Benthic invertebrates – low diversity, often very high biomass, profundal midge larva (*Chironomus*) and *Chaoborus* present

Zooplankton – crustaceans, etc., low diversity but high biomass

Fishes – many species, typically *Cyprinidae*, *Percidae*, *Centrarchidae* and *Cichilidae*, no stenothermal fish in hypolimnion.

Many of the characteristics of eutrophic lakes cited by Hellawell and Cole are descriptive of Edinboro Lake in terms of physical features, chemical water quality, phytoplankton, macrophytes, and fishes.

Key nutrients responsible for eutrophication are nitrogen and phosphorus. However, in most freshwater lakes, algal growth is usually limited by the availability of phosphorus (Hellawell, 1986). In 1996, the National Research Council found that in glaciated regions of the northeastern and north-central United States, lakes are phosphorus limited, in the absence of anthropogenic nutrient loadings. In lakes where nitrogen might otherwise be the limiting nutrient, as the availability of phosphorus is adequate, some algae (*Cyanophycae* – blue-green algae) are able to fix dissolved nitrogen, which diffuses readily from the atmosphere, and phosphorus levels again become the critical factor. When nutrients are plentiful, algal growth likely becomes limited through self-shading effects. That is, the density of algae near the surface absorbs sufficient light to prevent the indefinite survival of other algae at greater depths (Hellawell, 1986).

How do nitrogen and phosphorus enter lake ecosystems? Both these nutrients have natural origins within a drainage basin and within lake ecosystems. For example, internal loading of phosphorus and nitrogen is the result of regeneration processes through the decay of plant and animal tissue and algal cells, sediment release, and contributions from groundwater flow (Environmental Protection Agency, n.d.). In addition to natural origins, nitrogen and phosphorus can be delivered to surface waters at an elevated rate as a result of human activities. Excess nutrient input from human activities is commonly referred to as cultural eutrophication to differentiate between the natural process of eutrophication. Phosphorus, because of its tendency to sorb to soil particles and organic matter, is primarily transported in surface runoff with eroded sediments. Inorganic nitrogen does not sorb as strongly and can be transported in both particulate and dissolved phases in surface runoff. Dissolved inorganic nitrogen can also be transported through the unsaturated zone (interflow) and ground water. Nitrogen can be directly discharged to a water body via outfalls for wastewater treatment plants and combined sewer outflows.

"Once in the water body, nitrogen and phosphorus act differently. Nitrogen, because it does not sorb [bond] strongly to sediment, moves easily between the substrate and the water column and cycles continuously. Phosphorus, on the other hand can sorb to sediments in the water column and on the substrate and become unavailable. In lakes and reservoirs, continuous accumulation of sediment can leave some phosphorus too deep within the substrate to be reintroduced to the water column; however, a portion of the phosphorus in the substrate might be reintroduced to the water column. In addition, the activities of benthic invertebrates and changes in water chemistry, such as the reducing conditions of bottom waters and sediments often experienced during the summer months in a lake, can cause phosphorus to desorb from sediment. The sudden availability of phosphorus in the water column can stimulate algal growth. Because of this phenomenon, a reduction in phosphorus loading might not be effective in reducing algal blooms for a number of years" (National Research Council, 1996).

"…The control of external nutrient sources is not sufficient to alleviate the symptoms of eutrophication in all lakes. In many cases, in-lake treatment to decrease the rate of phosphorus recycling from bottom sediments or to restore damaged habitat also is necessary to reverse long-term and severe impacts to excess nutrient loading." (National Research Council, 1996). Why? "…A pollutant…in static water…may persist for considerable periods after the pollution stops, since the exit pathways tend to be much more restricted. Reduced intensity of algal blooms in static waters may not be concomitant with lowered nutrient inputs although…it could help avoid future exacerbation of the problems. This apparent hysteresis is attributable to the former input of nutrients which have accumulated in the benthic sediments and which continue to be available through diffusion and circulation through the lake. The movement of nutrients between various components of the lake ecosystem, i.e. the water column, sediments and biota, is complex, being influenced by such factors as the dimensions and physical properties of the lake, including its propensity to stratify, …its overall productivity and the chemical characteristics of the chemicals involved" (Hellawell, 1986).

For many lakes, the control of point sources of nutrients alone has not been enough to prevent or reverse eutrophication. As municipal discharges were regulated to control point source inputs of nutrients the role of non-point sources in eutrophication became the primary concern. Yet, increasing land-use controls to prevent excess nutrient discharges will not entirely eliminate eutrophication. In some lakes, internal recycling of nutrients from the bottom sediment can help to maintain eutrophic conditions in lakes for long time periods after sources of external load are controlled (National Research Council, 1996).

Edinboro Lake and Cultural Eutrophication

Lakes are classified based on productivity, which generally increases as the lake ages. Lakes with low productivity are called oligotrophic, and have low rates of photosynthetic productivity. Oxygen levels in the hypolimnion of these lakes remain high throughout the year. Lakes with greater productivity are termed mesotrophic and generally have larger nutrient inputs than oligotrophic lakes. Lakes with very high productivity are termed eutrophic and tend to have high nutrient inputs, plus profuse aquatic plant growth and algal blooms are common. Oxygen is usually depleted in the hypolimnion of an eutrophic lake (U.S. Environmental Protection Agency, 1981). Cultural eutrophication "…ultimately results in loss of water clarity, loss of oxygen in bottom waters, and a shift in the food web from valuable game fish to less desirable species…" (National Research Council, 1996).

A summary of data/information in the annotated bibliography that addresses Edinboro Lake and cultural eutrophication follows:

– Edinboro Lake is a eutrophic ecosystem and has been eutrophic for several decades. This appraisal of the lake's trophic status is based on information compiled for the project that "…shows summer anoxia (loss of oxygen) in bottom waters as early as the 1960s…" (Wolin, 1999a). A June 1970 State investigation of the lake concluded that Edinboro Lake was eutrophic, based on thermal stratification, oxygen depletion in the hypolimnion, the presence of blue-green algal blooms, and profuse growth of aquatic plants (Brezina, 1970).

– A 1976 water quality report concluded that Edinboro Lake is in "…the advanced state of eutrophication…" and a 1978 U.S. Environmental Protection Agency lake survey also indicated evidence of eutrophication.

– A U.S. Environmental Protection Agency survey reveals that strong thermal stratification was occurring in the lake. Temperatures ranged from 81 degrees F at the surface to 54 degrees in the bottom waters. Dissolved oxygen levels also showed a strong variation from surface to bottom -- an indication of eutrophication -- although the levels were in compliance with State water quality criteria. The measured pH levels, as well as the concentrations of iron, also did not violate these criteria. Concentrations of sulfate, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen did not exceed the limits recommended by the Council on Water Quality Criteria (1972). Total phosphorus concentrations ranged from 0.03 mg/l in the epilimnion of the Lake to 0.28 mg/l in the hypolimnion. These values are typical of eutrophic lakes (U.S. Environmental Protection Agency, 1981). The 1981 USEPA report further indicated that chlorophyll-a levels, bioassays, and extensive beds of vascular plants that Edinboro Lake was "highly eutrophic" at the time and that "any further increase in nutrient loading therefore should be avoided…"

– Circa 1980 Hartman (n.d.) provided water chemistry data for the lake (1970 and 1980) and streams (1978). He noted that "…scattered data are available from chemical analyses of water collected from Edinboro Lake, its major tributary streams, and the outlet stream from a variety of sources from 1968 through 1980…" The data are reported to "…vary greatly in the parameters measured and in the reliability of the data…". When summarizing the usefulness of the data to evaluate "…the trophic condition of the lake or in determining the factors present for its present state of eutrophication, it must be pointed out that almost all available information has been collected during periods of summer stabilization. Essentially no data have been collected during the spring and fall overturn or during winter stabilization."

– "Lakes will usually progress naturally from being oligotrophic to eutrophic over a long period of time. However, human activity around Edinboro Lake has accelerated the accumulation of nutrients and caused the lake to exhibit eutrophic characteristics before it has reached old age at its natural rate. This induced process of enrichment is called cultural eutrophication…Edinboro Lake is classified according to its nutrient contents based on levels of nitrogen and phosphorus, the two primary nutrients which limit aquatic plant growth and thereby primary productivity…" (U.S. Environmental Protection Agency, 1981).

- In 1982, an Environmental Protection Agency document indicated the "…character and water quality of Edinboro Lake is rapidly changing due to eutrophication…In this case,…the eutrophication of Edinboro Lake has been accelerated by human activities such as wastewater discharges, agriculture, and development in the lake watershed. Changes in the lake are measured by the amount of phosphorus and nitrogen (nutrients that promote plant growth) introduced to the lake. The amount of phosphorus reaching the lake has been estimated to be 2.7 times greater than the amount needed to make the lake eutrophic. Approximately 80% of the phosphorus and 95% of the nitrogen that reaches the lake is from non-point sources such as run-off." Point sources were shown to contribute 19% of the phosphorus loading and 5% of the nitrogen (U.S. Environmental Protection Agency, 1982). However, the nutrient budget calculations did not address the contribution of phosphorus and nitrogen from internal loading (Hartman, n.d.).

- Hartman (n.d.) speculated that the "…addition of nitrogen through fixation by blue-green algae in the summer bloom community is probably sizable. The summer mixing zone of Edinboro Lake (those areas less than 3 meters in depth) is extensive…and the sediments in this portion of the lake continue to release nutrients to surface waters even during periods of thermal stratification. Phosphorus and nitrogen from these littoral areas, added to the amounts of these elements reaching the epilimnion by vertical transport mechanisms from hypolimnetic waters, must contribute to the development of phytoplankton blooms. Any estimation of the nutrients available to the system should include the amounts of phosphorus and nitrogen contributed from these internal sources."

- Edinboro Lake is eutrophic based on the County's trophic state analyses conducted by the Erie County Department of Health in 1986, 1991, and 1996 (Wellington, n.d.; 1991; 1996). Wolin (1999b) has summarized Edinboro Lake water quality data for 1991-1996:

  The Pennsylvania Department of Environmental Protection's "…monitoring program provides the most recent information on the overall condition of Edinboro Lake. All samples were taken during one sampling date in either July or August of each year. This type of sampling provides a 'snapshot' of lake conditions but does not integrate processes happening throughout the year. Any increases or decreases in chemical or biological measurements may be due to natural daily, monthly, or year to year variation in the lake or in external factors such as weather conditions…."

  "Strong thermal stratification occurs in Edinboro Lake during summer. Surface water temperatures in mid-summer average 24.5 [degrees] C (76.1 [degrees] F) and ranged from 19.5-27.2 degrees C (67.1-81 [degrees] F). Bottom temperatures showed less variation, averaging 13.9 [degrees] C (57 [degrees] F) with a range of 13-15 degrees C (55.4-59 [degrees] F). Dissolved oxygen concentrations in the surface waters averaged 7.75 mg/l (approximately 94% saturation) and ranged from 5.25 mg/l to 11.3 mg/l (59-140% saturation). Bottom oxygen concentrations indicate severe oxygen limitation to anoxic (no oxygen) conditions occurring from 1991-1996. Surface pH values are higher than bottom waters in all years except 1992. This increase in pH is most likely due to increased CO_2 uptake by algae during photosynthesis. Alkalinity values in surface and bottom waters meet Pennsylvania water quality standards and are not a concern. Surface total phosphorus measurements average 0.066 mg/l and appear to show a decline from a high of 0.098 mg/l in 1992 to 0.04 mg/l in 1996. It should be noted that although these surface concentrations have declined, they are still high and characterize the lake as eutrophic (Wetzel, 1983). Bottom concentrations remain high with an average of 0.65 mg/l indicating phosphorus release is occurring from bottom sediments. Total nitrogen concentrations average 0.958 mg/l ranging from 0.76-1.25 mg/l in surface waters and average 2.41 mg/l in bottom waters with a range between 1.9 and 3.37 mg/l. Most of the increase in total nitrogen at the bottom is due to high ammonia nitrogen concentrations (averaging 1.76 mg/l). Ammonia nitrogen levels exceeded the state water quality standard of 1.5 mg/l. These are indicative of high organic degradation at the sediment surface and characteristic of eutrophic nutrient-rich conditions. Chlorophyll-a measurement averaged 0.042 mg/l ranging from 0.0196 to 0.062 mg/l. All concentrations are indicative of a eutrophic (nutrient-rich) lake and no decline in concentrations is apparent from the 1996 data. Sulfate data falls well within the state water quality standard of a maximum 250 mg/l. Metal concentrations for copper and aluminum cannot currently be assessed by state water quality standards without further information. Manganese levels in bottom waters exceed state water standards of…1.0 mg/l…

"Overall, the water quality of Edinboro Lake is poor-fair. Nutrient (total phosphorus and nitrogen) inputs remain high and indicative of eutrophic to hyper-eutrophic conditions. These high nutrient loadings accelerate algal growth, contribute to lower water quality, and continue to accelerate the eutrophication process in Edinboro Lake." (Wolin, 1999b).

Based on the information compiled for the annotated bibliography, Wolin (1999a) identified six possible major sources of excess nutrients to Edinboro Lake. The sources identified include:

- wetland (marsh) at the northern end of the lake
- inflow from Shenango and Conneauttee creeks
- septic systems and sewage treatment plants in the drainage basin
- resident waterfowl populations
- climate effects on lake nutrients
- internal release of phosphorus from sediments

Overview: Ecosystem Health, Stressors and Sources of Stressors

A general understanding of the physical and biological nature of Edinboro Lake and its drainage basin facilitates addressing the stressors and sources of stressors that threaten the ecosystem. Consideration of stresses to ecosystems requires an appreciation of how stresses and their sources affect overall ecosystem health.

"Ecosystem health generally is considered as a condition in which natural ecosystem properties are not severely restricted, the ability for progressive self-organization is present, the capacity for self-repair when stresses is preserved, and minimal external support for management is needed…" (National Research Council, 1996). Environment Canada and U.S. Environmental Protection Agency (n.d.) in part define healthy ecosystems as self-sustaining. That is, they are sustainable. Sustainable ecosystems have the "…ability to sustain diversity, productivity, resilience to stress, health renewability, and/or yields of desired values, resource uses, products, or services…while maintaining the integrity of the ecosystem over time…" (National Research Council, 1996). "…Sites modified by human activity may be considered ecologically healthy 'when their management neither degrades the sites for future use, nor results in degradation beyond their borders'…Problems associated with deterioration of ecosystem health must be addressed at a landscape scale of resolution since significant cumulative and interactive effects otherwise might be overlooked" (National Research Council, 1996).

The benefits of healthy ecosystems to the people who reside within systems boundaries are human health and welfare, quality of life, as well as economic benefits. Thus, healthy ecosystems promote healthy humans with reduced risk and exposure to such threats as pathogens or toxic contaminants. Healthy ecosystems also provide quality of life, which, depending on the ecosystem, can consist of such items as drinkable water, food, aesthetic enjoyment, feeling of well-being, and swimming, fishing, hunting. Economic benefits are attributable to healthy ecosystems. Examples of economic benefits include recreational industry, tourism industry, commercial fishery, and reduced health costs (Environment Canada and U.S. Environmental Protection Agency, n.d.).

As mentioned in the introduction, stresses can be imposed on natural ecosystems by human activities or environmental manipulation. When appraising the current state of the Great Lakes Basin, Environment Canada and the U.S. Environmental Protection Agency (n.d.) noted that these human imposed stressors affect the chemical, biological, and physical components of lake ecosystems. Key chemical stressors are toxic contamination and excess nutrients. Key biological stressors consist of excess competition, pathogens, exotic species, genetic loss, and population disruption. Key physical stressors result from land use practices and are identified as sedimentation, habitat access loss, habitat degradation or loss, and hydrological modification.

Chemical Stressors

"…Excessive algal growth due to high nutrient concentrations leads to algal decomposition and oxygen depletion. A shift in the makeup of the ecological community then follows, favoring species that benefit from excess nutrients, reduced oxygen, and the reduced sunlight and visibility conditions that are generated by excess algal growth…The impact of persistent toxic contaminants is less visible and often shows no effect until the contaminants are concentrated in the food chain, beginning with algae and zooplankton. Through the processes of biomagnification and bioaccumulation, the impact of toxic chemicals is greatest on animals at the top of the food web, such as predatory birds, fish, and mammals, including humans. Effects seldom result in acute symptoms or death at any level within the ecosystem, but they include impaired reproduction and reduced resistance to disease. Toxic chemicals enter the nearshore ecosystem via a number of routes, including atmospheric deposition, pesticide use, industrial discharge, municipal discharge, storm run-off, and leaching from contaminated sediments from both on shore and underwater." (Environment Canada and U.S. Environmental Protection Agency, n.d.). "Municipal and industrial waste discharges, urban run-off, and agricultural run-off all contain trace concentrations of toxic compounds…Often present in these discharges are organochlorine compounds, some of which are among the most toxic substances known to humans. Examples include dioxins and PCBs (polychlorinated biphenyls), which enter waterways from industrial sources, as well as DDT, toxaphene, and many other pesticides, which enter lakes and streams via run-off from agricultural lands and managed forests" (National Research Council, 1996).

Physical Stressors, Due to Land Use

Physical stress can do two things to ecosystems. Physical stress can "…directly alter habitat and it can disrupt the functioning of important physical processes that support the existence of the habitat. When a piece of land, shoreline, or lake bed is cleared or substantially modified for human use, most of the living and non-living components of ecosystems are destroyed. Some species cannot move or are not well-adapted to the altered or diminished habitat. These conservative species often require very specific habitat features, which sometimes include the presence of associated species. They tend to be relatively rare and the first to be lost when change occurs. Some species, however, have broader limits of tolerance and can continue to inhabit an area. Even these species are relegated to tiny fragments of their original territory. Such habitat fragmentation makes it difficult or impossible for isolated individuals within a species to interact. As a result, the flow of genetic information that is necessary to sustain populations is inhibited…The disruption of physical processes can also have a devastating impact on the health of ecosystems…Development in all its forms is a stressor…" (Environment Canada and U.S. Environmental Protection Agency, n.d.).

Biological Stressors

"In terms of biological stress, the global transfer of exotic organisms is one of the most pervasive and perhaps least recognized effects of humans on the world's aquatic ecosystems…[S]uch transfers lead to loss of species diversity and to extensive alteration of native communities. Decline and loss of species and genetic diversity are critical aspects in the loss of ecosystem integrity and the ability of ecological communities to remain resilient during times of environmental change…Not all exotic species are invasive or disruptive. Many are unable to compete with native species or simply exist in balance with native species. Some exotic species, however, are invasive and destructive to native species and communities…Each exotic species exists as a natural component of a natural ecosystem in the waters of its homeland. In a new location, it may be free of the natural checks established through long periods of evolutionary development and be able to invade and take over large areas. As they do, they cause drastic changes to food chains and habitats that are essential to our native plant and animal communities" (Environment Canada and U.S. Environmental Protection Agency, n.d.).

One factor that encourages the rapid spread of invasive exotic species is the disruption of the habitats that support native species. "…Natural disturbances are part of the ecosystem and are important to its long-term balance. However, human development of agriculture, industry, and communities causes disturbance of large-scale areas in relatively brief time frames, which do not allow the native species and biological communities to adapt. Changes in hydrology, water chemistry, and water temperature are examples of disturbances…" (Environment Canada and U.S. Environmental Protection Agency, n.d.).

Another example of biological stress is microbial contamination. Micro-organisms may be bacteria, fungi, microscopic algae, protozoa, and viruses. While these micro-organisms are in human waste they are rendered harmless by processes in sewage treatment plants. Pollutants can still be discharged into waters in places where there are combined stormwater and sanitary sewer systems, or when rainfall or snowmelt infiltrate a treatment plant and discharge untreated sewage into receiving waters. Wastes from farm animals and even wildlife can also be sources of pathogens (Environment Canada and U.S. Environmental Protection Agency, n.d.).

Environment Canada and U.S. Environmental Protection Agency (n.d.) identify sources of key chemical, biological, and physical stressors to lake ecosystems as:

- filling or shore modification
- dams or dikes
- dredging and draining
- navigation
- exotic species introduction
- excess harvest or stocking
- development, erosion, and runoff
- air, emission, or deposition
- point source discharges
- contaminated sediment

Stresses and Related Recommendations for Edinboro Lake

Hereafter follows a summary of the stressors and sources of stressors to Edinboro Lake based on the information and data compiled for the annotated bibliography. Stressors are identified first, followed by sources of the stressors, and finally recommendations regarding the stressors and their sources. The stressors and their sources are presented in chronological order in a list format.

Chemical Environment Stressor – Excess Nutrients

Soil dredged from the marsh was used to fill a portion of the marsh between 1955 and 1960 (Hartman, n.d.). Hartman observed that the dredge material rapidly eroded and transported nutrients into the lake basin. Per Hartman the input contributed significantly to the rapid eutrophication of the lake.

Brezina (1970) recommended that the State determine the extent of overload and malfunctioning on-lot sewage disposal systems located around the lake, as a possible source of nutrient enrichment. Phosphorus loading has likely declined since the lakeside community was connected to the sewage treatment plant in the 1970s (Steckler, 1999).

Wohler (1978) concluded that the northern inlet was "…experiencing high nutrient loading…" reflecting the eutrophic state of the lake system and enrichment by the inlet streams.

Elevated levels of nitrogen and phosphorus in streams entering Edinboro Lake were noted during a 1978 U.S. EPA survey (U.S. Environmental Protection Agency, 1981).

Hartman (n.d.) noted that preliminary observations suggest that nutrients are contributed from littoral zone sediments, particularly in the shallow northern end.

Circa 1980, Hartman (n.d.) attributed recent nutrient accumulation in the lake related to erosion associated with construction projects in the drainage basin.

In the early 1980s, the U.S. Environmental Protection Agency (1981) recommended that further increases in nutrient loading should be avoided as the lake was already considered highly eutrophic.

Phosphorus values in the lake, streams feeding the lake, and the outlet stream are in excess of 0.25 mg/l -- the level set by EPA in order to prevent eutrophication. At various lake locations and depths, total phosphorus values averaged 0.94 mg/l (n.a., 1981).

Minimal nutrients are contributed by streambank and roadside erosion, while approximately 1.6 tons of phosphorus from manure spread in the winter is delivered to the lake during spring thaw (n.a., 1981).

Animal manure and erosion attributed as the source of 60% of the total phosphorus and bacteria to the lake and streams (n.a., 1981).

Hartman (n.d.) refers to a letter from the Erie County Department of Health that attributes agricultural activities surrounding the lake as contributing fertilizer, animal waste, pathogens, and sediment via run-off.

Agricultural and urban run-off appear "…to be of greater importance in adding phosphorus and nitrogen to the lake…" (Pennsylvania Department of Environmental Protection, 1981).

Lack of livestock manure management and agricultural-related soil erosion were identified by the USDA Soil Conservation Service as non-point sources of nutrient loading to the lake (U.S. Environmental Protection Agency, 1982).

The Erie County Department of Health's 1986 trophic state analysis identified golf courses in the drainage basin and dredging activities in the lake's wetlands as possible sources of nutrients reaching the lake (Wellington, n.d.).

Residents in a majority of the Washington Township portion of the drainage basin are using on-lot wastewater treatment, likely septic systems. Roughly speaking, half of the lake shoreline is within that portion of the Township not served by the sewage treatment facility (n.a., 1995).

Annual atmospheric deposition of nitrogen in the French Creek drainage basin, which includes Edinboro Lake and its watershed, has been recently estimated as 36% (U.S. Environmental Protection Agency, 1999).

The Washington Township and General McLane High School sewage treatment plants are the two permitted point source discharges in the Edinboro Lake drainage basin (Wellington, 1999). Phosphorus limits on the plants are 1 mg/l per State water quality standards.

Sources of Excess Nutrients

Sources of excess nutrients cited by the information compiled for the annotated bibliography include non-point sources, point sources, and internal loading.

- **Non-Point Sources**

About 1980, non-point source runoff in the watershed appeared to contribute nitrogen and phosphorus to the hypolimnion, but this needs to be researched and verified (Hartman, n.d.).

Non-point source runoff determined to be the source of 95% of the total nitrogen and 80% of the total phosphorus entering the lake. Non-point source phosphorus loading was attributed to the portion of the drainage basin in agricultural and urban use. Agricultural, urban and forest uses were identified as non-point sources of nitrogen loading. However, most of Edinboro Lake's pollution problems are related to agricultural run-off (U.S. Environmental Protection Agency, 1981).

Agriculture as a Non-Point Source

Based on data collected by Wohler (1978), he concluded that a source of nutrients originates from the agricultural area above the dredged and developed area at the north end of the lake.

Boker and Hallenburg (1978) noted agriculture as a significant source of nutrients.

Wellington (1979) observed that agricultural loads were one source of nutrients entering Edinboro Lake.

About 1980, a letter from the Erie County Department of Health attributed non-point source pollution from agricultural activities surrounding the lake as entering the lake via run-off containing fertilizer, animal waste, and sediment.

Circa 1980, there were 15 dairy farms in the Edinboro Lake drainage basin and over half of the dairy farms were located in the Shenango Creek sub-basin. Only two of the 15 dairy farms had manure storage facilities in use to reduce non-point source pollution to the lake and its tributaries (n.a., 1981).

Lack of livestock manure management and agricultural-related soil erosion were identified by the USDA Soil Conservation Service as non-point sources of nutrient loading to the lake (U.S. Environmental Protection Agency, 1982).

A large dairy farm that is no longer in business may have been a source of nutrients via run-off containing organic wastes (Wellington, 1999).

There used to be about 12 farms in the Edinboro Lake drainage basin. Now there are six to eight farms, which means there is a lot less agriculture in the watershed (Steckler, 1999). One of those former farmers had a manure lot that regularly overflowed into a lake tributary (Steckler, 1999).

Heavy sediment loads entering Edinboro Lake via Conneauttee Creek were noted in the 1990s (Kline, Wiegman and Bier, 1993; Borough of Edinboro, 1997). The watershed for this lake tributary contains a significant amount of agricultural land (n.a., 1995) that could be a source of nutrient input via sediment, fertilizer, and animal waste.

Unless agricultural best management practices have been extensively implemented in the Shenango and Conneauttee watersheds, agriculture is probably still the source of sediment and nutrients (Wolin, 1999).

Urban and Development as a Non-Point Source

Man's encroachments that contribute nutrient input to the lake, include such sources as roads and subdivisions (Wellington, 1979).

Urban run-off contributes to eutrophication of Edinboro Lake (U.S. Environmental Protection Agency, 1981).

Urban run-off is one source of non-point source pollution that appears "…to be of greater importance in adding phosphorus and nitrogen to the lake…" (Pennsylvania Department of Environmental Protection, 1981).

Sources of non-point source pollution in the watershed include fertilizer in run-off from golf courses, lawns, and farms, as well as sediment from eroding construction sites, roads and agriculture (Steckler, 1999).

There is more housing in the watershed, increasing the amount of hard surface in the drainage basin, which increases the rate of storm water run-off (Steckler, 1999).

The lakeside community on the west side and commercial development on the east side of Edinboro Lake could be sources of non-point source pollution entering the lake (Steva, P., 1999).

Wastewater from auto repair garages, laundromats and car washes is treated by the Borough wastewater treatment plant (Kennerknecht, 1999), which appears to eliminate a source of urban non-point source pollution to the lake.

Septic tanks were believed to contribute less than 1% of the total nitrogen and phosphorus loading per year and precipitation was calculated to account for less than 1% of the total phosphorus and less than 2% of the total nitrogen (U.S. Environmental Protection Agency, 1982).

The U.S. Environmental Protection Agency (1981) concluded "…documented wastewater treatment problems in the unsewered areas of Washington Township appear to be minimal at this time. However, this may not continue to be the case if standard septic tank type systems were relied upon to support growth in all areas of the Township. Problems could result if improperly designed septic systems were allowed to proliferate in areas with high water tables, boulders, and unsuitable soils that are common throughout the Township…". It should be noted that the agency was unable to satisfactorily complete a random sample inspection of the septic tank units in Washington Township.

As of the Township's 1995 comprehensive plan, a small portion of Washington Township's residents are served by the municipal wastewater treatment plant. Sewer service located in proximity to Edinboro Lake and within the lake's drainage basin is depicted on the following map excerpted from the comprehensive plan (n.a., 1995).

Septic systems as a [non-point] source of phosphorus loading has likely declined since the lakeside community was connected to the sewage treatment plant (Steckler, 1999).

Malfunctioning septic systems are not likely to be a major source of nutrients or phosphorus, as new septic systems are state of the art and in general should not be a problem. Possible sources could be lawn-care products used at golf courses and residences (Wellington, 1999).

Residents in a majority of the Washington Township portion of the drainage basin are using on-lot wastewater treatment plants, likely septic systems. Roughly speaking, half of the lake shoreline is within that portion of the Township not served by the sewage treatment facility (n.a., 1995).

Septic systems and inflow from Shenango and Conneauttee Creeks were cited as a potential major source of nutrient loading to Edinboro Lake (Wolin, 1999a).

Internal Loading of Nutrients as a Non-Point Source

A primary, or at least probable, present source of nutrient input to the lake is likely to be lake sediments, or in other words internal loading (Wellington, 1999; Steckler, 1999).

Internal release of phosphorus from the lake sediments is a likely major source of nutrient loading to Edinboro Lake (Wolin, 1999a). In a hyper-eutrophic state situation, to which Edinboro Lake may be close, there is no oxygen in the hypolimnion, and phosphorus leaches out of the sediment. This can happen in the lagoon wetlands at the north end of the lake, too (Wolin, 1999).

Sewage treatment plants are probably not a primary source of nutrients, if functioning properly. What is on the bottom of the lake is a likely source. Nutrients dissolve in an anaerobic state and mix during fall turnover (Wellington, 1999).

The lagoon wetland area located at the north end of the lake is probably leaching nutrients into Edinboro Lake. These modified wetlands can act as sources of nutrients when the wetland is flushed. In this case, lagoons open to the lake or connected by culverts can contribute nutrients to the lake (Wolin, 1999).

- **Point Sources**

Washington Township began building its sewage treatment plant in 1974 and completed construction in 1976 (U.S. Environmental Protection Agency, 1981). At the time the plant, which discharges into Edinboro Lake via Whipple Creek, was deemed to be operating well within its required permit limits. However, the plant did contribute some nutrient load to the lake and that contribution could become a more important nutrient source in the future if other sources of pollution are controlled and if wastewater flows increase (U.S. Environmental Protection Agency, 1982).

In 1980, phosphorus and nitrogen loading to the lake was calculated and point sources were shown to contribute 20% of the phosphorus loading and 3% of the nitrogen to the lake from tributary streams. The discharges were contributed by the Washington Township Sewage Treatment Plant and General McLane School treatment plant (EPA, n.d.). At this time, the school and township plants accounted for 98.9% of the volume of discharges entering Edinboro Lake or Conneauttee Creek. The other two major point source discharges into Edinboro Lake were Boron Oil Company and Humble Oil Refining Company (Pennsylvania Department of Environmental Protection, 1981).

Historically, more than two point source dischargers had NPDES permits for discharges into tributaries of Edinboro Lake. In addition to the Washington Township Sewage Treatment Plant and General McLane High School, Hartman (n.d.) reported Huff Mobile Home Park and an Exxon Service Station at Interstate 79 and Route 6N.

During the 1990s Washington Township and General McLane High School are the known permitted point source discharges in the Edinboro Lake drainage basin (Wellington, 1999).

Since a 1995 hydraulic overloading at the Washington Township sewage treatment plant (STP) has caused an inflow or infiltration problem related to rain events. During rain events, the STP exceeds its permitted flow of 0.2 million gallons per day. The STP functions as permitted on a normal basis, but hydraulic overloading pushes solids out of the plant and disrupts sludge bed treatment. The material entering the lake from the STP has not been completely treated and contributes organic matter to the system. (Ebert, 1999.)

The hydraulic overloading is being addressed by the township and is expected to be under control in one or two years (Ebert, 1999.)

While the Washington Township and General McLane High School operate their sewage treatment plants to comply with the requirement of their NPDES permits, it is unclear whether the plants are in compliance. For example: Overflows from the Township STP likely send nitrogen into the lake. Also, the NPDES permit limit of 1 mg/l of phosphorus amounts to an eutrophic effluent being discharged into an eutrophic ecosystem. Either tertiary treatment or connecting the township plant to the Borough STP would help reduce phosphorus input in the long-run (Wolin, 1999).

Recommendations Regarding Excess Nutrients as Stressors

Consensus as to the source(s) of excess nutrients to Edinboro Lake is lacking. However, this is immaterial as a detailed nutrient budget would still be required to identify phosphorus and nitrogen input amounts and their sources. A phosphorus and nitrogen nutrient budget needs to be prepared for Edinboro Lake. Both nutrients need to be considered, given the interdependent relationship of phosphorus and nitrogen in lake ecosystems. A detailed nutrient budget is recommended rather than determination of phosphorus and nitrogen Total Daily Maximum Loads (TMDLs), as the latter has more to do with State regulations and water quality standards than ecosystem integrity and health. A detailed nutrient budget should include:

- the entire drainage basin to determine point and non-point sources of phosphorus and nitrogen inputs to the lake, including but not limited to sewage treatment systems, septic systems, agricultural fields and pastures, golf courses, atmospheric input, streams entering the lake, the lagoons at the north end of the lake and internal loading
- systematic in-stream and in-lake sampling (Note: In part sampling needs to address after-storm events to check on inputs that might not otherwise show up.)
- the mean total phosphorus for the lake
- phosphorus inputs from specific point sources and specific non-point sources
- extent of internal loading
- input from waterfowl
- phosphorus and nitrogen outputs from the lake
- atmospheric deposition of nitrogen

A science-based management plan needs to be developed for Edinboro Lake. A detailed nutrient budget is one part of such a plan. Other components would include a determination of the key ecological processes of the natural lake ecosystem, a comprehensive assessment of biological diversity significance associated with the lake and drainage basin, a comprehensive threats analysis, design of a geographic information system, and development of a management and monitoring program.

Even when working properly as designed, the Washington Township Sewage Treatment Plant is putting nutrients into the lake. The 1 mg/l (1000 micrograms/liter) NPDES permit limit imposed on the plant is adding eutrophic water to a eutrophic system. (Note: 30-100 micrograms/liter is considered eutrophic.) Tertiary treatment would be required to reduce the phosphorus levels in the sewage treatment plant's effluent to an acceptable level. Tertiary treatment is expensive. A solution is to evaluate the possibility to connect the Washington Township Sewage Treatment Plant to Edinboro Borough's facility. The effluent from the township plant would then not be discharged into Lake. The Erie County Department of Health and Pennsylvania Department of Environmental Protection have been considering the advantages of connecting the township's sewage plant to the borough's. Connecting the two sewage treatment plants as a remedy to point source phosphorus input is not popular at the local level. However, this option should be given serious consideration.

Should internal loading prove to be a major contributor of phosphorus to the Edinboro Lake system, consideration should be given to extensive sediment removal. Extensive dredging of sediment is a possible method of addressing phosphorus loading, **but cultural inputs of phosphorus must be cut off for this method to work**. Should extensive dredging be pursued, sediment sampling needs to be conducted prior to dredging in order to conduct a sediment analysis (Wolin, 1999). Toxic compounds might be present in significant levels.

Other recommendations involve taking immediate action to lessen agricultural inputs of nutrients. Many of the specific recommendations are the same as controlling sedimentation from agricultural sources. See the earlier section "Recommendations regarding sediment stressors" for suggested steps (e.g. stream bank fencing in pastures and implementation of best management practices).

Additional recommendations regarding control of nutrient stress sources include:

1. identifying cooperative farmers interested in volunteering to address nutrient issues

2. creation of nutrient management plans for farms within the lake watershed. Issues to address include manure storage and application, and fertilizer management plans

3. establishment of wide streamside buffers that consist of native vegetation.

4. wetlands should be utilized to improve the quality of surface water entering the lake. In the upper portions of the watershed, wetlands should be used at specific sites where nutrients are generated in surface water and could be captured and processed before they move to the lake

5. wetlands should be restored at the mouths of tributaries where they enter the lake in order to provide sediment traps. In particular, the wetland complex at the northern end of the lake should be restored

Chemical Environment Stressor – Toxic Contaminants

Polychlorinated biphenyls (PCBs) were detected during a 1980 sediment analysis of pesticides in Edinboro Lake. PCBs were reported at 22.0 micrograms per kilogram (Pennsylvania Department of Environmental Resources, 1981). While the PCB level reported is low, the fact that the contaminant was detected requires follow-up for two reasons. One reason is that PCB does not occur naturally so there must have been a source for the toxic contaminant. The other reason is that the reported presence of PCBs could have been a lab error and it would be worth determining if that is the case (Tibbot, 1999).

Mercury is a concern in all inland lakes because in muddy anoxic conditions bacteria create elemental mercury through methylation and the toxic metal enters the food chain (Wellington, 1999).

Sources of Toxic Contaminants

Sources of toxic contaminants cited by the information compiled for the annotated bibliography include the following:

- The source(s) of the PCBs found in lake sediments in 1980 is unknown.
- Mercury is a naturally occurring element as well as one present as an atmospheric pollutant that collects in anoxic lakes (Wellington, 1999). Additional sources of mercury related to human activities are possible, but are presently unknown.

Recommendations Regarding Toxic Contaminants as Stressors

- Edinboro Lake sediments should be sampled and analyzed for PCBs and mercury to determine at what levels these toxic contaminants are present in order to be know if a human health threat or threat of damage to wildlife exists.
- It should be determined when the Pennsylvania Department of Environmental Protection intends to re-sample fish to check for toxic contaminants in fish tissues. These tests should be conducted to determine if toxic contaminants occur in Edinboro Lake fish tissue and what, if any, threat to human or wildlife health exists. If appropriate, these results should be used to develop wildlife (fish, turtles, ducks, etc.) consumption advisory notices for the public.

Physical Environment Stressor – Sedimentation

Boker and Hallenburg (1978) conjectured that early European settlement of the drainage basin promoted siltation of the lake as land was cleared for agriculture and virgin timber was cut.

Between 1955 and 1960, soil dredged to create channels at the northern end of the lake was used to fill wetlands. The rapid erosion of this dredge material appeared to have contributed to heavy sediment loading to the lake per Boker and Hallenburg (1978), Pennsylvania Department of Environmental Resources (1981), and Hartman (n.d.).

Beginning in 1957, the mouths of Shenango Creek, Whipple Creek, and an unnamed stream to Shenango Creek were dredged. Increased erosion of Shenango and Whipple Creeks and sediment entering Edinboro Lake followed the dredging of the streams (Boker and Hallenburg, 1978).

Sediment input was associated with development activities in the north end of the lake by Wohler (1978). And ca. 1980, Hartman (n.d.) noted that in recent years siltation had entered Edinboro Lake from development activities in the watershed, such as construction of Interstate 79, a golf course, schools and year-round residences.

The 1986 Erie County Department of Health reported silt entering Edinboro Lake via dredging activities in the wetland where Conneauttee Creek enters the Lake (Wellington, n.d.).

Aerial reconnaissance conducted in 1992 indicated heavy sediment loads entering the lake via Conneauttee Creek (Kline, Wiegman, and Bier et al., 1993).

Based on aerial reconnaissance, heavy sediment loads are entering Edinboro Lake by way of Conneauttee Creek (Borough of Edinboro, 1997).

Hartman (n.d.) observed that an "accurate and reliable" bathymetric map of the lake prior to the dredging and channeling activities from 1955 to 1960 is not available. Early descriptions of the lake have reported the deepest water to range from 40 to 50 feet. The Ganzemuller and West (1973) map shows a maximum depth of 30 feet.

Based on current and past bottom contour maps of the lake, there may be up to ten feet of sediment on the bottom of Edinboro Lake (Wellington, 1999).

About 1980, Hartman (n.d.) reported that "…although it appears that sedimentation rates in Edinboro Lake were high following the dredging operations in the north end of the lake, and perhaps during highway construction and residential development within the watershed, no quantitative estimates of annual fill rates during that period are available…". The sedimentation rate in the lake does not appear to have been calculated since 1980 based on the information reviewed for the annotated bibliography.

Sources of Sedimentation

Sources of sedimentation entering Edinboro Lake cited by information collected for the annotated bibliography consist of the following:

- forestry and agricultural practices in the drainage basin during European settlement (Boker and Hallenburg, 1978)
- development activities at the north end of the lake (Wohler, 1978)
- development activities in the watershed, including construction of Interstate 79, golf course, schools and residences (Boker and Hallenburg, 1978; Hartman, n.d.)
- dredging and filling activities in the marsh at the north of the lake (Boker and Hallenburg, 1978; Pennsylvania Department of Environmental Resources, 1981; Hartman, n.d.)
- dredging of the outlet of Shenango Creek, the outlet of one of its tributaries and the outlet of Whipple Creek (Boker and Hallenburg, 1978)

- non-point source run-off from agricultural activities that surround the lake, containing sediments (Hartman, n.d.; U.S. Environmental Protection Agency, 1982)

- dredging channels in the wetland at the Conneauttee Creek inlet (Wellington, n.d.)

- heavy sediment loads in Conneauttee Creek from agriculture, the principal land use in the watershed (Borough of Edinboro, 1997)

- sediment entering the lake from non-point source run-off from farms, construction sites and roads (Steckler, 1999)

Recommendations Regarding Sedimentation Stressors

1. Create a map showing the lake watershed boundaries in conjunction with roads, municipal boundaries and major land use features, and distribute to all municipal and governmental agencies. Publicize to the public.

2. Recommend increased control of soil erosion and sediment laden run-off in the late watershed including:

    a. increased erosion/sedimentation control at construction and earth disturbance activities

    b. encouraging best management practices in agriculture (contour plowing, strip cropping, catchment basins, cover crops, stream-side fencing, maximum slop usage guidelines)

    c. creation of streamside buffer zones

    d. identifying cooperative landowners along tributaries who would like to participate in water quality enhancement of the lake though implementation of protective land use practices

    e. Wetlands and retention basins can be utilized to improve the quality of surface water entering the lake. In the upper portions of the watershed, wetlands and sediment retention basins should be used at specific sites where sediments are generated and before they move into surface waters.

    f. Wetlands should be restored at the mouths of tributaries where they enter the lake in order to provide sediment traps

3. Discuss lake sedimentation with the Pennsylvania Department of Environmental Protection and request additional consideration of this matter in the watershed.

    - Prepare a current bathymetric map for Edinboro Lake.

- Conduct a sediment core analysis in part to determine the past and present sedimentation rate for Edinboro Lake.

- Determine the original basin depth and conduct sediment analysis to aid in pinpointing when cultural eutrophication began, and to assess whether the lake was already eutrophic prior to the onset of cultural eutrophication. *Note: If the lake was eutrophic before cultural eutrophication began, efforts to address cultural eutrophication will be limited (Wolin, 1999).*

Edinboro Lake has been eutrophied by cultural activities, but the effect is more pronounced than would be expected in a deep lake. Sedimentation in Edinboro Lake contributes to cultural eutrophication. In a shallow lake there is less water to dilute nutrients, and sediments are easily disturbed by winds and storms. Also there is a large surface area for mixing in the summer. When the lake is shallow, more bottom sediments are close to the surface. There is a high phosphorus concentration in the bottom sediments, and mixing releases those sediments. Release of phosphorus contributes to eutrophication (Wolin, 1999).

Physical Environment Stressor – Habitat Degradation, Including Loss and Exotic Species

Habitat Degradation – Nearshore Development

In the 1930s and 1940s, the western shore of the Lake was developed as a summer community (Lee, 1993; Hartman, n.d.).

Circa 1980 approximately 600 nearshore homes existed by Edinboro Lake (Pennsylvania Department of Environmental Resources, 1981).

By the late 1990s, most of the lake's shoreline was developed. Only the northeastern shoreline remains free of development. "…Residential uses, especially along the west shore, and commercial uses make up most of this development…"(Borough of Edinboro, 1997).

Habitat Degradation – Littoral Zone Modification

In the 1940s, numerous channels were developed in the headwaters of the lake to provide boating access to lakeside residences (Lee, 1993).

Between 1955 and 1960, channels were created in the marshy area in the northeast section of the lake, converting the continuous marsh into a group of island marshes and peninsulas (Boker and Hallenburg, 1978; Hartman, n.d.).

A portion of the marsh at the north end of the lake was filled to create land for subdivision development (Hartman, n.d.).

A variety of measures have been used to control aquatic plant growth along the shoreline and in recreational areas, such as beaches and boat docks. Efforts to combat aquatic vascular plants and algae growth have included herbicide treatments, mechanical weed harvesting, and winter draw-down of the lake water level (Lee, 1993; n.a., 1981; Pennsylvania Department of Environmental Resources, 1981; Hartman, n.d.).

Shoreline dredging was initiated in 1990 and continued until 1993. Pennsylvania Fish and Boat Commission concerns regarding further dredging in Curtze Cove in the early 1990s resulted in dredging activities being cancelled in the cove. Due to concerns about loss of fishing habitat, herbicide applications are to be thoroughly reviewed and assurances made that a need exists before approval is given (Lee, 1993).

To control the excessive plant growth, a weed-spraying program is also carried out by a lake-related foundation on a yearly basis…The dredging and weed-control programs have been very successful in combating the effects of the pollutant problem; yet, unfortunately, they do not address the actual source of these problems." (Borough of Edinboro, 1997).

Habitat degradation – Exotic Species

Based on Pennsylvania Fish and Boat Commission surveys, common carp (*Cyprinus carpio*) have been reported in Edinboro Lake since 1938 (Lee, 1993). Common carp can be a severe problem in marshes and littoral zones due to their nature of uprooting vegetation during feeding. High carp populations result in a loss of submerged aquatic vegetation habitats used by other lake biota, including juvenile fish.

Invasive exotic plant species known to be within Edinboro Lake, the adjacent marsh, or along the shoreline are purple loosestrife (*Lythrum salicaria*) and Eurasian water-milfoil (Pennsylvania Fish and Boat Commission, n.d.; Kline, Wiegman and Bier, 1993).

Yellow flag (*Iris pseudacorus*) may or may not be present, as a survey of vegetation conducted in 1998 did not identify the species of iris recorded (Pennsylvania Fish and Boat Commission, n.d.). Yellow flag is an aggressive wetland plant (Gresham, Rhoads and Lotte, n.d.).

Sources of Habitat Degradation, Including Loss and Exotic Species

Sources of habitat degradation, including loss and exotic species cited by the information/data collected for the annotated bibliography include:

- development of a summer community on the west lakeshore in the 1930s and 1940s (Lee, 1993; Hartman, n.d.)

- nearshore home construction around Edinboro Lake (Pennsylvania Department of Environmental Resources, 1981)

- only the northeast shoreline of Edinboro Lake remains free of commercial and residential development (Borough of Edinboro, 1997)

- dredging and filling of a portion of the wetland at the northwest end of the lake in the 1950s (U.S. Environmental Protection Agency, 1982)

- dredging channels within the marsh at the north end of the lake beginning in 1957 (Boker and Hallenburg, 1978; Hartman, n.d.)

- shoreline dredging, herbicide applications, and mechanical weed harvesting to control aquatic plants (Lee, 1993; Pennsylvania Department of Environmental Resources, 1981)

- building of dams on the lake's outflow has altered the wetlands along the circumference of the lake. The result has been the destruction of some natural wetlands and the modification of others. New wetland areas have also resulted, although the comparative value of these is in question

Recommendations Regarding Habitat Degradation Stressors

Little can be done to restore the loss of the nearshore habitat that bordered the lake and which has been destroyed by commercial and residential development. Only the modified marsh, now a series of islands, peninsulas and lagoons/ponds, has the potential to be restored. Refer to the recommendations for excess nutrients stressors and sources as to how restoration of this area may aid in reducing nutrient loading to the lake.

- Undeveloped shoreline and nearshore areas around the lake should be targeted for protection as parks or natural areas by municipal governments or conservation organizations.

- Methods used to control aquatic vegetation within the littoral zone should be undertaken only after considering the effect the measures may have on shoreline habitats for waterfowl and fishes.

- Due to the threat posed to natural ecosystems by exotic species it is recommended that a comprehensive program be undertaken to identify and control invasive exotic species in the lake, and to prevent additional introductions of these pests.

- Weed harvesters should not be used to control aquatic plants, as this method does not distinguish between exotic, beneficial plants, or endangered species. Also species such as Eurasian milfoil are readily spread by the fragmentation produced by weed harvesters.

- Grass carp (*Ctenophharnygodon idella*) should <u>not</u> be used to control aquatic plants because of the damage they do to beneficial plants and aquatic habitats, including the release of nutrients and stimulation of algal growth (Wolin, 1999a). Also, Pennsylvania law prohibits the release of this invasive exotic species in open aquatic systems such as Edinboro Lake.

It should be understood that when aquatic plant control includes killing plants, the decaying matter adds nutrients to the lake ecosystem thereby adding to existing eutrophication problems. Consideration should be given to accepting aquatic plant growth within the littoral zone. Alternatives to herbicide use or mechanical weed harvesters might include hand-pulling plants or dumping sand in beach areas to prohibit plant growth.

Physical Environment Stressor – Hydrologic Modification

Post European settlement changes to vegetation in the drainage basin and Edinboro Lake were attributed in part to the building of a dam for a grist mill below the outlet about 1800 A.D. This dam "…flooded the valley and kettle lake, covering a bog or fen which may have existed, and drowning trees and other vegetation of the affected area…"(Boker and Hallenburg, 1978).

Over a period of about 150 years, Edinboro Lake was enlarged each time a new and higher dam was built. "…By 1950, the lake may have become relatively stabilized, following construction of the present dam which was built in 1922 (Boker and Hallenburg, 1978, Hartman, n.d.).

The water level of Edinboro Lake has been raised eleven feet (3.3 m) by the dam, built in 1922 below the outlet of the lake (Pennsylvania Department of Environmental Resources, 1981). As a result of the dam an extensive wetland had developed, with shrubs, emergent and floating herbaceous plants. This marsh was reported as functioning to keep silt from being carried to the deeper parts of the lake as well as retaining mineral nutrients during the growing season. The marsh was believed to have substantially reduced the potential for algal blooms in much of the lake (Boker and Hallenburg, 1978).

Periodic winter drawdowns of lake waters have been implemented to control aquatic vegetation in the lake. These drawdowns have been practiced for an unknown period of time, beginning prior to 1981 and continuing at least in 1987, 1992, 1994, 1995, and 1998 (Lee, 1993; Wellington, 1991 and n.d.; Pennsylvania Department of Environmental Protection, 1981; n.a., 1981).

Boker and Hallenburg (1978) deduced that the series of dams built on the lake outlet greatly changed the regimes of the streams flowing into the enlarged lake.

Sources of Hydrologic Modification

Sources of hydrologic modification cited by information compiled for the annotated bibliography include the following:

- Beginning about 1800 A.D., a succession of dams flooded the immediate area of the original kettle lake, especially the north end (Boker and Hallenburg, 1978) with the current lake level eleven feet above the original lake surface (Pennsylvania Department of Environmental Resources, 1981).

- The dam on the lake outlet has changed the regimes of lake tributaries, per Boker and Hallenburg (1978).

Recommendations Regarding Hydrologic Modification Stressors

The present dam below the lake outlet has raised the lake level eleven feet, flooding the original lake shoreline and nearshore area. A review of the bottom contour maps of Edinboro Lake (n.a., n.d.) reveals that roughly one-third of the present lake is less than or equal to ten feet deep. Aquatic vegetation occurs within this area of the lake created by the dam.

If further study warrants it, a change in the level of the lake could be considered. Should efforts to control aquatic vegetation to reduce phosphorus input be continued, consideration should be given to permanently lowering the lake level. This would reduce the extent of the lake's littoral zone and re-establish a naturally vegetated buffer zone that could also reduce non-point source run-off into the lake. Such an endeavor would require considerable effort to ensure that invasive exotic species did not vegetate the shoreline. However, as current aquatic plant control efforts are already intensive, this may be a credible pursuit.

Biological Environment Stressor – Pathogens

Based on the eutrophic character of Edinboro Lake, Brezina (1970) recommended that an investigation determine if there were overloaded and malfunctioning on-lot sewage disposal systems located around the lake.

In the early 1970s, septic systems associated with lakeside area residences were recognized as responsible for the input of coliform to the lake (Hartman, n.d.). Installation of sewers in the lakeside area in 1973 resolved the input of coliforms from septic systems from this area of the lake (Hartman, n.d.). Hartman (n.d.) refers to a ca. 1980 letter from the Erie County Department of Health that stated that "…run-off from animal wastes in the watershed remains a source of coliform input to the lake…". Circa 1981, fecal coliform and fecal streptococci bacteria levels exceeded State water quality criteria in the summer and the bacteria appeared to be entering the lake via tributary streams (U.S. Environmental Protection Agency, 1981). Coliform levels continue to be high during heavy precipitation resulting in recent beach closures.

Sources of Pathogens

Sources of pathogens cited by the information compiled for the annotated bibliography include the following:

- Malfunctioning on-lot sewage treatment systems within the lakeside community on the west lakeshore were identified as sources coliforms in the 1970s (Hartman, n.d.).

- Fecal micro-organisms were believed to be entering the lake via unidentified sources in lake tributary watersheds (U.S. Environmental Protection Agency, 1981).

- Improper handling of livestock waste was a source of coliform input into the lake circa 1980 (Hartman, n.d.).

Additionally, the overloading of sewage treatment facilities which results in the release of inadequately treated effluent, and excessive amounts of Canada goose feces, are also suspect.

Recommendations Regarding Pathogens as Stressors

- Malfunctioning septic systems along the shoreline of Edinboro Lake could still be a source of pathogens. Suspected malfunctioning on-lot sewage treatment systems should be investigated and, as appropriate, corrective measures implemented.

- Dairy farms and/or other agricultural livestock in the drainage basin should be identified, and it should be determined whether individual farms could be sources of pathogens to Edinboro Lake. Farmers should be encouraged to implement Best Management Practices for the handling of animal waste.

- Evaluate tributary sub-basins for opportunities to install streamside pasture fencing and other best management practices at cooperating farms.

- Evaluate the hydraulic overloading of the Washington Township sewage treatment plant and the resulting release of improperly sterilized effluent as one of the sources of pathogens. Given that the discharge from this plant also has other negative implications for the lake (e.g. is a source of nutrient input), develop a plan to eliminate this discharge, i.e. move discharge point downstream of lake. If elimination is not possible, a major plant upgrade should be undertaken in order to greatly improve effluent quality.

- Evaluate excessive Canada goose feces as a potential source of pathogens and if necessary work with Pennsylvania Game Commission to control this source. If appropriate, assess habitat use of this bird adjacent to lake and consider habitat modification as a mode of control, e.g. replace large grassy areas with woody vegetation.

Biological Environment Stressor – Exotic Species

Because invasive exotic species degrade habitats, this stressor has been incorporated into the "Physical Environment Stressor – Habitat Degradation." Refer to this section for information on this stressor.

Information Gaps and Additional Research Needs

The conclusion of this study is that enough information exists in order for the Edinboro Lake community to make decisions and take action relative to making improvements to lake health. However, in order to make additional decisions and develop a long-term plan, the collection of certain unavailable baseline and monitoring information is recommended.

Recommendations for Further Study of the Edinboro Lake Ecosystem

Water Quality

Water quality monitoring for Edinboro Lake should be conducted as follows:

1. Chemical and biological parameters such as those conducted by the Erie County Department of Health. Consider expanding the coverage to individual tributaries.

2. Plankton data should be improved and plankton identified to species whenever possible.

3. Plankton samples should be taken a minimum of once a month and a special effort should be made to obtain samples at the onset of spring and fall mixing periods and through the ice during winter months.

Ecosystem

Although a wide variety of information exists on Edinboro Lake, research needs to be undertaken to obtain a comprehensive and current understanding of the ecosystem. In addition to specific suggestions made earlier in this report, that research should include:

1. comprehensive water budget

2. complete study of stratification and mixing

3. trophic study

4. preparation of a bathymetric map

5. determination of sedimentation rates

6. assessment of the lake's biotic community that includes an evaluation of the fish community and identification of fish indicator species for management and monitoring purposes

The tributaries to Edinboro Lake need to be reevaluated. In particular, Shenango and Conneauttee Creeks, and the lake's outlet need to be studied. Stream reevaluation should be conducted, using the current U.S. Environmental Protection Agency Rapid Bioassessment protocols.

Hydrologic Modifications

The effects of the existing dam on the ecology and water quality of the lake should be investigated to determine whether or not the removal of the present dam would have significant positive impact upon lake management.

Recommendations About Cultural Eutrophication at Edinboro Lake

The natural/expected trophic state of the lake without existing cultural eutrophication should be determined to provide baseline information for assessing management endeavors and for management monitoring purposes. Determining the trophic state of Edinboro Lake prior to cultural eutrophication would also pinpoint when cultural eutrophication began. The information gained by determining the natural trophic state of Edinboro Lake prior to human impacts can be used to model changes to the lake's trophic state under different management regimes. Note: Determination of the trophic state of Edinboro Lake does not negate the need for the preparation of a nutrient budget for the lake (Wolin, 1999).

A study should be conducted to determine when the cultural eutrophication of Edinboro Lake began. Determination of the start of cultural eutrophication is accomplished by a sediment analysis that determines both the depth of the sediments as well as when cultural eutrophication began. The sediment analysis will indicate whether the lake was eutrophic before cultural eutrophication began, as it will be difficult to address cultural eutrophication if the natural state of the glacial lake was already eutrophic (Wolin, 1999).

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NOTE TO READER: ***Annotated Bibliography: Health and Management of the Edinboro Lake Ecosystem*** is a separate three-volume companion document. It is available for review by contacting the Western Pennsylvania Conservancy or the Edinboro Regional Community Services, Inc.

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