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A

THE URBAN LAKES OF NEW YORK CITY

by

RICHARD L. NEWMAN

VOLUME I

A dissertation submitted to the Graduate Faculty in Earth and Environmental Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The City University of New York.

2001

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This manuscript has been read and accepted for the Graduate Faculty in Earth and Environmental Sciences in satisfaction of the dissertation requirement for the Degree of Doctor of Philosophy.

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ABSTRACT**THE URBAN LAKES OF NEW YORK CITY****by****Richard L. Newman****Advisor: Professor Victor Goldsmith**

Lakes in urban or urbanizing areas serve multiple functions and often possess substantial value. Despite their uniqueness, until now they have not been extensively studied.

Heretofore, most attention on the impact of urbanization on waterways has focused on lotic systems (streams). However, the primary focus of this effort is the lentic environment (lakes).

A total of one hundred and thirty-four lakes, ponds and reservoirs are identified within New York City, and a representative subset of nine, are selected for detailed study. All nine are anthropogenically-enhanced to some degree, and are shallow (all but one have maximum depths under 2.5 meters). However, these nine lakes may not be representative of urban and suburban lakes in general because of their shallow depths, their buffering (isolation) by parkland, and the absence of any that are completely natural.

A field sampling program was conducted to assess the sanitary quality and trophic state of the nine lakes, along with the impacts of urban runoff. Data was obtained at each lake during the fall of 1997, the spring of 1998, and the summer of 1998.

Based on the field program and literature search (including unpublished New York State data and reports), three quantitative classification systems are developed and tested.

Each of the nine lakes is assigned a score within each system. The three classification systems include Water Input Mechanism, Degree of Artificiality, and Degree of Urbanization. Degree of Urbanization is a measure of the watershed's runoff characteristics, its pollutant export potential, the extent to which the lake is buffered from the impact of urban runoff, and the degree of stream alteration in the drainage area. Statistical analyses are performed to determine whether trophic state and water quality are influenced by proposed classification system scores, and the results indicate little or no influence.

Remedial measures such as dredging, erosion control, diversion of street and highway runoff, and flow augmentation are suggested for the nine detailed study lakes, and future research is recommended. The results of this study, including the proposed classification system, are applied to urban and suburban lakes in New Jersey, California, Georgia, and Florida.

ABSTRACT (Expanded)**THE URBAN LAKES OF NEW YORK CITY**

by

Richard L. Newman

Advisor: Professor Victor Goldsmith

Lakes in urban or urbanizing areas serve a variety of functions and often possess substantial value. Despite their uniqueness, until now they have not been extensively studied. They function as components of urban drainage systems, as recreation sites, as aquatic habitats, and as focal points in parks, commercial developments and residential subdivisions. Their value for passive and active recreation, for aesthetic and economic enhancement, and as habitat, depends on the maintenance of reasonably good water quality, which is more difficult to achieve in an urban setting.

Negative impacts of urbanization on waterways include increases in flooding due to more intense runoff associated with increased ground surface imperviousness, deterioration of water quality caused by import of eroded sediments and pollutants accumulating on urban surfaces by the aforementioned runoff into waterways, and loss of aesthetic and ecological values through such actions as culverting, concrete lining, rip-rapping of streams, along with removing riffles, pools and shoreline vegetation. Previously, most attention has focused on the impact of urbanization on the lotic environment (rivers, streams, creeks and brooks) rather than on lentic systems (lakes and ponds). An assessment of the impacts of urbanization on the lentic environment is an important focus of this effort.

New York City ponds and lakes can be classified as being natural, anthropogenically-enhanced, or artificial. In urban or urbanizing areas, nearly all lakes tend to be enhanced or artificial, having been created or altered through such actions as impoundment of streams, excavation below the groundwater table, lining the shoreline and/or bottom, and introduction of alternate sources of water. In addition to tributary stream flow and groundwater seepage, sources of water might include direct precipitation, urban and suburban runoff, sewage treatment plant effluent, combined sewer overflow, industrial and agricultural discharges, renovated wastewater, dedicated wells, and the municipal water supply.

A total of one hundred and thirty-four lakes, ponds and reservoirs were identified within New York City, and a subset of nine were considered as being representative of this population, using the above classification, and were chosen for detailed study. All nine lakes are either artificial or anthropogenically-enhanced to some degree, and are generally shallow (all but one have maximum depths under 2.5 meters).

The lakes and ponds within New York City are located in geological sites that vary from folded metamorphic rock to glacial moraines and outwash planes. The nine lakes utilized in this study are all located in New York City parkland and are to some degree buffered against (isolated from) urban runoff. However, most receive stormwater runoff from park roads and from adjacent streets and highways via storm sewers discharging directly into the lakes or into tributary streams. While the nine lakes selected for detailed analyses (based on the classification systems developed as part of this study) are generally good representatives of the other New York City lakes (a small portion of which are not

located within parkland), they may not be good representatives of urban and suburban lakes in general because of their shallow depths, their buffering by parkland, and the absence of any that are completely natural.

A field sampling program, conducted as part of this study, was designed to assess the water quality and trophic state of the nine lakes, along with the impacts of urban runoff. Data was obtained at each lake during the fall of 1997, the spring of 1998, and the summer of 1998, based on evaluating secchi transparency, on vertical profiling of the water column (for temperature, pH, conductivity and dissolved oxygen), on the collection of samples (for analyses for nutrients, chlorophyll, selected metals, indicator bacteria, total organic carbon and conventional water quality parameters (such as color, turbidity, hardness, chlorides and oxidation-reduction potential)), and on the performance of visual observations (in accordance with the protocols of New York's Citizen's State Lake Assessment Program). The field data indicated that the lakes were shallow and mainly eutrophic or hypereutrophic. Low metal concentrations seem to indicate that the lakes were not severely impacted by urban runoff.

Based on the field component of this research and the literature search (including unpublished New York State Department of Environmental Conservation information, data and reports), three classification systems were developed and tested. Each of the nine lakes was assigned a score within each system. The first classification system involves the mechanism whereby water is input to the lake; the second involves the extent to which a lake is artificial; and the third is associated with the extent to which the tributary watershed is urbanized. The proposed third system generally tracks such

characteristics as the runoff coefficient, the pollution export potential, the degree of parkland buffering, the extent of nearby on-site wastewater disposal, the degree of stream alteration, and the extent of poorly maintained neighborhoods. Statistical analyses were then performed to determine whether trophic state and water quality are influenced by assigned classification scores, and the results indicated little or no influence.

Independently of scoring, the project was, in part, designed to determine whether water quality was influenced by Water Input Mechanism (three of the nine lakes are fed mainly by impounded tributaries, three primarily by groundwater seepage, and three primarily by City water which has been treated with orthophosphate to control corrosion). Due to the great variability among the lakes, one-way analyses of variance could not detect differences among the three groups of lakes for eleven water quality variables at the 95% level of significance.

Site-specific and general remedial measures such as dredging, erosion control, diversion of street and highway runoff, and flow augmentation are suggested for the nine detailed study lakes, and future studies are recommended. The results of this study, including the proposed classification system are applied to urban and suburban lakes in Middlesex County in New Jersey, San Diego County in California, the Metropolitan Area of Atlanta, Georgia, and Palm Beach County in Florida. These results are compared with New York City lakes, with several similarities and some differences being highlighted.

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I would like to thank my mentor, Professor Victor Goldsmith for guiding me through the conception, development and implementation of this dissertation. I would also like to offer my gratitude to my advisory committee (Professors Coch, Locke and Fillos, along with former member Professor Harris) for all the assistance and advice that they offered during the conduct of this Project.

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CHAPTER 1

INTRODUCTION

1.1 - Problem Statement

While lakes possess a variety of values and have the potential to offer substantial enjoyment to mankind, they are fragile systems that act as sumps for all materials transported down from their watersheds (Jones et al. 1996, New York Federation of Lake Associations and Department of Environmental Conservation 1990), and their longevity in geological terms is usually brief (Britton, Averett and Ferreir 1975, Horne and Goldman 1994 and New York Federation of Lake Associations and Department of Environmental Conservation 1990, North American Lake Management Society 1988, Water Pollution Control Federation 1991). Conventional lake succession theory holds that lakes pass unidirectionally through a series of trophic states, culminating in the climax condition of meadow or forest land. This model is subject to a wide degree of variation, including reversal, with major influencing factors being depth, nature of the watershed, and climate.

Urbanization and other human activities tend to stress these fragile systems to the extreme unless great care is taken to prevent or mitigate these stresses. Activities of man tend to cause the export of large volumes of nutrients, sediments and other pollutants to lakes which deteriorate water quality and cause rapid filling, resulting in the drastic acceleration of the trophic succession process from thousands of years to decades.

The objective of this project is to assess the trophic state and water quality of several lakes and ponds in a variety of urban and suburban settings and to determine

whether these factors are affected by the extent to which the lakes are natural or artificial, by the mechanism through which water is introduced to the lakes or ponds, and by the extent of urbanization of the watershed.

1.2 - Approach

Three new lake and pond classification systems are suggested and an attempt is made to develop quantitative scales for each system. Various aspects of urbanization and their impacts on lotic and lentic environments (including artificial lakes) are reviewed, and a history and descriptions of several of New York City's lakes and ponds are presented.

Nine candidate lakes having varying degrees of urbanization in their drainage areas, varying degrees of artificiality, and differing water input mechanisms are selected out of a total of 134 lakes, ponds and reservoirs in New York City for a multi-seasonal field sampling program designed to determine the trophic state, limnological features and general water quality of each lake. Based on the results of the field program, each of the nine lakes are classified under three of the existing systems described in Section 2.4.1 (See Table 5.9). The status of each lake is evaluated, and regression analyses are performed, determining the relationships among the various measured water quality parameters. Additionally, the lakes are scored under each of the proposed three classification systems (See Table 3.3), and further regression analyses are performed to determine whether significant relationships exist between classification system scores and selected water quality parameters (some of the water quality parameters are designed to function as surrogates for trophic state and for the impact of urban runoff). Finally, analyses of

variance are performed which are designed to assess whether water input mechanism has an impact on trophic state and general water quality.

It should be understood that the field program (which was directed and conducted by the writer as a component of the New York State Department of Environmental Conservation's evolving Ambient Monitoring Program in Region 2, as discussed in Appendix G (Newman 1999)) had to confront a wide variety of variables, only a few of which could be controlled by utilizing the "lake district" concept (lakes located in a single geographic area which are generally created by common natural events (Horne and Goldman 1994)). Among the uncontrolled (but generally defined) variables are geology, lake maintenance (dredging, harvesting, condition of hydraulic structures, etc.), waterfowl, aquifer conditions, morphology, watershed size, weather, quantity of direct urban runoff, and degree of buffering by parkland (severely eroded in many cases). Use of a "lake district" in this case allowed for some control on climate and on the number of governmental jurisdictions involved. Resource and logistical limitations did not allow for synoptic sampling during or immediately subsequent to rain events. Additionally, these limitations did not allow for spatial sample replication during each seasonal sampling visit, nor for temporal replication within each of the three seasons.

Finally, to test the viability of the three proposed new classification systems, they are utilized to score four urban lake systems outside of New York City. These results are then compared with the scores for similar New York City lakes (see Tables 8.1, 8.2, 8.3, and 8.4).

CHAPTER 2

URBAN LAKES: GENERAL DISCUSSION & BACKGROUND: BENEFITS AND PROBLEMS

2.1 - Urban and Artificial Lakes: Values, Planning and Management

Lakes are important resources on our planet. As sources of enjoyment, they support fishing, boating and swimming. Fishing and swimming are among the fastest growing and most popular forms of outdoor recreation and enjoyment. Lakes' commercial value in food supply, tourism and transportation is worth many billions of dollars each year. Lakes also provide life sustaining functions such as flood protection, generation of electrical energy and sources of drinking water. Additionally, as a place of beauty, lakes offer solitude and relaxation. This aesthetic quality is not an insignificant gift, as over 60% of Wisconsin lake property owners who were asked what they valued most in lakes rated aesthetics as the most essential factor (North American Lake Management Society 1988).

In many residential areas, small artificial bodies of water have been constructed as integral parts of developments. These bodies of water have been developed for many reasons, including utilization of undevelopable flood plain land, economic enhancement of adjacent property, recreation, aesthetic or scenic beauty, and the provision and preservation of open space. Along with these evident advantages, there also exists the possibility of such undesirable features as maintenance problems, water quality problems, sediment and trash accumulation, and safety. (Debo 1977) Additionally, there exists the possibility of waterfowl kills caused by botulism (resulting from the soluble exotoxin

secreted by *Clostridium botulinum* (Bryan, Bryan and Bryan 1964)) which often occurs when well-meaning people feed bread and similar materials to the waterfowl. Under warm and hypoxic water conditions, the rotting food becomes an excellent medium for *Clostridium* (Harris 2000). The writer has observed such kills on New York City Lakes on several occasions. However, even in the absence of anthropogenically supplied food, under anaerobic conditions, *Clostridium* can thrive in the sediments, and their toxins tend to concentrate in the insect larvae growing in these sediments, which in turn are consumed by the waterfowl. (Wanielista and Yousef 1981)

In a survey conducted in the metropolitan area of Atlanta, Georgia, which was designed to assess how artificial lakes are actually perceived by property owners living adjacent to them, it was obvious that many had a clear perception of both the advantages and disadvantages associated with the lakes. (Debo 1977) Most of the respondents felt that the lakes had a positive economic impact on the value of their homes and were a positive factor in their decisions to purchase their homes. Furthermore, the lakes provided them with some benefits. Concurrently, many respondents placed a low dollar value on the economic impact of the lakes and stated that they would not purchase another home near a lake. Most of the respondents were cognizant of the fact that the lakes created maintenance problems, but almost all stated that they would be willing to pay for this maintenance if they had access to the lake and could utilize the associated facilities. The positive perceptions appeared to depend upon the larger size of some of the lakes and the community recreation facilities and open space available adjacent to the lakes. The results of the study indicated that the following recommendations should be integrated into the

planning, development and utilization of a residential lake:

- 1- Develop community park and recreation facilities adjacent to the lake;
- 2- Provide for several access points around the lake so that residents that do not own lakefront property will be able to utilize the lake;
- 3- Make the lake as large as possible;
- 4- Establish an on-going maintenance program for the lake and related facilities;
- 5- Assess each homeowner in the subdivision a small monthly assessment for the maintenance and improvement of the lake;
- 6- Establish an active lake association which involves the entire subdivision;
- 7- Involve the maximum number of residents of the subdivision with the lake so that they are able to obtain all potential benefits from the lake, and also assume appropriate responsibilities.

While artificial lakes of the type located in the Metropolitan Atlanta Area (drainage lakes or impoundments) have numerous advantages such as:

- 1- Providing a new or increased watercourse for expansion of aquatic flora and fauna;
- 2- Creating active and passive recreational potential through boating, fishing, bathing, viewing and picnicking;
- 3- Creating wilderness areas around impoundments, with the impoundments as the main foci;
- 4- Minimizing downstream flow fluctuations;
- 5- Minimizing the impacts of droughts and floods;
- 6- Improving downstream water quality by trapping sediments and by mixing less

mineralized flood waters with more ionized low flow (baseflow) water; and

7- Improving microclimate around the impoundment,

they also have negative impacts such as:

1- Flooding useful and scenic lands;

2- Exposing mud flats by fluctuating water elevations;

3- Decreasing the depth of the impoundment over time by sedimentation;

4- Fluctuating downstream flows if the impoundment is used for peaking hydro-power generation; and

5- Loss of a stretch of running river for riverine fishing and other recreational activities, along with disruption of riverine ecology. (Yevjevich 1992)

One form of urban lake is now generally known as a real estate lake. This is any body of water in an urban or suburban environment created or developed for the enhancement of real estate value. Beginning fairly recently, real estate lakes have been established in association with some urban and suburban developments. (Rickert and Spieker 1971) However, some lakes were in existence long before they were surrounded by urbanization or suburbanization. Many farm ponds and rural mill ponds have become real estate lakes, as urban/suburban sprawl has encroached on agricultural land. Water supply reservoirs have sometimes been converted into real estate lakes (and other forms of urban lakes such as the Central Park, Ridgewood and Silver Lake Reservoirs in New York City). Lake Barcroft in Fairfax County, Virginia, formerly served as a reservoir within the Alexandria municipal water supply system. In 1950, its use for water supply was discontinued and it was sold to a developer. The Lake is now surrounded by residences

for the fairly affluent.

Real estate lakes may vary in size from miniature ponds having a surface area of less than an acre, to considerably larger lakes measuring several hundred acres. However, the most common sizes vary from 5 to 50 acres. Originally, most real estate lakes were surrounded by single-family dwellings, generally on quarter-acre or half-acre lots, but currently many lakes are serving communities which consist of multiple dwellings. Lake Anne at Reston, Virginia was built as the focus of town activity and is surrounded by residential and commercial developments. Some residential lake developments substantially depart from the more standard approaches. West of Lisle, Illinois, an apartment complex has been built around four lakes that evolved from four abandoned limestone quarries, with the lakes being utilized for both summer and winter recreation. (Rickert and Spieker 1971)

An artificial lake can be created by either of two procedures, or by a combination of the two. (Matson 1993) The most common method is by impounding a stream with a dam. However, an impoundment requires topographic relief, be it natural or artificial. Impoundment lakes are widespread in the suburbs of many cities located in areas possessing humid climates and rolling terrains. This type of artificial lake is extremely common in the Washington-Baltimore area. Examples of such impoundments in New York City include Van Cortlandt Lake, the Richmondtown Millpond and Conselyea's Pond.

In areas wherein the land surface is flat and the water table is high, lakes are created by excavating into the phreatic zone. Large numbers of artificial lakes have been

created at borrow pits previously utilized as a source of fill for road construction, or at abandoned rock quarries. Excavated lakes are most common in the glaciated terrain of the mid-west, and in the Atlantic and Gulf coastal plains. Large numbers of excavated lakes are being created in southern Florida to serve the ever burgeoning retirement communities. Examples of such excavated lakes in New York City include Prospect Lake, Central Park Lake and the Harlem Meer.

Artificial lakes are developed for three primary purposes, namely; to increase property values, to enhance aesthetic attractiveness, and to provide water-oriented recreation opportunities. However, they are also developed for water supply, as components of drainage and flood control projects, as components of multi-purpose projects (water supply, flood control, power production, irrigation and recreation), as farm ponds, and for aquiculture. (American Water Works Association Research Foundation 1991, Debo 1977, Environmental Protection Agency 1973, New York Federation of Lake Associations and Department of Environmental Conservation 1990, North American Lake Management Society 1988)

A large number of artificial lakes (including several within New York City) were originally created to power various types of mills. The water wheel was probably invented in the first century B.C., and the Romans introduced vertical water wheels, powered by stream flow (undershot wheels), throughout Europe during the last centuries of the Empire to grind corn and to saw stone. By the eleventh century, they were in general use to grind flour, to move the bellows of forges, to operate saws, to make paper, to pump water, to full cloth, and to work salt mines, factories and breweries. These wheels were

often sited under bridges to take advantage of the swifter current at those locations, but their vibrations posed a threat to the structural soundness of the bridges. It is not certain when someone thought to take advantage of the head available at a waterfall, but more powerful overshot wheels, utilizing the steady flow from impounded millponds, were in common use by the fourteenth century. Watertight dams and millraces were difficult to construct and expensive to maintain, and there were often objections to having public waterways obstructed by private weirs, but eventually the more powerful overshot wheels replaced the undershot wheels. (Kirby, et. al. 1956)

A clear, blue lake, surrounded by green forest and grass can be one of the most aesthetically appealing aspects of the urban and suburban landscape. A lake presents a pleasing highlight in the suburban environment, and with some innovative planning, it is even quite possible to create a lake with highly appealing aesthetic quality in a heavily urbanized environment.

Water-oriented recreation is currently quite popular due to increased affluence and more available leisure time. Swimming, boating, fishing, and ice skating are some of the activities that lure potential homeowners to lake oriented communities. However, since these activities are not always compatible, conflicts can develop which may require the imposition of appropriate controls. In reality, intensive recreational utilization, such as the presence of large numbers of motorized vessels on a small lake, can severely detract from those aesthetic values which originally attracted many homeowners. (Rickert and Spieker 1971)

Planners and engineers now recognize that preserving the natural drainage is often

preferable to replacing it with enclosed storm sewers, because the natural drainage can generally accommodate (convey and store) more runoff during major rain events than can the artificial storm drainage systems (this more modern approach is currently being incorporated into New York City's "Bluebelt" planning efforts in southern Staten Island (New York City Department of Environmental Protection February 1997, New York City Department of Environmental Protection March 1997, New York City Department of Environmental Protection April 1999)). Additionally, due to continuing heightened concern over environmental quality, urban planners have been deviating from former patterns of development. Many now advocate maximum possible preservation of pre-existing natural features, particularly trees and original drainage patterns. (Caputo circa 1980, Dramstad, Olson and Forman 1996, Hamill et al. 1989, Middlesex County Planning Board 1983, New York City Department of Environmental Protection February 1997, New York City Department of Environmental Protection March 1997, New York City Department of Environmental Protection April 1999, Robinette 1972, New York City Department of City Planning 1989, Stony Brook - Millstone Watersheds Association 1983) The preservation of open space to break the monotony of urban and suburban sprawl is becoming more frequently utilized in urban design. (Gallion and Eisner 1963)

The concept of "blue-green" development not only improves the quality of the urban environment, but concurrently, it provides for more efficient drainage. Rather than building large artificial drainage conduits in urbanizing areas, the developer preserves the natural drainage patterns and flood plains, and creates artificial lakes and ponds by means of impoundments, or through a combination of impoundments and excavations. These

lakes serve the multiple purposes of providing recreation, aesthetically appealing vistas, and capacity for temporary storage of runoff. Temporary storage eases the demand on storm drainage capacity and often yields systems which are substantially more economical than conventional systems.

In order to be successful, a real estate lake or any other form of urban lake must be aesthetically appealing and must provide opportunities for recreation. Therefore, the water quality must be satisfactory and free of harmful pollutants. Consequently, it is necessary that the source of water to be stored in the lake should be relatively uncontaminated. Polluted streams cannot be developed into successful real estate and/or urban lakes. Actually, since lakes function as sinks for nutrients and sediments (Charlesworth and Foster 1993, Jones et al. 1996, North American Lake Management Society 1998, Water Pollution Control Federation 1991) the creation of a lake on a polluted stream will only serve to magnify the extent of the pollution. Pesticides and metals are an additional concern, since these substances are concentrated on sediments through adsorption, and in the food chain, through biomagnification. (Rickert and Spieker 1971)

In an urbanized setting, a pollution survey is required to determine the streams which are appropriate for artificial lake development. A regional survey (including inspections) of the catchment area should also be performed in order to locate both existing and potential sources of pollution. (American Water Works Association Research Foundation 1991) Streams receiving large quantities of sewage treatment plant (STP) effluent are obviously poor choices. (Urbonas and Stahre 1993) Similarly, streams

receiving large amounts of runoff from heavily urbanized areas may also be poor choices. If an urban area contains waste generating industries and an elevated population density, the runoff to the streams may be more intensely polluted than STP effluent and occasionally even more polluted than untreated municipal wastewater. Suburban and rural streams, which drain heavily fertilized lawns and agricultural lands are also poor candidates for artificial lake development. Suspect streams should be evaluated in detail in order to assess the existing and potential levels of nutrient loading.

Additional consideration must be given to future development potential in the area upstream of the proposed lake site. Intense future upstream urban development would likely contribute a substantial degree of pollution to the lake, unless the new development utilizes advanced best management practices (BMPs) to control or prevent pollution. Such undesirable lake deterioration might lead to costly attempts to retrofit pollution controls or possibly to the loss of the lake for the intended purposes of aesthetic enhancement and recreation.

The inflow that can be anticipated at a potential lake site can be computed from data on runoff, precipitation, groundwater recharge, and evapotranspiration. However, planned artificial lakes need not be totally dependant upon natural inflow. Lake levels and appropriate hydraulic residence times can be sustained by supplying water from other sources such as municipal supplies or wells. Nevertheless, this option may be costly, and such costs should be addressed within the planning effort. (Rickert and Spieker 1971) Furthermore, the use of municipal water supplies may introduce further unforeseen water quality problems as will be discussed in the next chapter. Within New York City, Central

Park and Kissena Lakes are supplied with municipal water, while Prospect Lake (now supplied by municipal water) and the lakes in Flushing Meadow Park (currently supplied primarily by groundwater) were once supplied by water pumped from wells.

2.2 - Basic Limnological Aspects

The actual condition of lakes prior to urbanization, suburbanization, deforestation, agriculture, and other human activities may not have been nearly as pristine as is generally believed. The geological fate of lakes of moderate depth is to gradually fill in and slowly evolve into wetlands. The position of a lake along this geological continuum influences the natural water quality that might be expected in the lake. (North American Lake Management Society 1988) Virtually all lakes would eventually become eutrophic without any anthropogenic influences.

A lake, basically considered as a water system, is influenced by a series of hydrological, physical and chemical conditions, including the nature of the watershed, the configuration of the lake basin, and the quality of the lake water and bottom sediments. These physical and chemical aspects of the lake system subsequently develop and sustain a community of biota that is unique to each lake environment. The lake organisms act to enhance the complexity of each lake system, not only through the wide variety of linkages established to one another, but also through the ways in which they affect the physical and chemical features of the lake. All these components of the lacustrine system (physical, chemical and biological) are in a continuous state of flux, and the chemical and biological components are particularly active. (North American Lake Management Society 1988)

Because lakes are such interactive systems, it is not possible to vary any one feature, such as the quantity of aquatic weeds, or the water clarity, without impacting some other characteristic of the system, such as fish production. As an example, lake managers might decide to eliminate all aquatic weeds by means of mechanical harvesting, thereby inadvertently eliminating an important habitat required for fish survival. Additionally, algae would almost certainly proliferate, stimulated by some of the nutrients that the aquatic weeds had previously utilized. If the lake managers then decided that chemical application would eliminate the algae problem and help to clarify the water, the next occurrence in the chain of events might be additional penetration of sunlight through the water, thereby encouraging a new round of weed growth.

Lakes continuously receive substances from their watersheds and from the atmosphere, as well as energy from the sun and from the wind. As a result, lake quality is affected as much by matter that is discharged into the lake as it is by matter already present. A lake is a sink, and whatsoever enters it is greatly dependent upon conditions in the surrounding drainage area (watershed or catchment). Often, lakes serving urbanizing watersheds contain sediments that could be considered hazardous under the Resource Conservation and Recovery Act (Jones et al. 1996). Major factors include drainage area topography and geology, soil fertility and erodibility, drainage area vegetation, the quality of surface water sources such as direct runoff and tributary streams, and the quality of groundwater seepage. The atmosphere may also add materials to the lake, including acidity (nitric and sulfuric) from rainfall (Sheehan 1998), fine particulate matter, and toxics such as heavy metals, dioxins, and PCBs at some locations.

The three fundamental materials that are discharged to the lake from its watershed include water, dissolved materials conveyed in the water, and particulate matter. The quantity of water reaching the lake (along with topography) determines the volume of the lake, as well as a host of other factors that affect the overall health of the lake ecosystem. As with any container, given a net flow rate, a lake requires a predictable period to fill and to empty. Unlike streams, lakes generally retard the passage of water. Therefore, water entering the lake will remain within it for a period defined as the hydraulic residence time (which is equal to the volume of the lake divided by the flow rate of incoming tributaries and/or runoff (equal to the time it would take the lake to fill if it were completely drained)). The water quality of the lake is a function of the history of the lake water, as well as of the nature of the incoming water.

Because of residence time considerations, programs designed to enhance the water quality of a lake by improving the quality of the incoming water will encounter a lag between the time that incoming water quality improves and the time that improvement becomes obvious in the lake. This lag is partly a function of residence time. Delays between the improvement in quality of inflowing water and its manifestation in lake water will also take place because water quality impacts and is impacted by the biota, benthic deposits and the particular aquatic chemistry of the lake. (North American Lake Management Society 1988)

Lakes, ponds and reservoirs possess a water budget as follows: Water input = Water output +/- water storage in the lake. Inputs include direct precipitation, direct runoff, groundwater infiltration and tributary surface stream inflows, while outputs include

outlet stream discharges, evaporation, exfiltration to groundwater and diversions for domestic, agricultural, or industrial purposes. When inputs exceed outputs, lake levels rise due to storage. However, during periods of drought, lake levels fall as water losses are in excess of gains.

One class of lakes, known as seepage lakes, exist at the intersection of the water table, with the ground surface. Seepage lakes are sustained mainly through groundwater inflow, and their levels oscillate in accordance with fluctuations in the local water table. Drainage lakes (the other major class of lakes), however, are generally sustained by discharges from tributary rivers and streams, and their levels are usually dependent upon surface runoff from the surrounding drainage area. With both classes, the balance between hydrological inputs and outputs affects the supply of nutrients to the lake, the residence time of the water in the lake, and thus, the productivity and water quality of the lake. (North American Lake Management Society 1988) In selected urban environments, municipal water supply can constitute an additional source of water and a classification of urban lakes, based on these three sources of input will be utilized hereinafter.

Lakes and reservoirs are significant and ever-changing features of the landscape because they form in depressions on the earth's topography and they are sumps for material conveyed by both air and the water. With a few exceptions, they tend to be, geologically speaking, extremely ephemeral features of the planet's surface, and their ultimate fate to become filled with sediment and support terrestrial life. (Britton, Averett and Ferreira 1975) Recent limnological literature has focused on eutrophication, which involves enrichment of lakes with nutrients, loss of aesthetic features due to an

overabundance of algae and aquatic macrophytes, and loss of depth through excessive inputs of sediment. At present, accelerated cultural eutrophication (resulting from man's activities) is a serious problem in many lakes, and as a result, new approaches to lake management are being pursued.

Ownership and management of urban lakes are often under multiple jurisdictions. Frequently, each management entity collects limnological data, independently of the others, and comparisons are often difficult to make. Therefore, it is necessary to pursue consistency and accuracy in sampling activities in order to achieve useful comparisons. (Britton, Averette and Ferreira 1975)

The physical, chemical and biological aspects of lakes are complex and interwoven. Any given aspect affects and is affected by the others. As an example, sunlight penetrating the water stimulates the growth of phytoplankton (floating one-cell plants). If all conditions are favorable, the algal cells become so numerous that they inhibit light penetration. Diminished light penetration may not only cause the arrest of continued phytoplankton production, but it may also reduce the rate of warming of the lake by the sun. And so, a biological process, algae growth, affects and is affected by light penetration, which subsequently influences the heat balance of the lake (a physical processes).

Limnologists have defined various zones in lakes and ponds, based on the extent of light penetration in the water. The littoral zone is the shallow-water area where light penetrates to the bottom. Sometimes, wave action may result in shoreline erosion and cause particulate materials to be suspended in the water. These suspended particles may

result in elevated turbidity and thereby reduce light penetration and thus, the depth of the littoral zone. Emergent (above the water surface) and submergent (below the water surface) rooted green plants (aquatic macrophytes) are confined to the littoral zone. (Britton, Averette and Ferreira 1975, Horne and Goldman 1994)

The limnetic or pelagic zone is the open water area of the lake that reaches from the water surface to the depth where light intensity is diminished to about 1% of the surface light. Theoretically, the lower boundary of this zone is the compensation level, which is the depth at which oxygen utilization by bacteria, plant and animal respiration equals the photosynthetic oxygen output by green plants. The depth of the compensation level is a function of the light-scattering and absorbing characteristics of the material in the water. The pelagic zone is inhabited by free-floating or weakly swimming organisms (plankton), swimming organisms (nekton), special organisms that only inhabit the water surface (neuston), and a group of organisms among the neuston which comprise large wind-blown assemblages (pleuston). The combined littoral and pelagic zones are considered to be the euphotic zone, which is the area wherein there is adequate sunlight to support photosynthesis. (New York State Federation of Lake Associations and Department of Environmental Conservation August 1996)

The profundal or aphotic zone is the deepwater area where only respiration and decomposition occur. Light intensity in the profundal zone is inadequate to support photosynthesis. As a result, organisms inhabiting the profundal zone are dependant upon food produced in the euphotic zone. Important profundal zone organisms include zooplankton, benthic invertebrates, fungi and bacteria.

The benthic zone is the lake bottom wherein descending particulate matter is deposited and the organic component is decomposed. It is inhabited by various types of burrowing animals (infauna) and animals confined to the surface of the benthic zone (epifauna). (Britton and Averett 1975, Horne and Goldman 1994)

Heat in an aquatic ecosystem performs two major functions: it establishes thermal stratification and mixing in water bodies, and it controls the rates of chemical reactions and biological processes. (Horne and Goldman 1994) Thermal stratification, which is driven by insolation (and there has been a major effort to develop models which can predict the thermal structure or stratification of lakes and reservoirs as they respond to meteorological forcing (Henderson-Sellers et al. 1993)), is the most profound physical occurrence in a lake's annual cycle and dominates most features of lake structure. Heating reduces the density of the upper layers of water which, in combination with the kinetic energy contributed by the wind, yields a three-layered system. If the lake is deep enough, the summer stratification creates an upper warm, light layer (the epilimnion), a cold, dense lower layer (the hypolimnion), and an intermediate transitional layer (the metalimnion). The region wherein the greatest change in temperature occurs is known as the thermocline (or more properly, the seasonal or parent thermocline), and it is always located within the metalimnion.

The seasonal thermocline generally spans a temperature difference of 10 or 15 degrees C. in temperate climates, and is not fixed in depth. It slowly descends during the summer until the lake turns over in the autumn. While the seasonal thermocline is confined to the metalimnion, temporary thermoclines commonly form in the epilimnion.

These temporary thermoclines are subsequently mixed down to intermediate depths by afternoon winds or nocturnal convection currents. (Horne and Goldman 1994)

During summer, the volume of the epilimnion expands, while the volume of the hypolimnion contracts. Finally, destratification occurs during the autumn, when heat losses due to conduction and evaporation exceed the input of solar heat, and the temperature of the epilimnion no longer exceeds that of the hypolimnion. Once destratified, lakes that mix from top to bottom are defined as holomictic, while if they mix only partially (due to great depth or chemically induced stratification), they are defined as meromictic. Dimictic lakes mix twice annually (fall and spring), and monomictic lakes, which do not freeze, mix continuously through the winter. Polymictic lakes (which are generally shallow) mix very frequently throughout the year. Amictic lakes never mix (because they are covered with ice throughout the year). (Horne and Goldman 1994)

In addition to thermal stratification, lakes may chemically stratify when a vertical ionic concentration gradient (which can actually inhibit thermally driven mixing) creates a vertical density gradient. Such a situation can be caused by a substantial discharge of dissolved substances into a lake or pond. (Effler 1999, U.S. Department of Health, Education, and Welfare 1964)

Water bodies are often classified on the basis of the geological processes through which they were created. Most natural lakes were formed by tectonic, volcanic or glacial forces. Many of the oldest and deepest lakes on the planet have tectonic origins, while some of the clearest and youngest are volcanic. However, most lakes in existence today were formed through glacial action. The remainder were created through mass

movements, alluvial action, aeolian processes, meteorite hits, solution of limestone, and animal activity. Of increasing importance are anthropogenic activities which result in the creation of artificial lakes, ponds and reservoirs. (Brakke 1984)

Lake succession, from creation through destruction, occurs gradually (but not in a geological sense) for all but a few small lakes and ponds that rapidly fill with sediment, or are destroyed by the same process which formed them. Once the lake is formed, a biological community is usually quickly established. The lake then promptly evolves to some trophic equilibrium, which subsequently changes slowly, but which may oscillate forward and backward as climate changes. If the supply of sediments and nutrients is high, the lake is probably eutrophic. Eutrophic lakes are productive, turbid, shallow and rich in algae, and they undergo considerable variations in surface and benthic oxygen levels. Oligotrophic lakes, which receive low inputs of nutrients and sediments, are generally unproductive and deep, and have very transparent waters that are fully saturated with dissolved oxygen. Mesotrophic lakes are found between these two extremes, and they tend to be moderately fertile. Dystrophic lakes are brown in color due to their high humic acid content. They are generally unproductive. (Environmental Protection Agency March 1979) Finally, hypereutrophic lakes have been defined as ecosystems that are disturbed and unstable. They are typically shallow and unstratified, and consequently subject to extreme transformations due to alterations in light, wind and temperature. Intrinsic to these systems are unbalanced nutrient and dissolved oxygen cycles caused by these transformations. (Burden and Malone 1984) Hypereutrophy is generally characterized by “pea-soup” conditions. (North American Lake Management Society

1988)

Among the parameters useful for analyzing the condition of a lake, especially at the bottom, is the redox potential or oxidation-reduction potential (ORP or Eh), which is a direct potentiometric measurement of the equilibrium established between all oxidized and reduced species in solution. For any chemical reaction, Eh can be expressed as follows:

$$Eh = \Delta G / -nF$$

where:

ΔG = change in Gibbs free energy of the reaction in kilojoules/mol

n = number of electrons involved in the reaction

F = Faraday's Constant in kilojoules/volt mol, and

Eh is in volts

It can also be expressed as:

$$Eh = E^0 + 2.303(RT/nF)\log(\alpha_{ox}/\alpha_{red})$$

where:

E^0 = Standard Electrode in volts

R = The Gas Constant, 8.314×10^{-3} kilojoules/degree Kelvin mol

T = degrees Kelvin, and

α_{ox} and α_{red} = activities of oxidized and reduced species, respectively

(From Drever 1988)

It is called a potential, because the substances are not truly connected in nature. The change in the oxidation state of several metals and nutrients are defined by their ORPs; e.g., at neutral pH and 25 degrees C, oxygenated lake water has a redox potential of about

+ 500 milli-volts (mV). Under these conditions, most metals and nutrients tend to be thermodynamically stable in their most oxidized forms. Iron will be present as Fe^{3+} , not as Fe^{2+} . Also, nitrate rather than nitrite or ammonia will be present, while sulfate will be more stable than sulfide. As the name suggests, dissolved oxygen (DO) is closely associated with redox potential, and so as the DO concentration of the water drops, the Eh drops. When the DO is depleted, several substances are chemically reduced, each at a specific Eh. For example, between an Eh of +450 and +300 mV, ammonia becomes more stable than nitrate, and between +300 and +200 mV, Fe^{2+} is favored over Fe^{3+} . When Eh approaches zero, hydrogen sulfide is favored over sulfate. These reactions all tend to reverse when DO is reintroduced. (Horne and Goldman 1994)

Although the influence of Eh extends throughout the water column, this influence tends to be strongest in a thin layer (the oxidized or reduced microzone) at the sediment-water interface, where reducing conditions change to oxidizing conditions. (Horne and Goldman 1994) The aforementioned redox potential changes occur slowly in sterile water, but in natural waterways, aquatic microorganisms render the reaction rates far more rapid than those for purely chemical reactions. Most redox reactions are conducted by bacteria that obtain their energy through conversion of a substance to its thermodynamically favored state as determined by DO or Eh. (Drever 1988, Fetter 1988, Novotny 1995, Robertson, et. al. 1989)

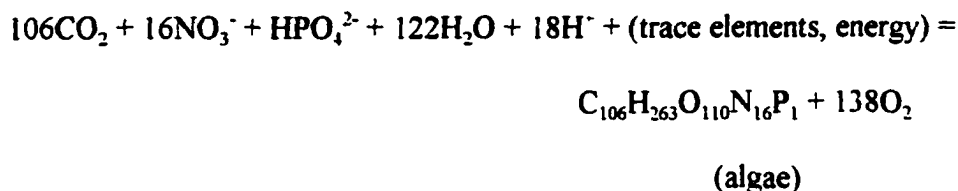
Changes in Eh are most significant in eutrophic lake conditions and in several unique environments such as reducing acidified bogs. In most lakes, the Eh usually remains near +500mV, because DO rarely falls far from saturation. However, in eutrophic

lakes, the depressed DO concentrations near the sediment-water interface unusually drop the Eh to below +200mV. As discussed earlier, this changes oxidized ferric iron to ferrous iron, a process that converts insoluble ferric phosphate to soluble ferrous phosphate. As a result, the liberated phosphate ions may assist in accelerating eutrophication during the summer stratification. (Horne and Goldman 1994)

Oxidation-reduction conditions within streams, lakes and the seas, are generally controlled by the processes of photosynthesis and microbiological decomposition of organic matter. (Drever 1988, Horne and Goldman 1994) Photosynthesis is the process through which carbon dioxide is converted to organic matter and oxygen. Photosynthesis utilizes energy from sun to form substances (organic matter and molecular oxygen) that are unstable together, from the stable compound, CO₂. In the absence of photosynthesis, the molecular oxygen in the atmosphere would be steadily depleted by the oxidation of organic matter and reduced metals until no free oxygen remained.

In addition to carbon, plants require nitrogen compounds, phosphorus compounds and a wide variety of trace elements in order to conduct photosynthesis. In aquatic systems, phytoplankton and macrophytes will grow and multiply until all available phosphate and nitrate is depleted, at which point, photosynthesis terminates. In unpolluted fresh waters, phosphorus is normally the limiting nutrient, whereas nitrogen is occasionally limiting in polluted waters. Saline waters are usually limited by nitrogen. (Horne and Goldman 1994) The availability of particular trace elements is occasionally limiting for short periods of time, but this is unusual. Photosynthesis constitutes the ultimate source of food for all organisms in surface waters.

The importance of phosphate in the carbon-oxygen balance of waters, particularly in lakes is substantial. The equation representing photosynthesis is as follows:



This shows that each atom of phosphorus (as phosphate) added to surface waters will lead to the fixation of about 106 atoms of carbon in organic matter, and when organic matter produced from one atom of phosphorus decomposes, it can potentially consume 138 molecules of oxygen. (Drever 1988) This indicates that a small amount of phosphorus can impose a prodigious oxygen demand on an aquatic system.

2.3 - Impacts of Urbanization on Lotic and Lentic Waters

Urbanization first occurred near the coasts and this historical trend is continuing. Approximately 80% of the population of the United States resides in coastal areas, including the Great Lakes. The negative impacts of urbanization and suburbanization on estuarine waters has been well documented in a number of sources, including the Nationwide Urban Runoff Program (NURP). (Environmental Protection Agency January 1993)

During urbanization, pervious locations, including vegetated and forested areas are converted to land uses generally having large areas of impervious surfaces, which result in augmented runoff volumes and contaminant loadings. While urbanization may increase the economic value of property under a wide variety of environmental conditions, it

usually results in changes to the physical, chemical and biological features of the watershed. Vegetative cover is removed from the land surface, and cut-and-fill activities, which increase the development potential of the site, take place. Natural depressions, that can temporarily store water, are graded to create a uniform slope, thereby increasing runoff during a wet weather event. (Schueler 1987) As population density rises, there will be an associated rise in contaminant loads generated by human activities. These contaminants generally reach surface waters by way of surface runoff (usually when sorbed on the finest particulate matter (Ashley 1997)), without receiving any treatment. (U. S. Department of Agriculture June 1986) However, even vegetated areas such as golf courses which are often located near water courses, can be sources of contaminants such as nutrients and pesticides. (McLaughlin July 1994)

Even before substantial urbanization occurs, lower density old and new suburbs can pose a substantial risk for lakes and ponds. Remaining farmlands pose a continuing risk of pollution from runoff containing animal wastes, fertilizers, pesticides, sediment, salts and oxygen demanding materials, unless appropriate preventive measures are taken. (U.S. Department of Agriculture in cooperation with the New York State Department of Environmental Conservation 1995, New York State Department of Environmental Conservation 1998, Nichols 1991) On-site wastewater disposal systems are often prone to failure unless the best possible planning, design, construction and maintenance is utilized, with contaminated effluent finding its way into surface waterways and adding a substantial nutrient loading. (Environmental Protection Agency October 1980, Environmental Protection Agency January 1980, Environmental Protection Agency

October 1981, U.S. Department of Agriculture 1978, New York State Department of Environmental Conservation 1998, Rutgers 1989, DeSana August 1999). When such activities occur in certain critical watersheds, they can constitute threats to public water supplies. (Richman 1997, Boria and Wilson 1999)

As urbanization proceeds, alterations to the natural hydrology of an area are inevitable. Such alterations take place in response to clearing and grading, and the creation of impervious surfaces and maintained landscapes. The greatest problems involve the substantially augmented runoff volumes, and the consequent erosion and additional sediment loading to surface waters that are invariably associated with these changes to the landscape. Uncontrolled construction site sediment loads are on the order of 35 to 45 tons per acre per year, while loadings from undisturbed forests are generally under one ton per acre per year. (Environmental Protection Agency January 1993) Hydrological changes to the watershed are compounded after construction is completed. Impervious surfaces such as rooftops, roads, parking lots and sidewalks reduce the recharge capacity of the ground and lead to substantially magnified quantities of runoff. (Dunne and Leopold 1978, Ferguson 1998, Ferguson 1994, Novotny 1995, Urbonas and Stahre 1993) Such flow modification and vegetation removal measures lead to physical habitat degradation, which is the most prevalent stressor of aquatic communities. (Markowitz 1996)

Nearly 5% of the land in New York State is urban. (New York State Department of Environmental Conservation 1985) Urbanization is an inevitable outgrowth of construction and developmental activities. The physical and chemical aspects, and the biological configuration of urban waterways are generally quite different from those

draining an unaltered watershed. An urban waterway generally exhibits a dearth of life, with indigenous organisms typically associated with stressed environments resulting from hydrological changes, and/or point and nonpoint sources of pollution. The conditions that usually impact urban waterways where point discharges and combined sewer overflows are absent are as follows:

- 1- Increased storm water runoff, which leads to an increase in the frequency and intensity of flooding, intensified channel erosion, and changes in benthic composition;
- 2- Alteration of the receiving waterway temperature regimen;
- 3- Increased entry of toxics such as metals, pesticides, oils, road salt, synthetic organic chemicals, and detergents;
- 4- Increased nutrient inputs;
- 5- Substantially enhanced discharges of sediments;
- 6- Increased inputs of organic matter;
- 7- Elevated quantities of litter (rubbish and debris) along tributary stream banks. (New York State Department of Environmental Conservation 1985)

In addition to raising and concentrating peak flows, urbanization reduces groundwater recharge and therefore, it also reduces base flows. This happens because the drastically increased imperviousness associated with urbanization results in a larger percentage of direct runoff, leaving a reduced quantity of water available for soil moisture replenishment and for groundwater storage and maintenance of baseflow. (Blyer March 29, 1998, Buxton and Chernoff 1995, Buxton et al. 1981, Cohen et.al. 1968, Cohen et.al.

1970, Kimmel 1972, Middlesex County Planning Board March 1981, Novotny December 1991, Spinello and Simmons 1992, Spinello et al. 1997) Furthermore, urban storm runoff conveys pollutants from the ground surface into rivers, streams and lakes. This problem is exceptionally intense in urban areas, where impervious surfaces collect pollutants which are quickly washed into drains and subsequently, unhindered, into surface waters during wet weather events. (Ferguson 1998)

While the necessity for managing urban storm runoff for flood prevention and mitigation has long been recognized, the full intensity of pollution problems associated with urban runoff has only been recognized within the last two decades, and thus far, little progress has been made in achieving substantial reductions (McSweeney 1997).

However, stormwater has been regulated for many years at the local level near valuable recreational lakes such as Lake Tahoe and water supply reservoirs such as the Occoquan Reservoir in Virginia. (Davis et.al. 1999) Based on a hypothetical, but typical U.S. city, Environmental Protection Agency calculations indicated that the runoff resulting from the first hour of a moderate to heavy rain event would contribute substantially more contaminant load than would the same city's wastewater during the same period of time. (Actual studies showed that the concentrations of heavy metals and solids in urban runoff are two to fifty times their concentrations in typical raw wastewater. (Environmental Protection Agency December 1974)) These comparisons are depicted in Table 2.1.

Among the sources of urban runoff are the following:

- 1- Street Pavements - The components of road surface deterioration, including the decomposition products of asphalt and other petroleum-based substances, become

incorporated into the urban runoff pollutant load. The quantity of pollutants such as oil and other hydrocarbons, which tend to accumulate in the sediments is a function of the age and type of surface, the traffic load, and the weather.

- 2- Vehicles - Fuels and lubricants leak; particulates wear off tires and brake linings; exhaust emissions accumulate on the road surface, and corrosion products drop from vehicles. While the amount of material contributed by individual vehicles may be infinitesimal, the cumulative impact from numerous vehicles is substantial. Vehicles are a major nonpoint source of metals, including lead.
- 3- Fallout - Air pollutants such as dust (which is generated by the crushing or grinding of organic or inorganic materials), and contaminants from stacks, vents and automobiles will settle on the land surface and wash off as polluted runoff.
- 4- Vegetation - Leaves, grass cuttings and other plant materials that fall, or are deposited on the urban surface may be incorporated into the runoff problem. The extent of the problem depends on the location, season, landscaping procedures, and disposal practices. Actually, the aquatic biota in the upper reaches of tributary streams are dependent upon these allochthonous sources of food, but in urban locations this material will likely overwhelm the oxygen budget of the waterway.
- 5- Spills - Producers and manufactures often store large quantities of hazardous substances in order to create the artifacts that our society requires. Sometimes, through carelessness, mismanagement or accidents, leaks or spills of these materials introduces them into the air, land or aquatic environment. Household

TABLE 2.1		
COMPARISON OF RUNOFF LOAD TO WASTEWATER LOAD		
PARAMETER	RUNOFF LOAD (lbs./hr.)	WASTEWATER LOAD (lbs./hr.)
Settleable & Suspended Solids	560,000	1,300
BOD ₅	5,600	1,100
COD	13,000	1,200
Total Coliform	40x10 ¹² organisms/hr.	4.6x10 ¹⁴ organisms/hr.
Total Kjeldahl Nitrogen	880	210
Phosphates	440	50
Zinc	260	0.84
Copper	80	0.17
Lead	230	0.13
Nickel	20	0.042
Mercury	29	0.27
Chromium	44	0.17

(From New York State Department of Environmental Conservation, *Stream Corridor Management: A Basic Reference Manual*, 1985)

products such as paint thinner, lacquers, resins and detergents also find their way into storm drainage systems.

6- Land Surface - The type of ground cover available in a watershed, and the levels of vehicular and pedestrian traffic depend on land use, and will affect the quality of runoff.

7- Litter - This consists of a variety of discarded items and animal droppings.

Although quantities may be small, these contaminants are probably the most

aesthetically insulting component of urban runoff.

8- Anti-Skid Compounds & Chemicals - In the urban areas of the northeast, large quantities of substances designed to melt ice in the winter are broadcast onto roads. Salts, sand and ash are the most commonly utilized agents. A variety of other chemicals are used as fertilizers and pesticides, and many of these chemicals become part of urban runoff.

9- Construction Sites - Erosion of soil from land disturbed by construction is an obvious sources of particulate matter in urban runoff. The most significant of these sources include large scale projects such as transportation and utility construction, along with major residential urban development and renewal. Proper construction methods and appropriate control practices will control the quantity and quality of the runoff. (New York State Department of Environmental Conservation 1985, Environmental Protection Agency January 1993, Environmental Protection Agency November 1996, New York Nonpoint Source Coordinating Committee 1992, Pitt and Field 1990, Schueler 1987)

Stormwater runoff has been identified as a major contributor to the deterioration of many urban watercourses. (Perciasepe 1995) Organic and metallic toxicants are considered to be responsible for a major proportion of these detrimental effects and have been found in urban runoff discharges during previous studies. (Field et al. June 1997, Novotny January 1992, Paulson and Amy July 1993, Pitt et al. September 19-24, Schueler 1987, Norman 1991)

Table 2.2 summarizes the estimated stormwater discharges of frequently detected

organic and metallic toxics from all US cities with populations in excess of 100,000 (total area of 15,000 square miles). These quantities apply to discharges that directly enter the surface waters of the US and are based on one hundred stormwater outfall samples collected through the National Urban Runoff Program (NURP). This NURP information is drawn mainly from residential areas, with some commercial land uses having an influence. More recent information indicates that industrial runoff can possess far higher concentrations of these toxics than the areas represented in the NURP data. Additionally, dry weather flows in storm drains that may be contaminated by non-stormwater discharges (such as flows from illicit industrial and commercial cross-connections) can also substantially elevate toxics loadings. (Pitt and Field 1990)

Pitt and Field also observed that roof runoff and urban creeks (along with combined sewer overflows (CSOs)) had the greatest number of observed maximum toxic organic values. Additionally, roof runoff contained the highest concentrations of zinc (no doubt associated with galvanized metal), while parking areas demonstrated the highest nickel concentrations. Also, vehicle service areas showed the highest cadmium and lead concentrations, while streets had the highest aluminum concentrations. Surprisingly, landscaped areas presented the highest chromium concentrations and urban creeks had the most elevated copper levels. (Pitt and Field April 1990) However, a New York City study found that runoff from heavily industrialized areas had the highest concentrations of cadmium (5.35 ug/l), copper (115.6 ug/l), lead (61.0 ug/l), nickel (61.5 ug/l) and zinc

TABLE 2.2	
TOTAL DISCHARGE OF TOXICS IN URBAN STORMWATER	
SUBSTANCE	DISCHARGE (tons/year)
Arsenic	80
Chromium	350
Copper	700
Cyanide	200
Lead	3,000
Zinc	3,000
Bis (2-ethylhexyl) phthalate	30
Chlordane	5
Chrysene	3
Fluoranthene	10
Pentachlorophenol	70
Phenanthrene	4
Pyrene	8

(From Pitt and Field April 1990)

(594 ug/l), while highway runoff contained the highest concentrations of chromium (32.0 ug/l), mercury (0.2 ug/l) and molybdenum (20 ug/l). (New York City Department of Environmental Protection June 1988)

Dissolved phosphorus is the substance that has the greatest influence on the productivity of fresh water lakes and impoundments. Algae affect the quality and appearance of aquatic systems. They have an influence on the level of fish production, and they also influence the cost of treating water supplies for domestic and industrial uses.

Ultimately, the level of algae observed in most temperate latitude lakes depends upon the

quantity of dissolved phosphorus discharged to the lake. According to a Cornell University study of 13 central New York lakes, the focus on dissolved, rather than on total phosphorus inputs to the lakes constitutes an important distinction, which should be considered by anyone assessing lake inputs, identifying sources, or making management and policy determinations with regard to water quality. (Boulein et. al. 1977) This is because of the insolubility of many phosphorus compounds in the aquatic environment, along with the tendency of phosphates to be adsorbed onto soil particles and thereafter to settle to the bottom where they become unavailable to phytoplankton (in street runoff, nutrients are associated with fine solids (Environmental Protection Agency August 1976)). However, as subsequently discussed in Chapter 5, under reducing conditions, insoluble and adsorbed phosphorus tends to be released back into the water column. Additionally, the most commonly used lake response models relate Trophic State Index, chlorophyll *a* and secchi transparency to total phosphorus concentrations (in both lake inputs and in ambient lake waters) rather than to dissolved phosphorus concentrations.

Considerations with regard to the unique impacts of phosphorus on lake productivity are threefold. The first is that among the nutrients necessary for aquatic plant support, phosphorous is the most geochemically rare. Secondly, nitrogen and carbon tend not to be limiting in fresh water, since some blue-green algae can utilize N_2 directly, while highly soluble CO_2 (diffused from the air or converted from HCO_3^- and/or CO_3^{2-}) provides a virtually unlimited supply of carbon. (Horne and Goldman 1994) Additionally, lakes and streams located in watersheds underlain by nitrogen-rich bedrock tend to have high concentrations of the nitrate that is released during weathering. (Waterline January 1999)

Finally, in most temperate freshwater lakes, summer levels of algae are generally proportional to annual inputs of dissolved phosphorus per volume of water in the upper layers of the lakes (even in those lakes characterized by consistently low nitrate levels). Most of the dissolved phosphorus carried by streams is conveyed during or immediately after rain events or snowmelt. Therefore, measurements of dissolved phosphorus should be conducted during periods of high stream discharge if the watershed contributions are to be correctly estimated. (Bouldin et al. 1977, Walker, Westerberg and Bode 1989)

Alternatively, other sources (North American Lake Management Society 1988) argue that total phosphorus is the single most important nutrient necessary to determine loading in lake inflows and outflows. In the past it was assumed that if erosion was controlled, then phosphorus was controlled (based on the aforementioned conclusion that phosphorus attaches itself to soil particles and is not easily dissolved). However, recent research has revealed that phosphorus applied to farmlands is conveyed to water supplies through runoff, even when no significant erosion exists. (DeSena May 1999) Nevertheless, there is enough data that associates phosphorus with the light fraction of sediment discharged into lakes in urban runoff to convince environmental practitioners that phosphorus inputs to urban eutrophying lakes can be controlled by controlling light sediment inputs. (Pisano and Aronson 1981)

The contaminants in stormwater runoff discussed previously produce a wide variety of impacts in downstream aquatic systems. Among these impacts are the following:

- 1- Sediment may destroy fish habitats through the blanketing of spawning and feeding

areas, and through the elimination of certain organisms lower on the food chain. Furthermore, sediment can directly impact fish through gill abrasion and fin rot. Also, it can reduce sunlight penetration, thereby impairing photosynthesis of aquatic plants. Suspended sediment diminishes recreational values, reduces fishery habitat, adds to the wear of water supply pumps and distribution systems, drastically reduces the life of a lake, and adds to water treatment costs. Nutrients and toxic substances adsorbed onto sediment particles are transported to waterways and may enter aquatic food chains, cause fish toxicity difficulties, impair recreational uses, or reduce the value of the water resource for supply purposes. (New York City Soil and Water Conservation District May 1999)

- 2- Urban Street Surfaces and other impervious surfaces, which have been heated by sunlight, may be a major source of thermal energy which is conveyed to receiving waters by urban runoff, adding stress to the biota. Cold water fisheries may be eliminated or the habitat may become only marginally supportive of any fishery. Thermal stress may lead to dissolved oxygen (DO) stress, and reduce the resistance of fish to disease.
- 3- Nutrient Enrichment of surface waters may result in excessive algae and aquatic plant growth, choking open waters while consuming aquatic DO (mainly through plant die-off). Fish and other aquatic organisms, water dependent recreation, and the utilization of the resource for water supply will be negatively impacted.
- 4- Organic materials are discharged to surface waters, either as dissolved or suspended components of urban runoff. Biochemical decomposition of these materials will

reduce or even deplete the DO in the receiving waters. This will result in either fishery habitat stress or elimination.

5- Toxic Chemicals can enter aquatic systems, either dissolved in runoff or sorbed onto sediment or organic particles. The primary impacts of these substances in surface water ecosystems involve their entry into the food chain, their bioaccumulation up the food chain, their direct acute and chronic toxic effects on aquatic life, and general habitat degradation.

6- Bacteria & Viruses, which include disease producing organisms (pathogens), and are usually associated with human and animal wastes, may survive and contaminate drinking water supplies, impair recreational uses of the waters, and impact fish, domestic animals (which should not be permitted near waterways) or wildlife. (New York State Department of Environmental Conservation April 1992, Novotny 1995, Novotny 1991, Schueler 1987)

Contemporary urban lakes, both natural and man-made, usually begin their existence in rural areas. However, as urban areas expand, the watersheds undergo various changes. (Schueler 1987) Such changes have included filling, culverting, lining or channelizing tributary waterways, and modifying to their banks and beds through removal of adjacent vegetation and dredging. Industrial and housing developments, roads, landfills and power plants all affect both sediment and pollutant delivery to lakes, and the resulting lake water quality. These urban features are often linked to the tributary network by means of storm drains and industrial outfalls. Such point sources directly contribute to sediment accumulation rates in lakes and strongly influence the quality of the benthic

deposits in the lakes. Nonpoint sources such as the atmosphere may also supply sediment and pollutants through deposition in the catchment area or directly into a lake.

(Charlesworth and Foster 1993, Dramstad, et. al. 1996, Dunne and Leopold 1978, Riley 1998)

In summary, urbanization affects lakes in three interrelated fundamental ways:

- 1- By altering the hydrology of the watershed through reduction of the permeability of the land surface (primarily to accommodate the automobile and related development), surface runoff and its associated erosive and scouring forces is drastically increased. Concurrently, time of concentration is substantially reduced, causing the capacities of local streams to be exceeded (thereby leading to flooding). This urbanization-induced change in the hydrological regime of urban waterways causes elimination of habitat through bank and channel erosion (Loughran and Campbell 1995), washout of aquatic organisms in high energy areas, and smothering of benthic communities in low energy areas. (Roesner and Ott 1995) Concurrently, groundwater recharge is reduced, as is associated stream baseflow.
- 2- By giving rise to high loadings of such pollutants as sediment, nutrients, toxic organic and inorganic substances, heat, oil, debris, oxygen demanding materials, and microorganisms from diffuse sources ("leakage of the urban landscape" (Schueler 1987)).
- 3- By altering natural drainage by filling low order streams, and by placing others in culverts or storm sewers. Additionally, to address the aforementioned flooding

problem, streams are widened, straightened and lined, and buffering and shading vegetation is removed from the shorelines, all resulting in a sterile, hydraulically flashy, aesthetically unappealing, and debris-laden and sediment-laden watercourse.

These classical aspects of urbanization generally will have a devastating impact on urban lotic and lentic waters unless vigorous conservation measures and sound management practices are implemented in the watershed and in the waterways, preferably prior to urbanization, but if necessary on a retrofit basis. (Ferguson 1998, Riley 1998, Schueler 1990) Even more fundamentally, without watershed level land use planning and management, with an eye on cumulative water impacts where water resource considerations are integrated into the into the real-life local land use decision-making, little will be accomplished in controlling diffuse pollution. (Arnold January 1999) Such land use planning should be manifested in the form of comprehensive watershed plans (New York City Soil and Water Conservation District May 1999, New York State Department of Environmental Conservation 1993). Expressed more simply, the long term effectiveness of lake clean-up efforts depends on controlling sources of pollution within the watershed (Environmental Protection Agency August 1995).

Analytical tools in the form of mathematical models of varying complexity are available to simulate the effects of varying storm types on a given watershed (Nix 1991, New York State Department of Environmental Conservation and New York State Soil and Water Conservation Committee 1994). The more complex models are capable of routing flows and pollutants through the watershed and producing hydrographs and pollutographs at many locations, but large amounts of data may be required to calibrate

and verify these models. (Environmental Protection Agency September 1977) Some of these urban catchment models have occasionally been utilized to explore real-life land use alternatives. (Quinlan and Simmons 1993)

Additionally, new thinking is needed in zoning, with practices such as compact development, reduced impervious surfaces, and planned green space being codified. (DeSena April 1999) Also, concepts such as utilization of on-site retention (Poertner 1973), greenways, recharge, and avoidance of steep slopes for development and other means of erosion control should be utilized. (New Jersey Department of Environmental Protection circa 1987, Field and Lager 1975, New York State Soil and Water Conservation Committee 1988) A good plan for stormwater management should combine on-site and regional controls. (New Jersey Department of Environmental Protection 1987) However, watershed planning may still be hindered due to the potential for legal challenges because the impact of land use controls on water quality cannot easily be demonstrated, because the diffuse and intermittent nature of most nonpoint sources make individual contributions difficult to quantify, and because the long term performance of various controls is uncertain. (Freedman et al. 1994) Research is still needed on such matters as the preparation of effective and implementable diffuse pollution rules, documenting the effectiveness of nonstructural controls for reducing diffuse pollution, and understanding the impact of snowmelt diffuse pollution on receiving waters. (Griffin, Kreutzberger and Binney 1991) Nevertheless, because of impacts such as traffic congestion, blight and loss of open space, in addition to negative water impacts, public policy should at least eliminate the economic incentives and laws promoting urban and

suburban sprawl. (Fuhs 1999)

Along with land use decisions in a watershed, assessment of resulting water quality should be performed using a wide variety of physical, chemical and biological techniques, such as are utilized in the Tennessee Valley's River Pulse (Flynn and Williams 1994) and EPA's Index of Watershed Indicators (Environmental Protection Agency September 1997), which in addition to assessing water quality also assess the runoff potential of a watershed by evaluating its degree of imperviousness. A comprehensive urban water quality monitoring and assessment program can answer such questions as:

What are the uses (designated and actual) of the waterway?

What are its problems?

What are the pollutants and habitat factors affecting the water body?

What are the sources of the problems?

What are the goals in correcting the problems?

What management approaches achieve the goals?

How effective were the corrective measures? (Bannerman 1998)

2.4 - Lake Classification Systems

2.4.1 - Existing Classification Systems

Several lake classification systems currently exist, based on a variety of features. Among these features are trophic state (Naumann, Thieneman), natural agent creating the lake (Hutchinson), morphometry, thermal and circulation patterns, climate, and salinity.

The trophic state of a lake is based on the level of biological productivity in the

lake. Trophic state is often linked to natural succession and aging of lentic waters as they pass from their origins to their ultimate fates as dry land. At the early stages of the aging continuum are oligotrophic lakes, which are characterized by high water clarity, low productivity and high dissolved oxygen (Britton, Averett and Ferreira 1975). As clarity diminishes and increasing concentrations of nutrients result in higher levels of productivity, the lake enters the mesotrophic stage. Subsequently, the eutrophic stage, which is characterized by high nutrient concentrations, high biological productivity and low water clarity, is reached. Finally, prior to filling and extinction, the lake passes through the hypereutrophic stage, which is characterized by “pea-soup” conditions. (North American Lake Management Society 1988) It should be noted that the rate of lake eutrophication is highly variable, can be reversed, and can be strongly influenced by the activities of man. Furthermore, eutrophication rates are controlled by the two overriding factors of lake depth and drainage basin size and fertility. (Horne and Goldman 1994) As discussed in Chapters 4 and 5, Carlson’s Trophic State Index is a quantitative method for expressing the trophic state of a lake.

The Hutchinson Classification System is based on the natural agents that create lakes, such as tectonic forces (single fault lakes, graben lakes, lakes formed by sea floor uplift, and lakes formed by movements of the earth’s crust which alter existing drainage patterns), volcanism (crater lakes, and lakes formed by lava dams and by differential cooling of lava), glaciation (cirque lakes, kettle lakes, chains of lakes (paternoster lakes), and piedmont lakes), riverine forces (oxbow lakes and scroll lakes), solution of limestone by acidic waters (solution lakes), melting of permafrost (cryogenic or thermokarst lakes),

and by large scale mass movements that dam local drainage. (Horne and Goldman 1994, Environmental Protection Agency March 1979)

Lakes and ponds can be classified in terms of morphological features such as hydraulic retention time (or hydraulic residence time), maximum depth, mean depth, maximum length, maximum width, shoreline length, shoreline development (reflecting shoreline irregularity), stage (elevation of a lake's surface), surface area, volume, and drainage area. (Britton, Averett and Ferreira 1975, Horne and Goldman 1994, North American Lake Management Society 1988)

Thermal energy, derived from insolation, plays a major role in the vertical mixing and stratification of lakes and ponds. Such waters are classified in terms of their mixing patterns. As stated earlier, lakes mixing only partially after destratification are termed meromictic, while those mixing completely from surface to bottom are holomictic. Monomictic lakes mix continuously through the cold season, while lakes which are covered by ice during the winter and mix during the fall and spring seasons are dimictic. Shallow polymictic lakes mix continuously or periodically, while polar or high altitude amictic lakes, which are always covered by ice, never mix. (Horne and Goldman 1994)

Since climate profoundly affects the chemistry and ecology of lakes, it forms the basis of yet another classification system. Lakes can be polar (and high alpine, receiving increased solar radiation at high altitudes), temperate and tropical. (Horne and Goldman 1994)

Finally, salinity also forms the basis of a classification system. Saline or athalassohaline lakes are hyposaline (3 to 20 parts per thousand (ppt)), mesosaline (20 to

50 ppt) or hypersaline (> 50 ppt), and the composition of such lakes varies, depending on their origins. (Horne and Goldman 1994)

2.4.2 - Proposed Classification Systems

Several of the aforementioned classification systems are strictly qualitative (the Hutchinson System, mixing regime and climate), while others are quantitative (trophic state, morphology and salinity). Three additional classification systems are herein proposed as part of this research, including Water Input Mechanism, Degree of Artificiality, and Degree of Urbanization of the watershed. Linear numerical scales ranging from zero through five are suggested for each system, and a variety of descriptors are assigned ranges of values within each system which can overlap ranges of other descriptors, with only the averages of these ranges being plotted in Figures 2.1, 2.2 and 2.3. These systems operate as continua, and judgement must be used in setting scores for the various descriptors in each system (Sections 2.4.2.1 through 2.4.2.3), and in assigning the three classification system scores to target lakes (Chapters 3 and 8), especially when physical buffers and other confounding lake system and watershed factors exist. An attempt is made (as discussed in chapters 5, 6 and 9) to assess the assumption of generally linear relationships among the descriptors in the three proposed systems as they relate to expected lake water quality impacts, by performing regression analyses between classification system scores and various measured water quality variables for the New York City lakes selected for detailed study. The statistical package utilized (WinSTAT), can determine which of seven possible equation types (linear, power, logarithmic, exponential or three forms of hyperbolic) best fits the data.

2.4.2.1 - Water Input Mechanism System

For the Water Input Mechanism system (See Figure 2.1), the numerical scales are based on an intuitive expectation of the water quality impact of each type of mechanism, with sources providing the anticipated greatest impact (most polluting) set at zero and the least at five. Direct inputs of secondary sewage treatment plant effluent, industrial treatment plant effluent, agricultural runoff, urban and suburban runoff (including industrial runoff), runoff from severely eroded parkland, and failing on-site wastewater disposal system (septic tank) overflow to an urban lake would function as substantial unmitigated sources of sediments and nutrients, and as probable sources of toxics, oxygen demanding materials and microbes. From a lake water quality perspective, they should all be assigned a score of zero in this system, and a major objective of most lake remedial programs should be either to attenuate these sources or divert them around the lake (See Figure 2.1-A).

Surface flows in impounded tributaries can be highly variable with regard to water quality. Schueler has stated that “urban streams are arguably the most extensively degraded and disturbed aquatic systems in North America.” (Schueler 1990) From a water quality perspective (ignoring the hydrological, morphological and ecological degradation), such streams are subject to municipal and industrial point discharges (both continuous and intermittent), as well as to severe nonpoint sources, all of which contribute oxygen demanding materials, microbes, nutrients, toxic organics and inorganics, light and heavy sediments (suspended and settleable solids), oils, floatables, heat, and salts. However, there exist in surface streams several mechanisms for attenuating these

FIGURE 2.1
WATER INPUT MECHANISM CLASSIFICATION SYSTEM

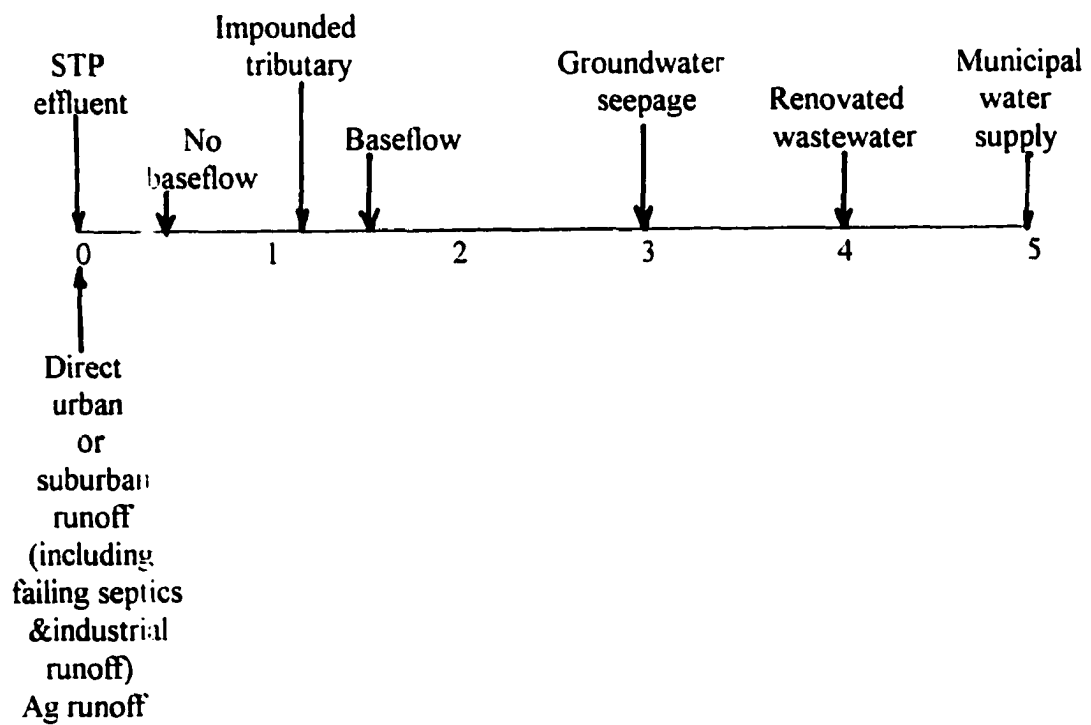
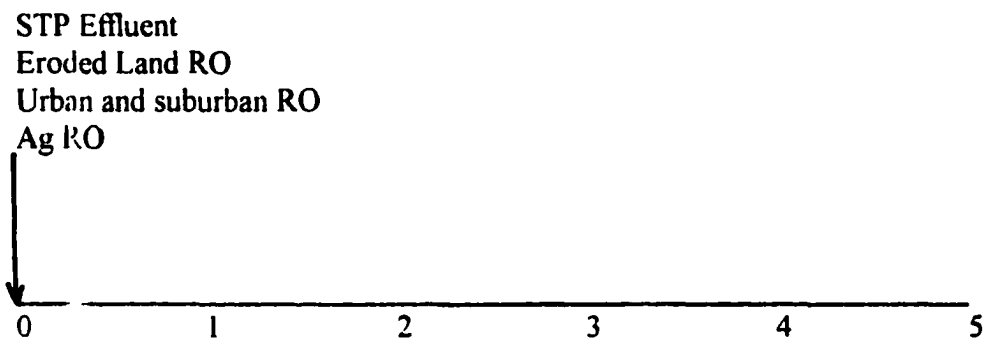


FIGURE 2.1 - A**WATER INPUT MECHANISM - DIRECT CONTAMINATED INPUTS**

contaminants and improving water quality, unless the system is overwhelmed by high contaminant loads. These mechanisms include sedimentation, biochemical oxidation, dilution and volatilization. Given the high degree of variability in water quality associated with surface streams, on our zero to five scale, impounded streams should vary from zero for degraded urban streams, to about 3.0 for streams retaining some shoreline buffers, some degree of stormwater control, and substantial baseflow. The average score for urban streams should be skewed toward the lower end of this range at 1.2 to reflect general conditions cited by Schueler (See Figure 2.1-B). Because they offer no dilution, ephemeral streams should range in their scores from zero to 0.8, with an average of 0.4 (See Figure 2.1-C), while perennial streams should vary from about 0.6 to 3.0, depending on the extent of baseflow, buffers and contamination sources, with the average set slightly toward the lower end of this range at 1.5 to reflect the general loss of baseflow associated with urbanization (loss of recharge and possible overpumping) (Buxton et.al. 1981), and the conditions cited by Schueler (See Figure 2.1-D).

As is the case with surface stream water quality, the quality of groundwater can be extremely variable, ranging from relatively good in sandy aquifers remote from human development, to highly contaminated under intensely developed areas. Sources of groundwater contamination include infiltration of contaminated surface water; on-site sewage disposal systems, including the use of organic solvents to extend the lives of such systems; unlined industrial pits, ponds and lagoons; leakage from sewers, industrial pipelines, and underground and surface storage tanks; waste diffusion wells; leachate from refuse disposal sites; accidental spills and intentional dump-outs; road salting; and

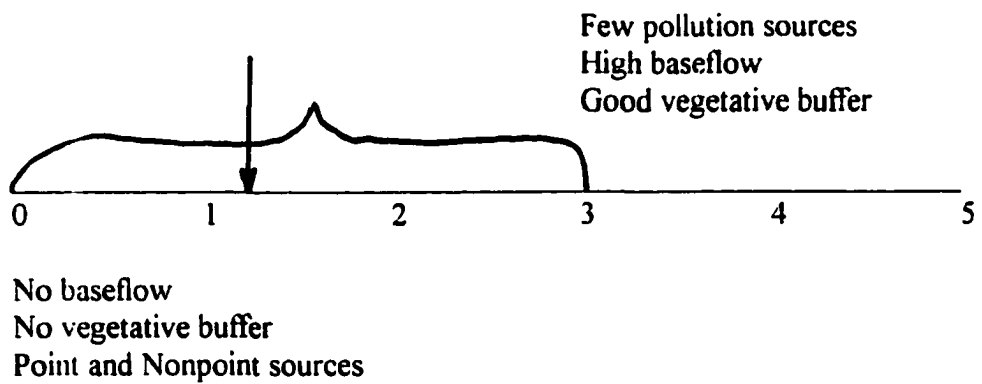
FIGURE 2.1 - B**WATER INPUT MECHANISM - IMPOUNDED STREAMS**

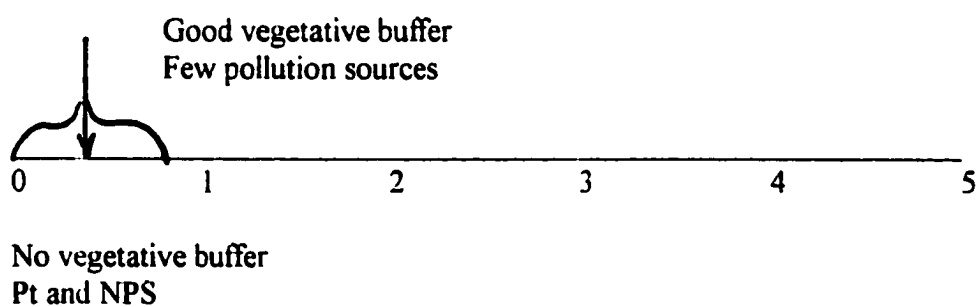
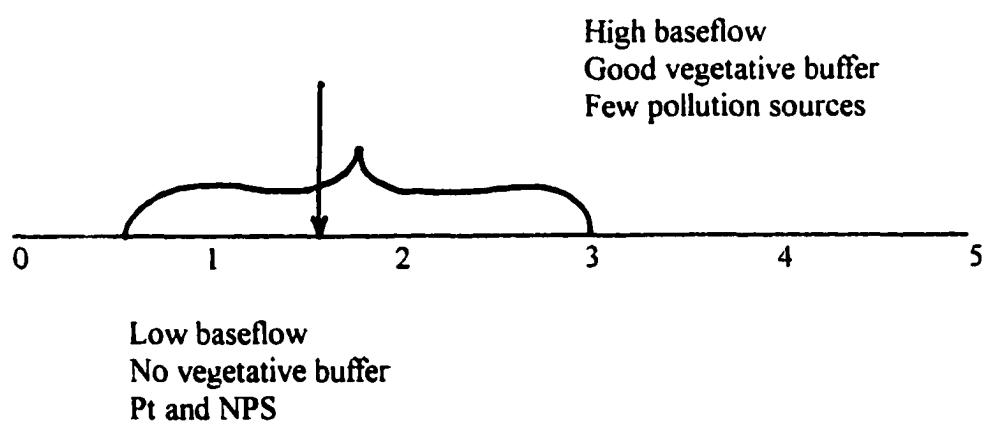
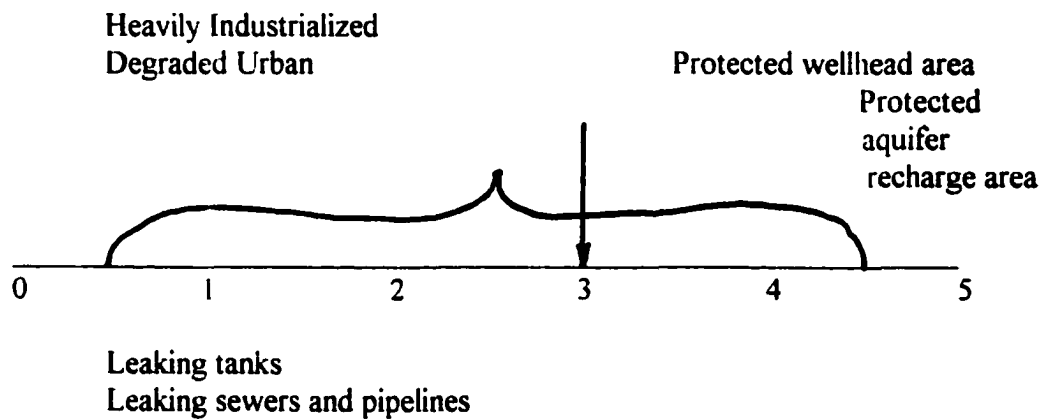
FIGURE 2.1 - C**WATER INPUT MECHANISM - IMPOUNDED EPHEMERAL STREAMS**

FIGURE 2.1 - D**WATER INPUT MECHANISM - IMPOUNDED PERENNIAL STREAMS**

agricultural operations. (Environmental Protection Agency 1985, Newman 1984)

Fortunately, numerous mechanisms exist in soil for attenuating chemical, microbiological and radiological contamination in groundwater flow. These mechanisms include dilution, dispersion, mechanical filtration, volatilization, biological activity, adsorption and ion exchange on soil particle surfaces, chemical reactions and radioactive decay. (Fetter 1984) However, these mechanisms can be overwhelmed by unremitting contaminant plumes, and by numerous conservative contaminants (those that do not react with soil and native groundwater) which are only weakly attenuated. In general, more attenuation mechanisms are available for groundwater flow than for surface stream flow.

Since groundwater can range in quality from contaminated, under intensely industrialized, urbanized and agricultural areas, to a purity approaching drinking water requiring only minimal treatment, under protected areas (such as large parks), on our proposed zero to five scale it should range from about 0.5 (not zero because of the aforementioned attenuation mechanisms) to about 4.5, with an average of about 3 which is skewed slightly toward the high end (See Figure 2.1-E), since groundwater from Brooklyn, Queens and Staten Island has been used for the public water supply (Pearlmutter and Arnow 1953, New York City Department of Health 1964), and has the potential for being utilized in the future for this purpose (Malcolm Pirnie 1998, unpublished New York State Department of Environmental Conservation correspondence on Staten Island Aquifer Management 1998). Currently, groundwater is being pumped from aquifers under southeastern Queens for municipal water supply purposes. Significant historical water quality problems associated with water supplies utilizing groundwater

FIGURE 2.1 - E**WATER INPUT MECHANISM - GROUNDWATER SEEPAGE**

within New York City (within the old Flatbush and Woodhaven Franchise Areas) included high chloride concentrations resulting from saltwater intrusion induced by overpumping, elevated nitrate concentrations caused by exfiltrating sewers (Kimmel 1972), and elevated hardness (along with an associated concern by the medical community over the use of sodium ion exchange softeners by coronary patients). Seepage of nitrate-enriched groundwater into an urban lake might constitute a problem during periods when the lake is nitrogen limiting.

Renovated wastewater generally consists of secondary wastewater treatment plant effluent that has been provided with additional forms of treatment so that it can be directly reused in some specified manner. Municipal and industrial wastewaters constitute a vast potential source for supplementing current and future supplies (Clark et. al. 1971). Uses of renovated wastewaters include irrigating parks, other landscaped areas, pastures, residential lawns, and golf courses; feeding recreational lakes; feeding industrial cooling systems and boilers; and for indirect utilization as part of a potable water supply after dilution in natural waters or percolation through native soil to existing groundwater zones. (Clark et. al. 1971) Renovated wastewater has also been used to develop barrier injection wells to alleviate salt water intrusion (Cohen et. al. 1968) and alternatively, to irrigate crops, thereby avoiding overpumping and saltwater intrusion (Richman 1996).

Renovated wastewater is of relatively good quality, having been provided with treatment appropriate to the needs of its intended use (in addition to secondary treatment and industrial pretreatment, as necessary to control organic and inorganic toxics). Unlike runoff, tributary flow or groundwater seepage, renovated wastewater should not be highly

variable in nature, since it is the product of designed treatment processes. For lake feedstock, its score in the proposed classification system should range from 3.5 (where effluent polishing is provided by filtration) to 4.9 (where advanced waste treatment including filtration, nutrient removal, organics adsorption, and disinfection would be provided, as is the case at Lake Tahoe (Clark et. al. 1971)). An appropriate average for this range should be about 3.8 (toward the low end - See Figure 2.1-F), since it is not expected that funds would be expended for advanced waste treatment merely to supply water to urban lakes unless the lake (or a tributary stream) is the only feasible discharge point for the wastewater treatment plant (a fairly common situation outside New York City). Also, costs for transport of the renovated water will render such a source infeasible if the treatment plant is remote from the lake (the New York City situation).

Municipal water supply would be expected to meet all Federal and State drinking water standards and, therefore, should be assigned the highest score of 5.0 in our proposed classification system (See Figure 2.1-G), having only minimal concentrations of physical, chemical and microbiological contaminants. Conditioned water, reflecting the additional treatment provided to municipal water supplies as needed for some industrial processes, would rate a score above 5, but such high quality water would not be appropriate as a recreational lake feedstock. Actually, the use of municipal water for this purpose is questionable, since high quality drinking water should not be utilized for lower level purposes such as recreation, aesthetics and habitat support where lower quality water will suffice. This is especially true if the municipal supply is provided with expensive complete treatment, including filtration. However, New York City is one of the few large

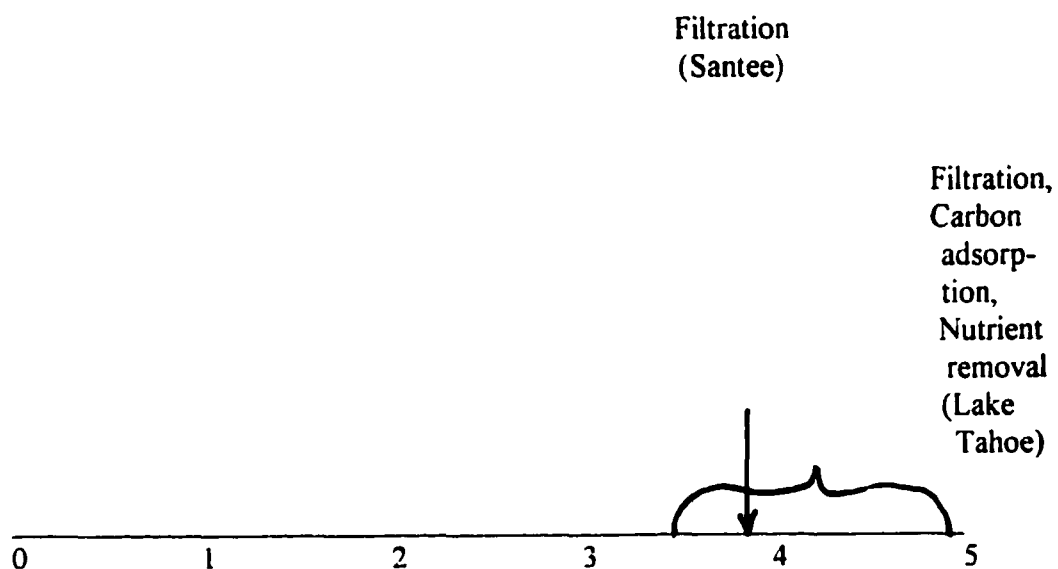
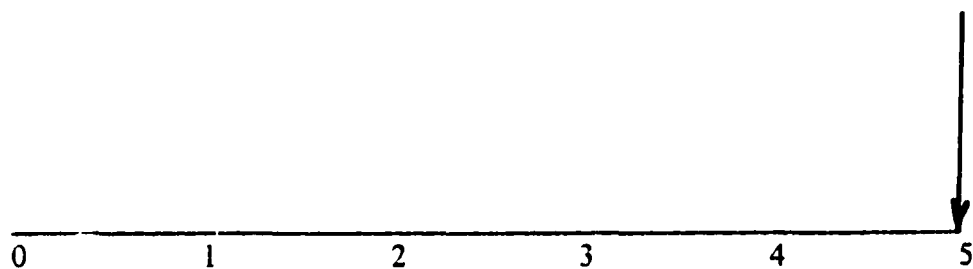
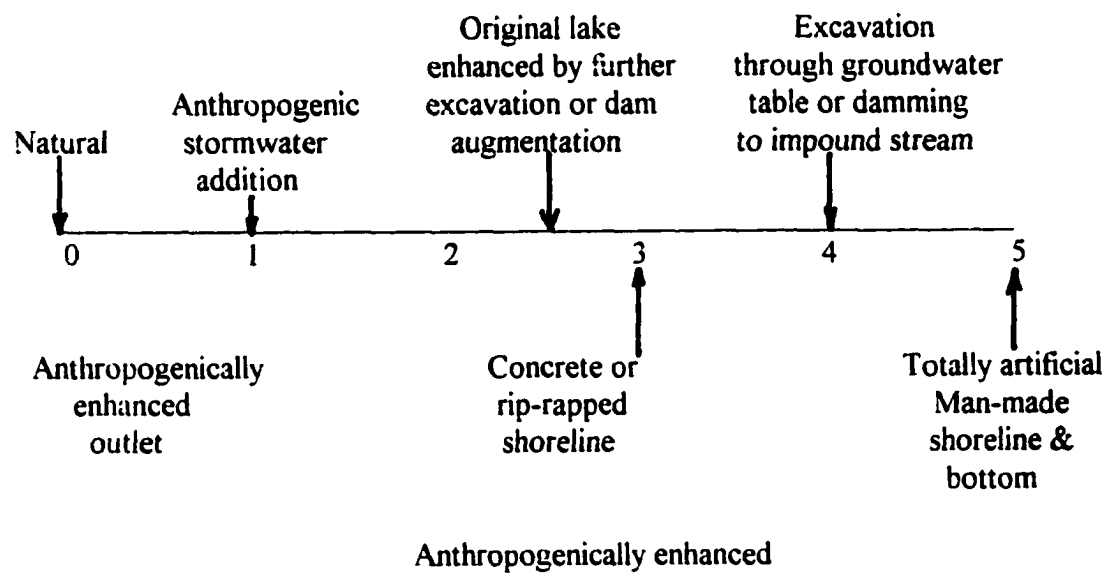
FIGURE 2.1 - F**WATER INPUT MECHANISM - RENOVATED WASTEWATER**

FIGURE 2.1 - G**WATER INPUT MECHANISM - MUNICIPAL WATER SUPPLY**

municipalities utilizing an unfiltered surface supply. Instead, the City depends on regulating an ever more developing watershed, long term storage, multiple chlorination, aeration at the Ashoken and Kensico Reservoirs to remove dissolved gasses which tend to cause taste and odor problems (aeration is not available in the Croton System where it could be used to precipitate manganese (personal discussions with NYC water supply officials 1969)), copper sulfate addition to control algae growth, alum addition in the Schoharie Reservoir to control occasional turbidity problems, caustic addition to raise pH, and recently, orthophosphate addition to protect against the leaching of metals from the distribution system, service connections and building plumbing systems. The absence of filtration has resulted in the occasional problems of high bacterial counts (attributed to avian sources at Hillview Reservoir) and the appearance of insect larvae in some portions of the Harlem service area. Nevertheless, municipal water, having the highest quality of all lake water inputs rates a score of 5. However, when applying this classification scoring system in New York City, the score is reduced because of the orthophosphate addition, which is considered to have a negative impact on the lakes. (Matsil 1994)

2.4.2.2 - Degree of Artificiality System

Not originally intended to be related to lake water quality nor trophic state, the Degree of Artificiality Classification system (See Figure 2.2) was only created as another limnological classification system consisting of a continuum ranging from totally natural lakes set at a score of zero, to completely artificial lakes created where none existed previously, having concrete shorelines and bottoms, and supplied with water from an

FIGURE 2.2**DEGREE OF ARTIFICIALITY CLASSIFICATION SYSTEM**

outside source (“bathtub lakes”), set at a score of 5 (See Figure 2.2-A). A series of possible incremental human interventions between these extremes constitutes the domain of anthropogenic enhancements. The descriptors utilized in Figure 2.2 are those observed in New York City and elsewhere.

Unlike the other two proposed classification systems wherein attempts are made to locate the descriptors relative to each other and to the numerical scale on the basis of their expected lake water quality impacts, the location of the descriptors on the scale in the Degree of Artificiality System depends on the relative extent to which natural conditions are perceived to have been altered by human intervention. These descriptor locations can also be interpreted as the degree of complexity of the intervention. As is the case with all three proposed classification systems, the position of each descriptor represents an average of a variable range of possible positions and is largely set on the basis of judgement.

The relatively minor modification of outlet enhancement of a natural lake or pond to control water levels is rated at 0.5 (minimal human intervention, minimal project complexity). (See Figure 2.2-B)

Under many circumstances it may be necessary to provide supplementary water to maintain lake water levels (Rickert and Spieker 1971). This can be accomplished fairly simply by means of a nearby water supply tap or by the provision of a nearby well. A more complicated and less beneficial approach, in the absence of adequate controls, would be to divert urban or suburban stormwater to the lake. Probably the most complex approach to addressing this problem would be to divert a stream not currently tributary to

FIGURE 2.2 - A**DEGREE OF ARTIFICIALITY - LIMITS AND RANGE**

Based on perceived deviation from
natural conditions or degree of
complexity of the intervention

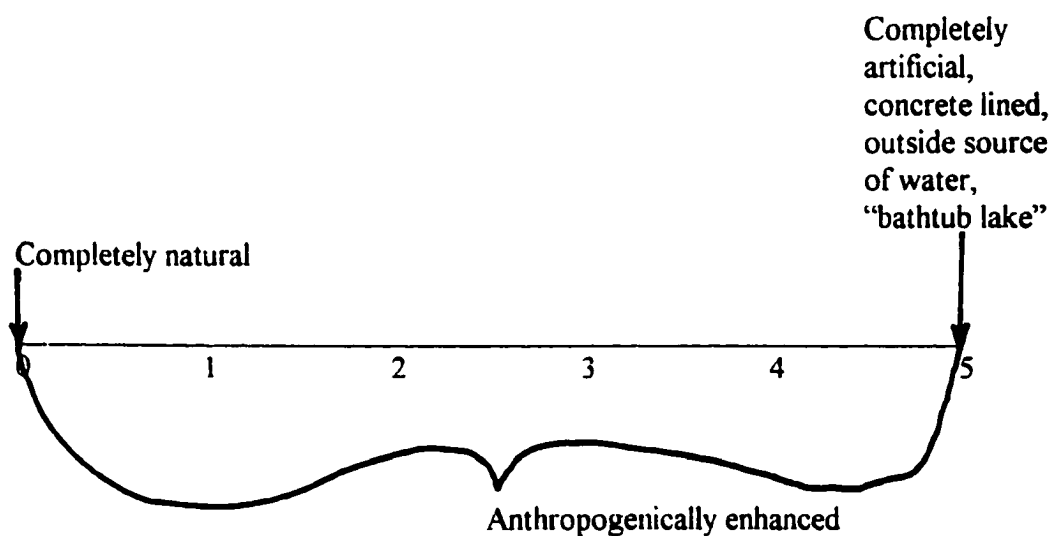
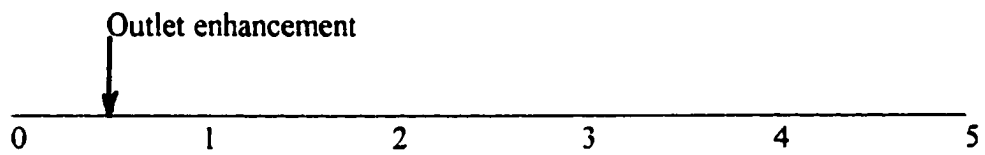


FIGURE 2.2 - B**DEGREE OF ARTIFICIALITY - OUTLET ENHANCEMENT**

the lake. On our numerical scale these approaches would range from about 0.3 for the water supply connection to about 4.5 for stream diversion. However, the average would be substantially skewed toward the lower end of this range at 1, since diversions of stormwater or streams not currently tributary to the lake would not normally be justified (See Figure 2.2-C). Past connections of runoff to urban lakes were probably made to manage flows already tributary to the lake and are, therefore, far less complex.

Excavation of a lake to provide increased depth or for general maintenance, and enhancement of a natural dam, also to provide additional depth or storage, are projects of moderate complexity and their scoring would vary with lake size from about 1.5 to 3.5 and should average about 2.5 (See Figure 2.2-D). Dredging costs are high and extremely variable, ranging from \$1,000 to \$40,000 per acre for a depth of three feet of sediment, in 1990 dollars. (New York State Department of Environmental Conservation and Federation of Lake Associations 1990) The variability in cost is most affected by sediment disposal, with the high end representing an urban situation wherein the sediments must be exported out of the area.

Shoreline hardening using rip-rap or concrete is an old technique to control shoreline erosion and to prevent shoreline collapse. It involves heavy construction and imparts a strong sense of deviation from natural conditions. The complexity of the project should vary with shoreline length, and the score in our proposed classification system should range from about 2.5 to 3.5, with the average set at 3 (See Figure 2.2-E). There currently exist numerous vegetative techniques for controlling shoreline erosion and they are to be preferred over classical hardening approaches.

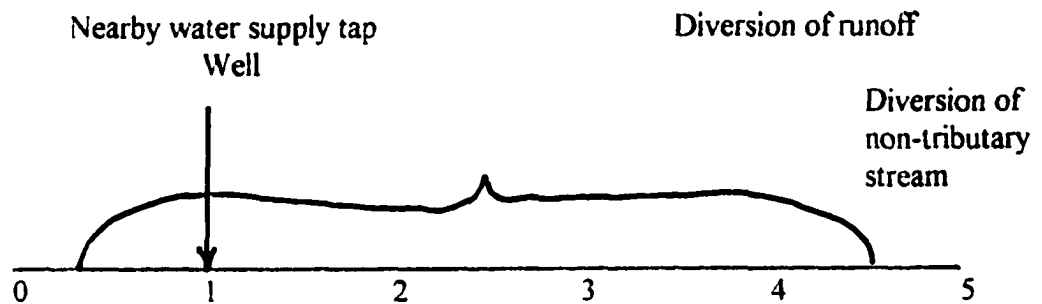
FIGURE 2.2 - C**DEGREE OF ARTIFICIALITY - SUPPLEMENTARY WATER**

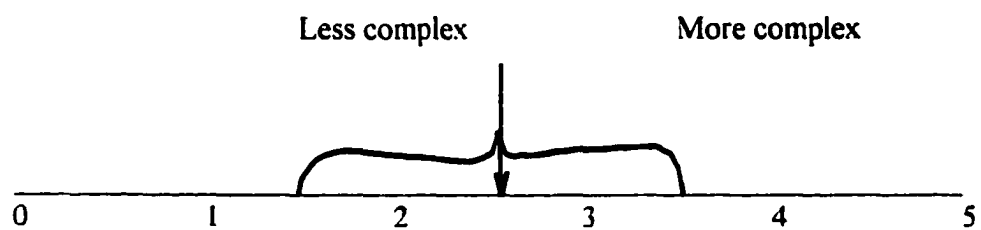
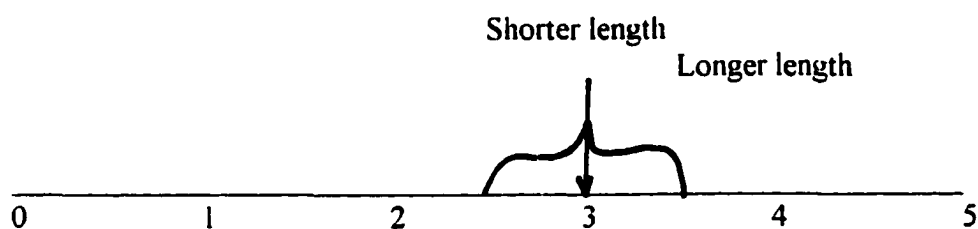
FIGURE 2.2 - D**DEGREE OF ARTIFICIALITY - EXCAVATION FOR INCREASED DEPTH OR
NATURAL DAM ENHANCEMENT**

FIGURE 2.2 - E**DEGREE OF ARTIFICIALITY - SHORELINE HARDENING**

Only justified where shoreline use is exceptionally high (Should use vegetative techniques)

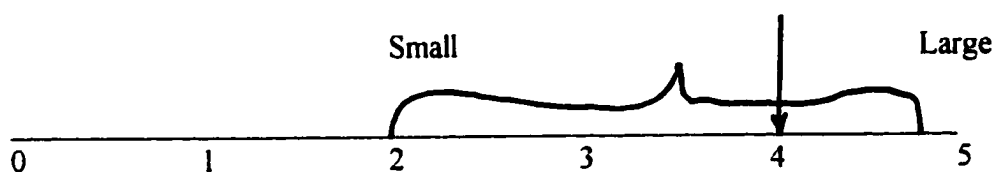


Creation of a lake or pond where none existed previously by excavating through the groundwater table or by impounding a surface stream certainly constitutes a major deviation from natural conditions and usually involves substantial heavy construction. As discussed earlier, many artificial ponds and lakes of varying sizes and degrees of complexity have been and continue to be constructed for a wide variety of purposes. A small pond (with an area of about a half acre) on a rural patch of private property can cost around \$30,000 in 1993 dollars (Matson 1993), while a substantially larger lake can cost far more. Generally, the complexity of the construction of an artificial lake can be expected to vary with its size, as would the perceived magnitude of the intervention in the natural system (not always necessarily a negative intervention). In this classification system, such an intervention should range in its score from 2 for very small ponds to 4.8 for large impoundments, with the average score skewed toward the high end at four (See Figure 2.2-F).

While lake water quality was not a major consideration in the development of the Degree of Artificiality Classification System (as stated at the beginning of this section), there are several elements of this system that do have water quality implications. Natural lakes (especially glacial lakes) tend to be deeper than artificial lakes (this is especially true for small impoundments) (North American Lake Management Society 1988), and shallow lakes tend to be more biologically productive than do deep lakes (Burden and Malone 1984). Also, mean depth is related to hydraulic residence time as follows:

$$d = V/A$$

$$T = V/Q$$

FIGURE 2.2 - F**DEGREE OF ARTIFICIALITY - CREATION OF NEW LAKE**

Rearranging terms:

$$T = dA/Q$$

where:

d = mean depth in feet

V = lake volume in acre-feet

A = lake surface area in acres

T = mean hydraulic residence time in years, and

Q = mean lake outflow in acre-ft/year.

Also, average total lake phosphorus concentration is related to hydraulic residence time in accordance with:

$$P = P_i / (1 + T^{0.5})$$

where:

P = average total lake phosphorus concentration, and

P_i = average inflow total phosphorus concentration.

(From North American Lake Management Society 1988)

This means that as hydraulic residence time (and mean depth) increases, the average lake concentration of total phosphorus (and the trophic state index of the lake) decreases (See Chapter 4 for a discussion of relationships among Carlson's Trophic State Index, total phosphorus concentration, chlorophyll a concentration, and secchi transparency, and Chapter 5 for the associated nomograph). Additionally, natural lakes tend to have lower watershed area to lake surface area ratios than do small impoundments (North American

Lake Management Society 1988), and in urbanized watersheds characterized by substantial impervious ground cover, the higher ratio of impervious watershed area to lake surface area of an impoundment would yield a higher trophic state index (a more productive lake - See Chapter 4) (Palmer et. al. 1984).

Contrary to this general trend of water quality deteriorating with increasing degree of artificiality, anthropogenic interventions such as flow augmentation (depending on the source and quality of the augmenting flow), dredging to remove phosphorus-laden sediment and to increase depth, and shoreline hardening to prevent shoreline erosion and collapse should almost always enhance water quality.

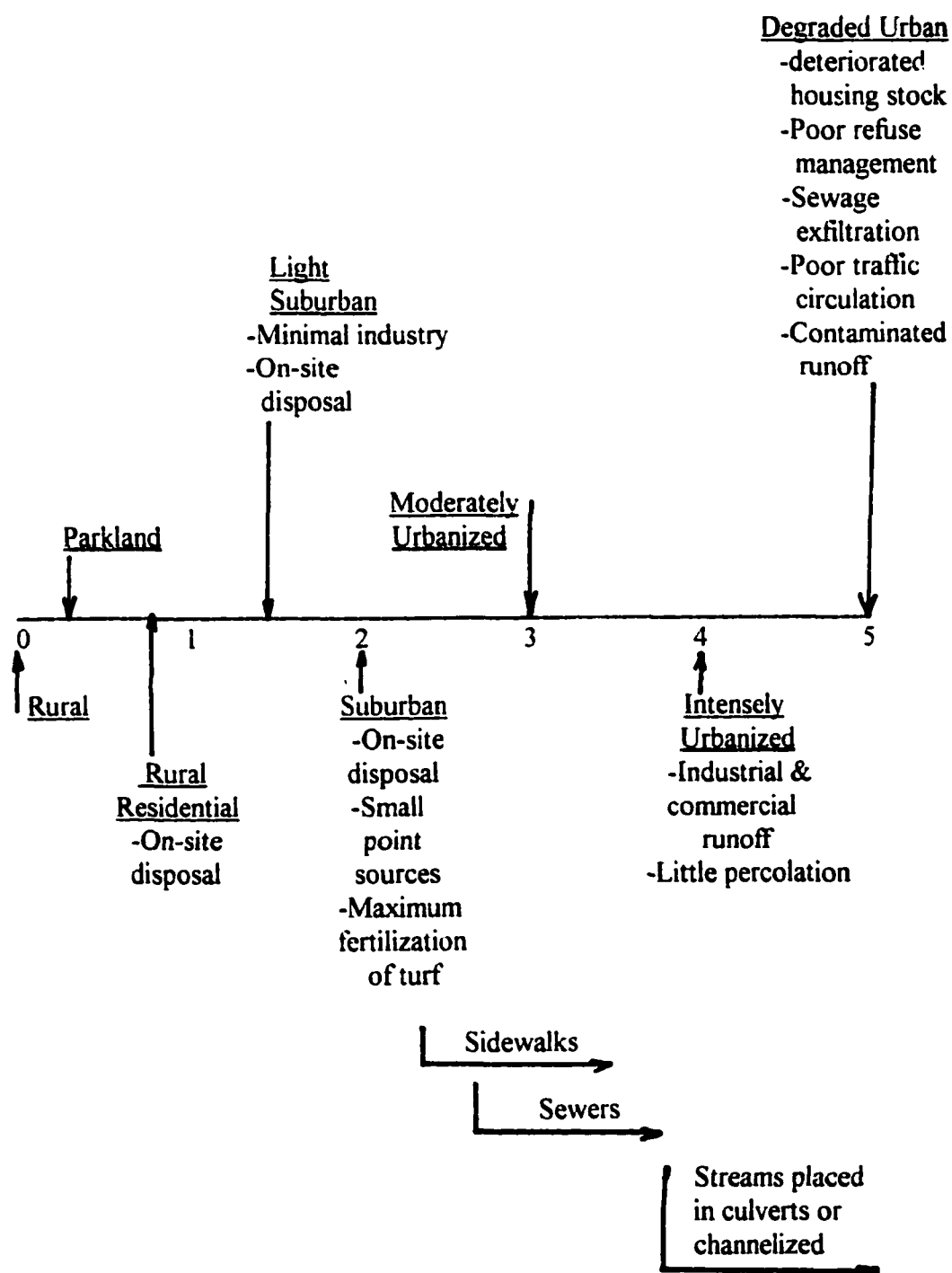
2.4.2.3 - Degree of Urbanization System

It has long been known that the extent to which a watershed has been urbanized influences the quantity and quality of both surface runoff (Novotny 1991) and subsurface recharge (Middlesex County Planning Board 1981). It is also known that the discharge of contaminated urban runoff to urban lakes contributes to the deterioration of those lakes (Pisano and Aronson 1981, Palmer et. al. 1984, Schueler 1990, Burden and Malone 1984). The intensity of the deterioration depends on a variety of factors such as the runoff quality and the morphometry of the lake. A variety of mathematical models have been developed which are capable of predicting runoff quality and/or quantity based on land use and land activities in a watershed (WMM, NPSMAP, GWLF, P8-UCM, AUTO-Q1, SLAM, STORM, and SWMM), while others can predict the response of lentic water bodies to pollutant loading (PHOSMOD, WASPS (EUTROWASP and TOXIWASP) and FLUX/BATHTUB) (New York State Department of Environmental Conservation and

New York State Soil and Water Conservation Committee 1994).

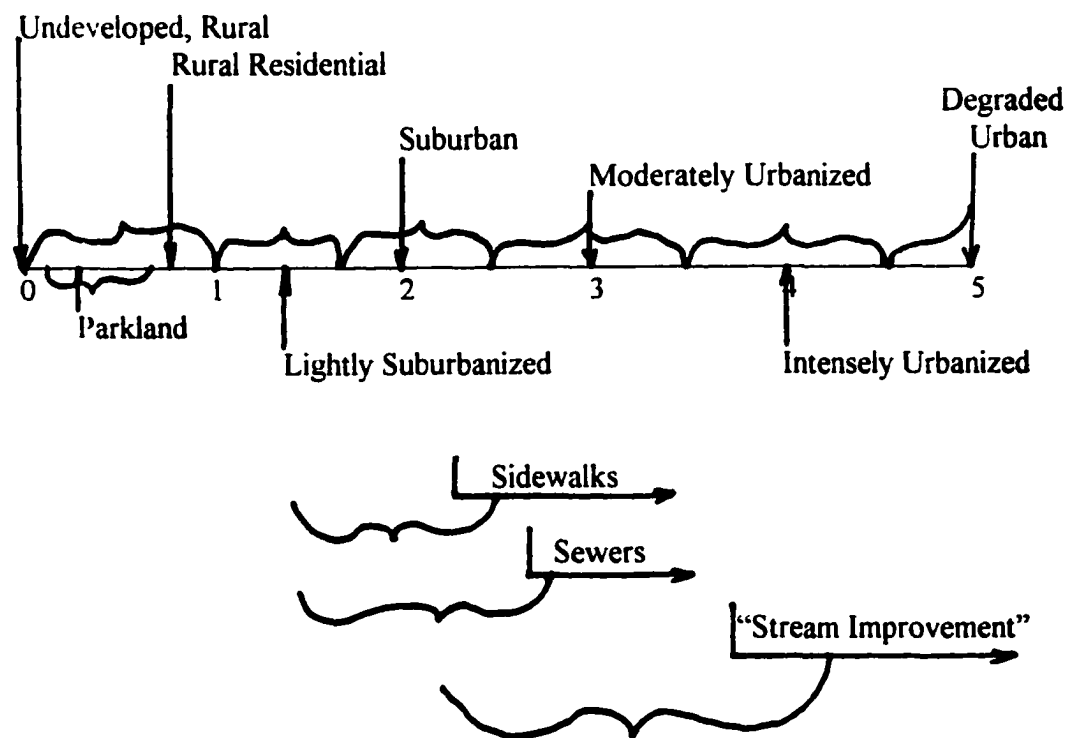
The Degree of Urbanization Classification System proposed herein (See Figure 2.3) generally characterizes the land use in a watershed tributary to a lake in a continuum, ranging from pristine (assigned a score of zero) to degraded urban (assigned a score of five). As was the case with the Water Input Mechanism Classification System, the placement of the descriptors on the linear scale and relative to each other is loosely related to intuitive water quality impact expectation. The proposed system generally tracks elements of stormwater drainage procedures currently in use such as the runoff coefficient from the rational method and the curve number from the SCS method (U.S. Department of Agriculture 1986), both of which depend on land use as expressed primarily by land cover imperviousness (Ferguson 1998, Novotny 1995). It also tracks the related pollutant export factor (Novotny 1995, Novotny 1992, Novotny 1991, Schueler 1990). Finally, it includes various physical changes to waterways (primarily lotic systems) that are associated with urbanization which have major ecological and aesthetic impacts, such as placing streams in culverts, straightening streams and lining them with concrete, removal of shoreline vegetation (which serves as a buffer, as a canopy, as a source of allochthonous food and as a mitigating factor against the urban heat island effect), and the use of the waterway as a midnight dump site. (Schueler 1990, Riley 1998).

While they are scored as zero in this classification system, even the most pristine undeveloped rural areas are subject to airborne contamination (Sheehan 1998) and to various natural pollutants such as sediment derived from stream meanders, acid from low pH soils (Newman 1984), and nutrients and metals derived from the weathering of rocks

FIGURE 2.3**DEGREE OF URBANIZATION CLASSIFICATION SYSTEM**

(Waterline 1999) and the leaching of these materials from various soils. Parkland, which may occasionally be very slightly disturbed, is placed at 0.3, while rural residential development, which may feature a few failing on-site wastewater disposal systems and some residual agricultural operations, is set at 0.8. Lightly suburbanized drainage areas featuring minimal industrial development and on-site wastewater disposal is set at 1.4. Suburbanized areas characterized by on-site wastewater disposal systems (some in a state of failure), excessive fertilization of turf, and some small point sources are set at two. Moderately urbanized areas associated with the provision of sidewalks, sewers and “stream improvements” are assigned a score of three. Agricultural areas imparting sediments, oxygen demanding materials, salts, nutrients, pesticides and bacteria to local streams are rated at 3.5, but this descriptor is not plotted in Figure 2.3 because it deviates from the pristine to intensely urbanized continuum represented therein. Intensely urbanized areas, along with associated industrial areas, having little permeable ground surface is scored at four. Finally, degraded urbanized areas, characterized by deteriorated housing stock and infrastructure, poor refuse management practices, abandoned industrial facilities, poor upkeep of lawns, high traffic volumes and congestion, midnight dumping and accumulations of debris are assigned a value of five. Such conditions (“Weeds in the Garden of the Living Environment”) probably evolved due to lack of planning, poor subdivision practices, excessive land values, ineffectual zoning, archaic street patterns, and unstable demographics. (Gallion and Eisner 1963) It must be noted again that the aforementioned descriptors cover a range of scores and overlap others, and only averages are assigned values (See Figure 2.3-A). Also, it is assumed that best management

FIGURE 2.3 - A
DEGREE OF URBANIZATION - RANGES OF LAND USE DESCRIPTORS
AND INDICATORS



practices are not in place for urban, agricultural and industrial runoff, and that some very small point sources are not controlled. Additionally, it is assumed that all descriptors are generally in a static mode, and that the introduction of change (such as infilling a moderately urbanized area, which will substantially increase sediment export) will cause a score to rise.

It should be clearly understood that this classification system is merely meant to generally rate a lake in terms of land use patterns in its watershed, with consideration given to the likely impact of these uses on lake water quality. It is not meant to serve in lieu of the aforementioned mathematical models, except, possibly in a very simplistic screening sense.

Table 2.3 indicates how miscellaneous pollutant concentrations vary with land use in the Washington, D.C. Metropolitan Area. Table 2.4 displays some of the runoff sampling data on metals concentrations gathered by the New York City Department of Environmental Protection in areas of varying land uses, pursuant to the development of their current Industrial Pretreatment Program. Finally, the International Joint Commission related the unit loads of pollutants in separate storm sewers to land use as displayed in Table 2.5.

Based on the limited general patterns of variation of runoff quality with land use, as displayed in Tables 2.3, 2.4 and 2.5, the placement of the descriptors on the numerical scale and relative to each other in a roughly linear fashion should serve as a “first cut” approximation of anticipated water quality impact. It must be noted that numerous factors such as lake morphometry, watershed soils and geology, climate and other water

inputs, in addition to runoff quality and quantity affect lake water quality.

<u>TABLE 2.3</u>				
<u>POLLUTANT CONCENTRATIONS IN RUNOFF (mg/l)</u>				
POLLUTANT	Hardwood Forest	New Suburban Sites	Central Business District	Older Urban Areas
Total Phosphorus	0.15	0.26	-	1.08
Total Nitrogen	0.78	2.00	2.17	13.16
Zinc	-	0.037	0.250	0.397
lead	-	0.018	0.370	0.389

(Modified from Schueler 1987)

<u>TABLE 2.4</u>						
<u>CONCENTRATIONS OF METALS IN RUNOFF (ug/l)</u>						
Land Use	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Low and High Density Residential	0.20	4.0	84.7	12.9	12.7	114
Commercial	3.64	8.1	78.2	49.4	17.0	300
Heavy Industry	5.35	12.6	115.6	61.0	61.5	594
Highway	2.36	32.0	41.7	41.3	5.4	204

(Modified from New York City Department of Environmental Protection 1988)

TABLE 2.5				
UNIT LOADS OF POLLUTANTS IN STORM SEWERS (kg/ha*yr)				
Pollutant	Parks and Playgrounds	Low and Medium Residential; Limited Industrial Activities	High Density Residential; Commercial Land Use	Medium and High Density Industrial
Biochemical Oxygen Demand	1.12	34	90	34
Nitrogen	0.22	9	11.2	7.8
Phosphorus	0.04	1.6	3.4	2.2
Suspended Solids	11.2	390	360	672
Cadmium	0.002	0.013	0.016	0.024
Chromium	0.003	0.026	0.028	0.044
Copper	0.007	0.045	0.049	0.077
Nickel	0.004	0.029	0.032	0.030
Lead	0.022	0.157	0.174	0.269
Zinc	0.081	0.570	0.630	0.980

(Modified from Novotny 1992)

2.4.3 - Need for New Classification Systems

The existing classification systems, as described in Section 2.4.1 have extensive utility across the science of limnology. However, in urban or urbanizing areas, which are subject to unique and highly stressful conditions, additional classification systems, such as the three proposed herein, are necessary to qualitatively and quantitatively characterize these unique conditions. In urban and suburban locations, lentic waters are vulnerable to all manner of anthropogenic manipulation such as the provision of additional sources of

water, alteration of the morphometry of the lake itself, and activities in the tributary watershed that can profoundly affect the water quality and trophic state of the Lake. Existing classification systems can accomplish these characterizations only to a very limited degree, if at all.

CHAPTER 3

NEW YORK CITY'S LAKES AND PONDS

3.1 - Geographical, Geological, Hydrological and Environmental Setting

New York City is located on the east coast of the United States at the mouth of the Hudson River. Lying at about 74° west longitude and 40° 30' north latitude, it consists of two islands, a portion of a third, and a part of the mainland. (New York City Departments of Environmental Protection and City Planning 1978, Pearlmutter and Arnow 1953). With the exception of the northern boundary of Bronx County and the eastern boundary of Queens County, NYC is entirely bounded by marine or estuarine waters. Its land area totals about 320 square miles, and its shoreline extends for 578 miles. The City's 6,000 miles of streets lie on lands that have been altered from their natural state by extensive excavation, filling and construction, and the shorelines have been filled to extend the land area (and to dispose of municipal and commercial refuse). Surface conditions of the land have been changed drastically as speculation-driven development inexorably advanced from the congested core of the City to its sprawling outlying areas, with gridiron street patterns being imposed on preexisting topography. (Gallion and Eisner 1963) Natural drainage has been altered as ridges have been smoothed and punctured (but not removed), and minor depressions have been filled.

New York City contains three different physiographic areas including an extension of the New England upland area which covers the counties of Bronx and New York, the till-covered portions of northern Kings and Queens Counties, along with most of Staten

Island County, and the outwash plain, which occupies southern Kings and Queens Counties, and a small portion of southeastern Staten Island. (Pearlmutter and Arnow 1953)

The City is intersected by the fall line of eastern North America, where the bedrock descends beneath the earth's surface, giving rise to two shoreline conditions, namely; a rocky shore characteristic of New England where ledge rock enters the water, and a coast more typical of Atlantic states south of New York where sand, gravel and other erosion products of the Appalachian Chain mix to form a more malleable and rapidly altering coastal edge (which is the termination of the coastal plain of eastern North America). (New York Departments of Environmental Protection and City Planning 1978)

The most northerly of the City's three physiographic regions is the glaciated and eroded component of a more extensive upland. It is mainly the result of pre-glacial stream erosion, slightly modified by glacial erosion and deposition, and is characterized by parallel linear valleys and ridges. Bronx County, being the only county of New York City having a substantial natural drainage system is drained by the Hutchinson River, the remnant of Westchester Creek, the Bronx River, and Tibbetts Brook, all of which flow to the south in parallel, narrow valleys. The dozen shallow creeks which once drained New York County (Manhattan) have all been filled (Pearlmutter and Arnow 1953), although the water still flows underground or through the municipal sewer system.

The central physiographic region consists of the terminal and ground moraine. The land north of the terminal moraine on Long Island slopes toward the upper East River and western Long Island Sound, and is dissected by the remains of several small

northward-flowing creeks (Alley Creek and Flushing Creek). (Pearlmutter and Arnow 1953)

Finally, the third physiographic region, which is the outwash plain, lies generally to the south of the terminal moraine and eventually merges with the tidal marshes, back bays and barrier islands of Long Island's south shore. The few streams which have developed on the outwash plain are small and occupy shallow, narrow valleys which intersect the water table. (Pearlmutter and Arnow 1953) However, another source (Spinello and Simmons 1992) indicates that "stream valleys on the south shore of Long Island are broad, straight and shallow, and generally follow the courses established by meltwater during glacial retreat. These streams are widely spaced, have few or no tributaries, and have gentle gradients...."

During pre-Cambrian times, the New York City area underwent a transgression. The surface of the resulting seabed was composed primarily of clay and carbonate sediment, which were subsequently lithified into shales and limestones. Subsequently, tectonic forces thrust up a chain of mountains as spectacular as the Rockies. As the orogenies progressed (the Taconic Orogeny during the Ordovician Period and the Arcadian Orogeny during the Devonian Period), the shales and limestones at their base were metamorphosed into the gneiss, schist and marble that currently underlie the City. Eventually, the forces of weathering and erosion wore these jagged mountains into the rounder slopes that we observe today. (Mockler and Ippolito 1991)

During the Pleistocene Epoch, four continental glaciers descended from the Arctic and subsequently receded. Only seventy-five thousand years ago, the Wisconsin ice sheet

advanced southward, pushing a mass of rock, soil and boulders (glacial till) before it. The terminal moraine across Queens, Brooklyn, and Staten Island) marks the southernmost advance of this most recent ice sheet. When the ice finally began to retreat (about seventeen thousand years ago), glacial meltwaters flowed south to the sea, carrying sediments (outwash) along with it. Large chunks of ice broke away from the retreating glacier and became imbedded within the moraine. Upon melting, they created deep depressions that subsequently evolved into kettlehole ponds. (Mockler and Ippolito 1991)

In spite of the proximity of New York City to the Atlantic, and to numerous bays, tidal straits and other estuarine waters, its climate tends to be continental rather than marine, because prevailing weather patterns generally approach from the west. Nevertheless, the nearby marine waters do tend to have a moderating effect on the local weather, and the region is affected by coastal storms (both nor'easters and hurricanes). The City's climate is also affected by the urban heat island effect which moderates the effects of winter, but intensifies those of summer. (Henderson-Sellers and Robinson 1989)

The mean annual temperature of the City is 52.6° F. (with temperatures below zero and in excess of one hundred degrees occurring only rarely), while the average annual precipitation is moderate at 42.92 inches and evenly distributed throughout the year. During summer months the precipitation is associated with short, intense thunderstorms, while the non-summer precipitation often occurs as widespread frontal storms. (Pearlmutter and Arnow 1953)

The 26,200 acre New York City Park System, which provides substantial numbers of sites for passive and active recreation (even though it has the smallest area of parkland

per capita of any major city in the United States), also provides for the conservation of natural resources within the City (although much of the City's parklands are man-made). (This is a remarkable achievement, considering that in the middle of the 19th century, many New Yorkers thought that the salvaging of green space was a private rather than a public responsibility, and that during that period, New York was not a national leader in creating parkland. (Lankevich 1998)) It also provides for relief from an intensely developed urban environment, while occasionally keeping lands such as steep slopes and flood hazard areas from being developed. Sadly, it has not kept the barrier islands out of development, nor has it functioned as a green buffer to separate conflicting land uses.

One hundred and thirty-four lakes, ponds and reservoirs have been identified within New York City by the New York State Department of Environmental Conservation (NYSDEC) and by local agencies (Environmental Protection, City Planning, and Parks and Recreation). Most of these water bodies are located totally or partially within the confines of the property managed by the New York City Department of Parks and Recreation. However, a few lie within cemeteries (Greenwood and Woodlawn) or are in non-municipal ownership (Clay Pit Ponds, Arbutis Lake, and the Lipsett Avenue Pond (known informally to some as Garbage Lake)). A listing of these lakes, ponds and reservoirs may be found in Table 3.1. The general location of these water bodies may be found in Figures 3.1- A through 3.1- E, using the map identifiers listed in Table 3.1.

The New York City Department of Parks & Recreation manages 637 acres of lakes, ponds and marshes within its vast park system. Visitors use these water bodies for boating, fishing, aesthetic purposes, observing nature, photography, environmental

education, and as an escape from the concrete, steel, noise, traffic and bustle of urban life (swimming is not permitted in any pond or lake within a New York City park).

TABLE 3.1			
LAKES, PONDS AND RESERVOIRS IN NEW YORK CITY			
LAKE	Map Identifier	BOROUGH	SURFACE AREA (ACRES)
Jerome Park Reservoir	Jrm Pk Res	Bronx	83.3
Van Cortlandt Lake	VnCtld Lk	Bronx	12.8
Elm Lake	Elm Lk	Bronx	<6.4
Maple Lake	Mpl Lk	Bronx	<6.4
Birch Lake	Brch Lk	Bronx	<6.4
Sycamore Lake	Skmr Lk	Bronx	<6.4
Crotona Lake	Crtna Lk	Bronx	3
Woodlawn Lake	Wdlwn Lk	Bronx	<6.4
180 th Street Impoundment on Bronx River	180 St Impd	Bronx	>6.4
Five unnamed ponds within Bronx Botanical Gardens and Bronx Park	Bnx Pk Pds	Bronx	each<6.4
Pond at Taft High School	Tft HS Pd	Bronx	<6.4
Central Park Reservoir	Ctrl Pk Res	Manhattan	106
Central Park Lake	Ctrl Pk Lk	Manhattan	12.8
Harlem Meer	HlmMr	Manhattan	10.6
The Pond (Central Park)	Ctrl Pk Pd	Manhattan	3.4
Turtle Pond (Central Park)	Trtl Pd	Manhattan	2.6
The Pool (Central Park)	Ctrl Pk Pl	Manhattan	1.6

TABLE 3.1 (Continued) LAKES, PONDS AND RESERVOIRS IN NEW YORK CITY			
The Loch (Central Park)	Ctrl Pk Lch	Manhattan	<6.4
Conservatory Water (Central Park)	Cnsrvtry Wtr	Manhattan	<6.4
Prospect Lake	Prspct Lk	Brooklyn	50.7
Dale Water Pond (Greenwood Cemetery)	Dle Wtr Pd	Brooklyn	<6.4
Dell Water Pond (Greenwood Cemetery)	DI Wtr Pd	Brooklyn	<6.4
Crescent Water Pond (Greenwood Cemetery)	Crst Wtr Pd	Brooklyn	<6.4
Sylvan Water Pond (Greenwood Cemetery)	Slyn Wtr Pd	Brooklyn	<6.4
Valley Water Pond (Greenwood Cemetery)	Vly Wtr Pd	Brooklyn	<6.4
Swan Boat Lakes	Swn Bt Lks	Brooklyn	each<6.4
Unnamed pond within Brooklyn Botanical Gardens	Bkln Btncl Gdn Pd	Brooklyn	<6.4
Three unnamed ponds in Dyker Beach Park	Dkr Bch Pk Pds	Brooklyn	each<6.4
Unnamed pond in Highland Park	Hlnd Pk Pd	Brooklyn	<6.4
Meadow Lake	Mdw. Lk.	Queens	84.0
Ridgewood Reservoir	Rgwd Res	Queens	51.1
Willow Lake	Wlw Lk	Queens	44.7
Baisley Pond	Bsly Pd	Queens	25.7
Oakland Lake	Okld Lk	Queens	13
Kissena Lake	Ksna Lk	Queens	7.7
Conselyea's Pond	Cnsly Pd	Queens	4.3
Springfield Pond	Spngfld Pd	Queens	<6.4
Crocheron Pond	Crchrn Pd	Queens	1

TABLE 3.1 (Continued) LAKES, PONDS AND RESERVOIRS IN NEW YORK CITY			
Seven unnamed impoundments along Laurelton Creek	Lrltn Ck Impds	Queens	each<6.4
Alley Pond	Aly Pd	Queens	<6.4
Little Alley Pond	Ltl Aly Pd	Queens	<6.4
Decadon Pond	Dcdn Pd	Queens	<6.4
Six unnamed kettle ponds in Alley Park	Aly Pk Pds	Queens	each<6.4
Unnamed pond in Bowne Park	Bwn Pk Pd	Queens	<6.4
Two unnamed ponds in Clearview Golf Course	Clrvw Glf Crs Pds	Queens	each<6.4
Four unnamed ponds in Cunningham Park	Cnghm Pk Pds	Queens	each<6.4
Unnamed pond in Queens Village	Qns Vlg Pd	Queens	<6.4
Two unnamed ponds in Aqueduct race Track	Aqdct Pds	Queens	each<6.4
Captain Tilly Pond	Cptn Tly Pd	Queens	2
Unnamed pond in Maple Grove Cemetery	Mpl Grv Cm Pd	Queens	<6.4
Three unnamed ponds in Forrest Park	Frst Pk Pds	Queens	each<6.4
Unnamed pond in Cypress Hills Cemetery	Cprs Hls Cm Pd	Queens	<6.4
Silver Lake Reservoir	Slvr Lk Res	Staten Island	51.1
Grassmere Lake (Brady's Pond)	Grsmr Lk	Staten Island	19.3
Wolfe's Pond	Wlfs Pd	Staten Island	15.4
Arbutis Lake	Arbts Lk	Staten Island	12.8
Clove Lake	Clv Lk	Staten Island	12.8
Orbach Lake	Orbc Lk	Staten Island	6.4

TABLE 3.1 (Continued) LAKES, PONDS AND RESERVOIRS IN NEW YORK CITY			
Martling Lake	Mtlg Lk	Staten Island	6.4
Cameron Lake	Cmrn Lk	Staten Island	<6.4
Eibs Pond	Ebs Pd	Staten Island	1.9
Shore Acres Pond	Shr Acrs Pd	Staten Island	<6.4
Great Kills Pond	Grt Kls Pd	Staten Island	<6.4
Jack's Pond	Jks Pd	Staten Island	<6.4
Wood Duck Pond	Wd Dk Pd	Staten Island	<6.4
Lipset Avenue Pond	Lpst Av Pd	Staten Island	<6.4
Sharrot's Pond	Shrts Pd	Staten Island	<6.4
Huguenot Pond	Hgnt Pd	Staten Island	<6.4
Acme Pond	Acm Pd	Staten Island	<6.4
Bloeser's Pond	Blrs Pd	Staten Island	<6.4
Long Pond	Lng Pd	Staten Island	<6.4
Hourglass Pond	Hrgls Pd	Staten Island	1.04
Pump House Pond	Pmphs Pd	Staten Island	<6.4
Richmondton Millpond	Rchmndtn MIPd	Staten Island	1.0
Walker Pond	Wkrs Pd	Staten Island	<6.4
Stamp Pond	Stmp Pd	Staten Island	<6.4
Brooks Lake	Brks Lk	Staten Island	<6.4
Willowbrook Pond	Wlwbrk Pd	Staten Island	<6.4
Annadale Wedge Pond	Andl Wg Pd	Staten Island	<6.4
Porzio's Pond	Przos Pd	Staten Island	<6.4

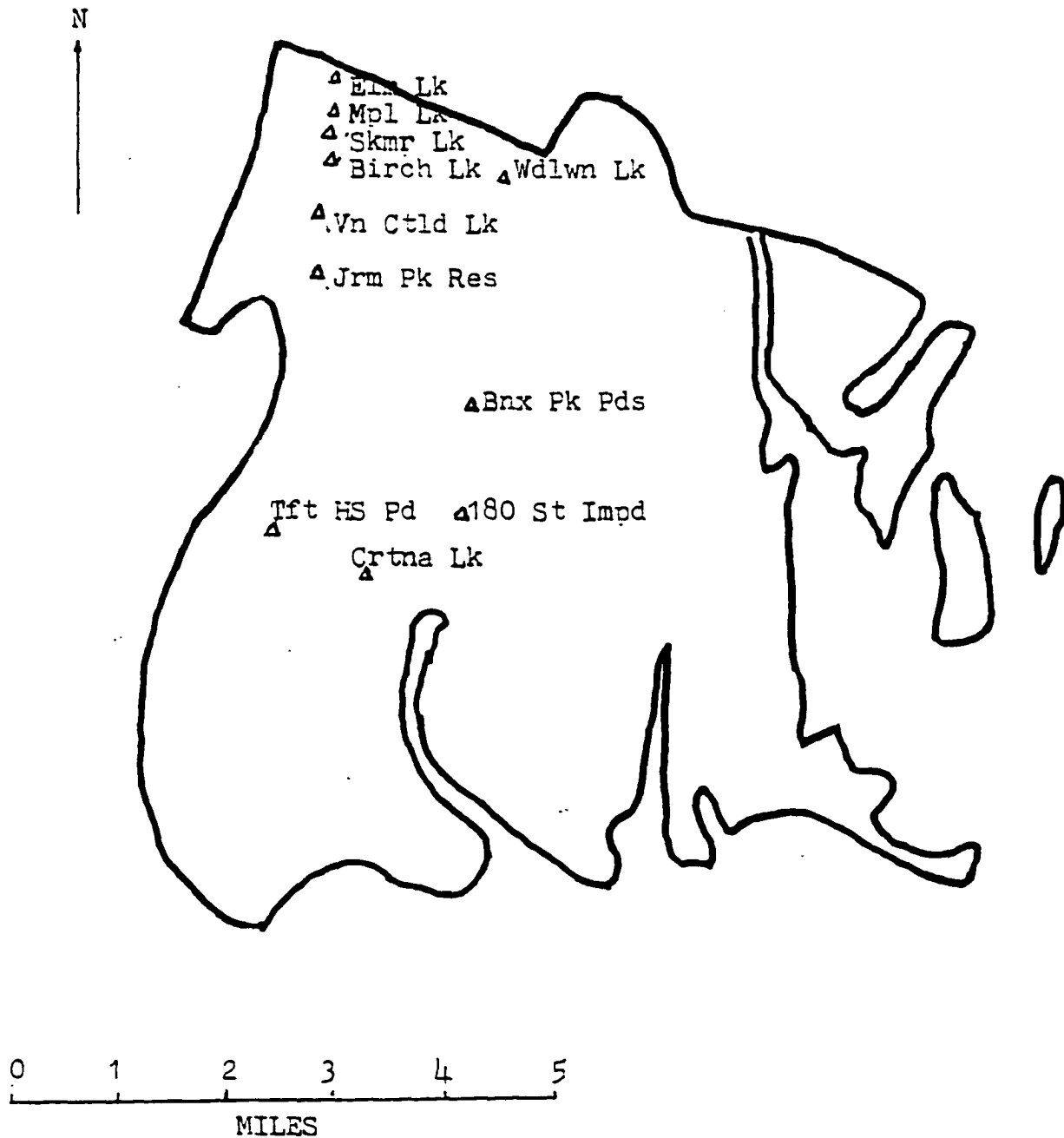
TABLE 3.1 (Continued) LAKES, PONDS AND RESERVOIRS IN NEW YORK CITY			
Alison's Park Pond	Alsns Pk Pd	Staten Island	<6.4
Four unnamed ponds in the New Creek Watershed	Nw Ck Pds	Staten Island	each<6.4
Unnamed pond in Great Kills Watershed	Frsh Kls Pd	Staten Island	<6.4
Ten unnamed ponds in the Staten Island Greenbelt	Grnblt Pds	Staten Island	each<6.4
Four unnamed ponds in Clay Pit Ponds State Park	Clypt Pk Pds	Staten Island	each<6.4
Valley Lake	Vly Lk	Staten Island	<6.4
Unnamed pond in Silver Lake Park	Slvr Lk Pk Pd	Staten Island	1.3
Two unnamed ponds at Sailor's Snug Harbor	Sng Hbr Pds	Staten Island	1.1 each
Unnamed Pond north of Fort Wadsworth	Ft Wdswth Pd	Staten Island	<6.4
Two unnamed ponds east of Port Ivory	Prt Ivry Pds	Staten Island	<6.4
Two unnamed ponds at Mount Loretto	Mt Lrto Pds	Staten Island	each<6.4
Spring Lake	Sprng Lk	Staten Island	<6.4
Blue Heron Pond	Bl Hrn Pd	Staten Island	1.3

(From New York City Dept. of Parks and Recreation Circa 1989, New York Code of Rules and Regulations 1995 and 1996, New York Dept. of Environmental Conservation June 1985, Ifcher, 1996, USGS Quad Maps)

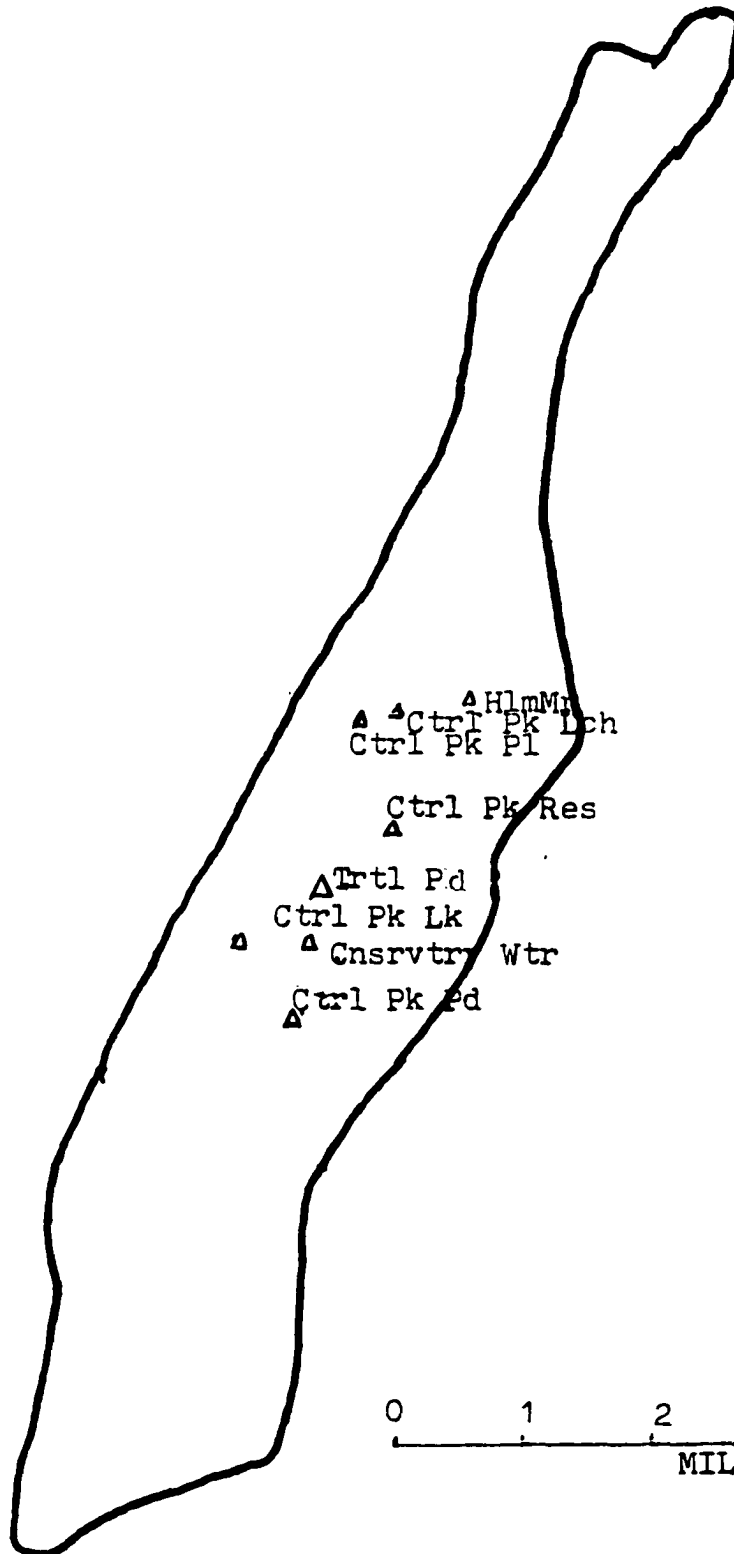
Additionally, the lakes serve various functional uses such as for stormwater retention, groundwater recharge, and as a habitat for fish, wildlife and plants. Some of the water

MAP OF BRONX COUNTY SHOWING GENERAL LOCATIONS OF LAKES,

PONDS AND RESERVOIRS



MAP OF NEW YORK COUNTY SHOWING GENERAL LOCATIONS OF
LAKES, PONDS AND RESERVOIRS



MAP OF KINGS COUNTY SHOWING GENERAL LOCATIONS OF LAKES,

PONDS AND RESERVOIRS

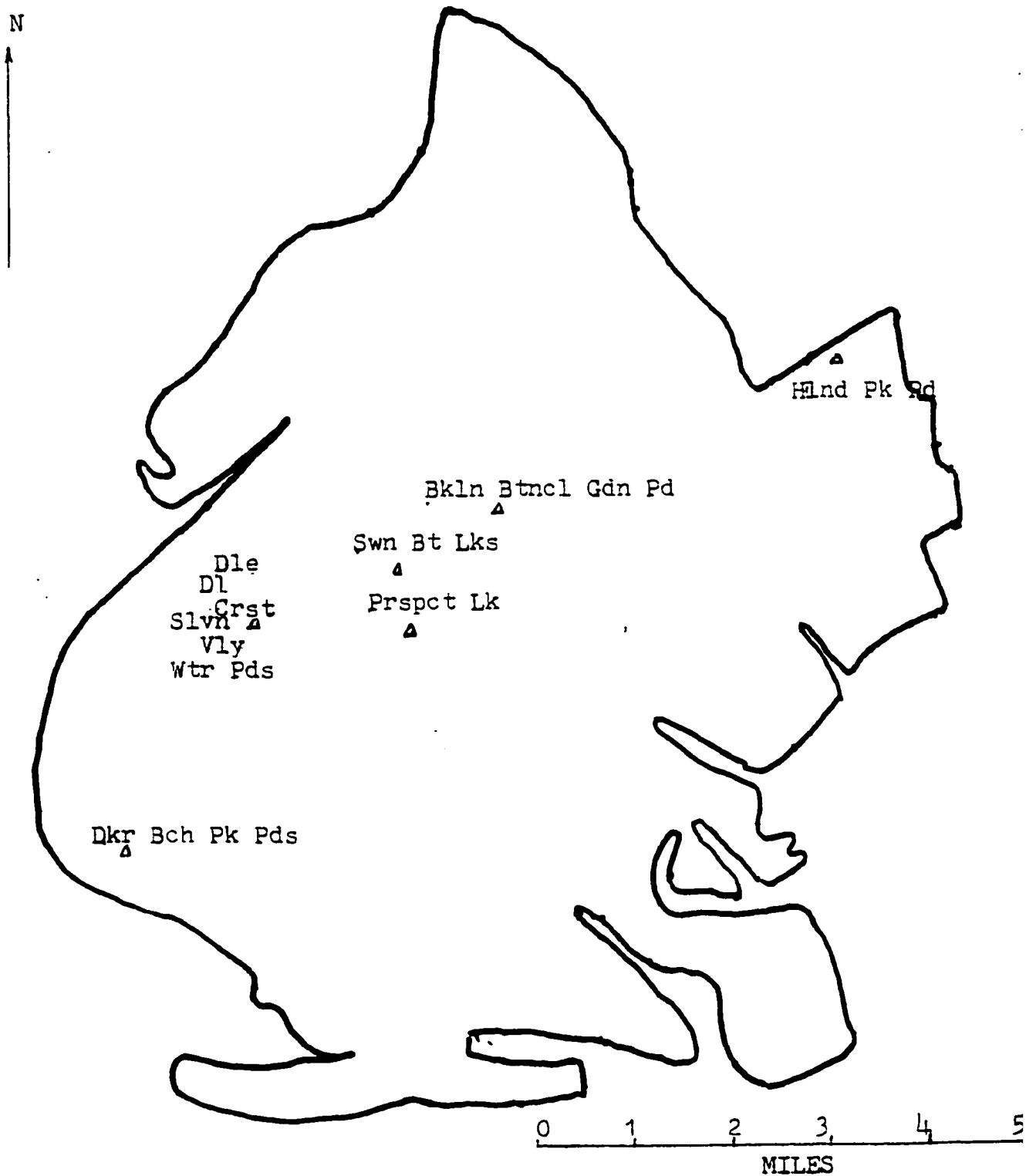
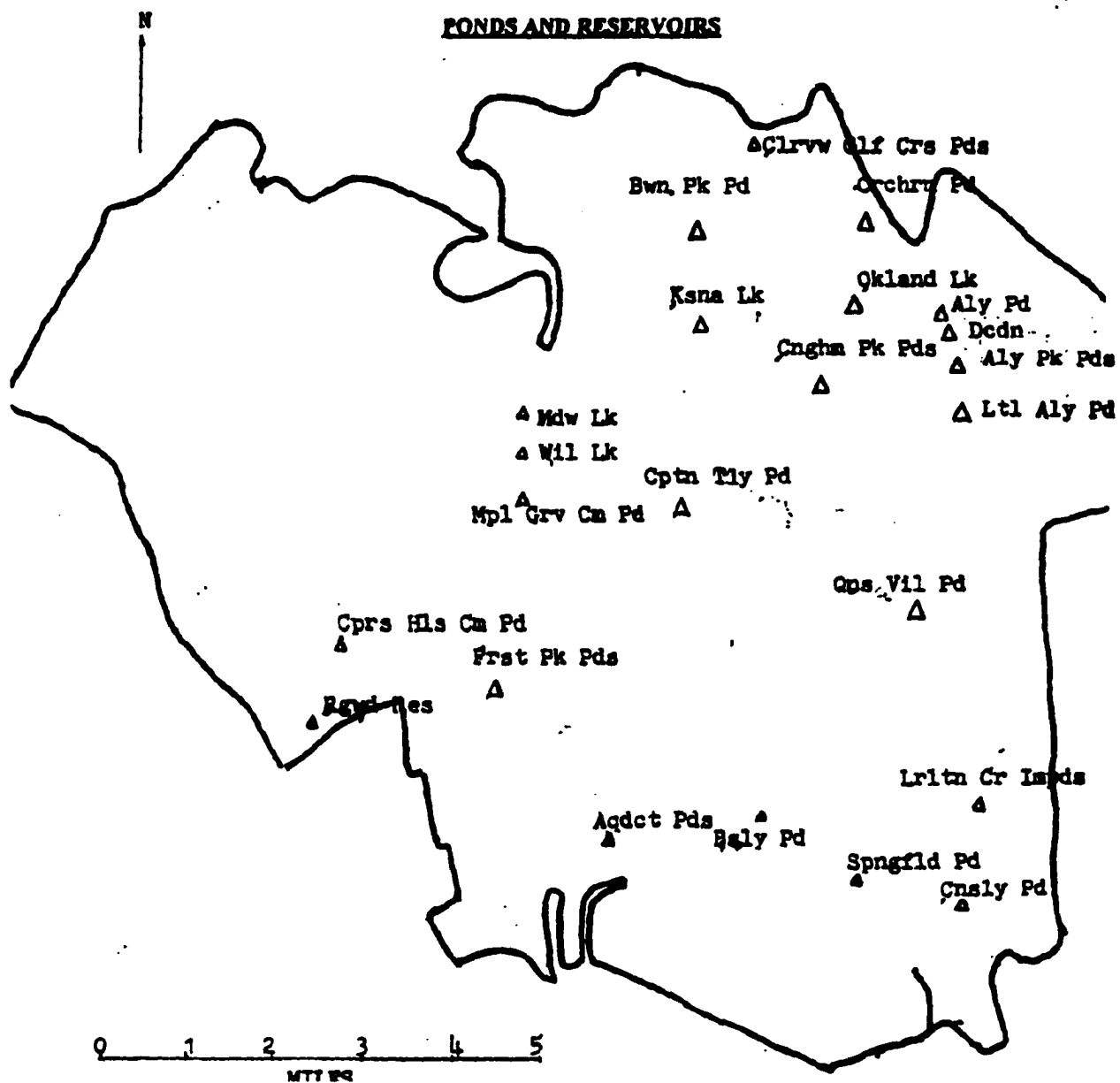
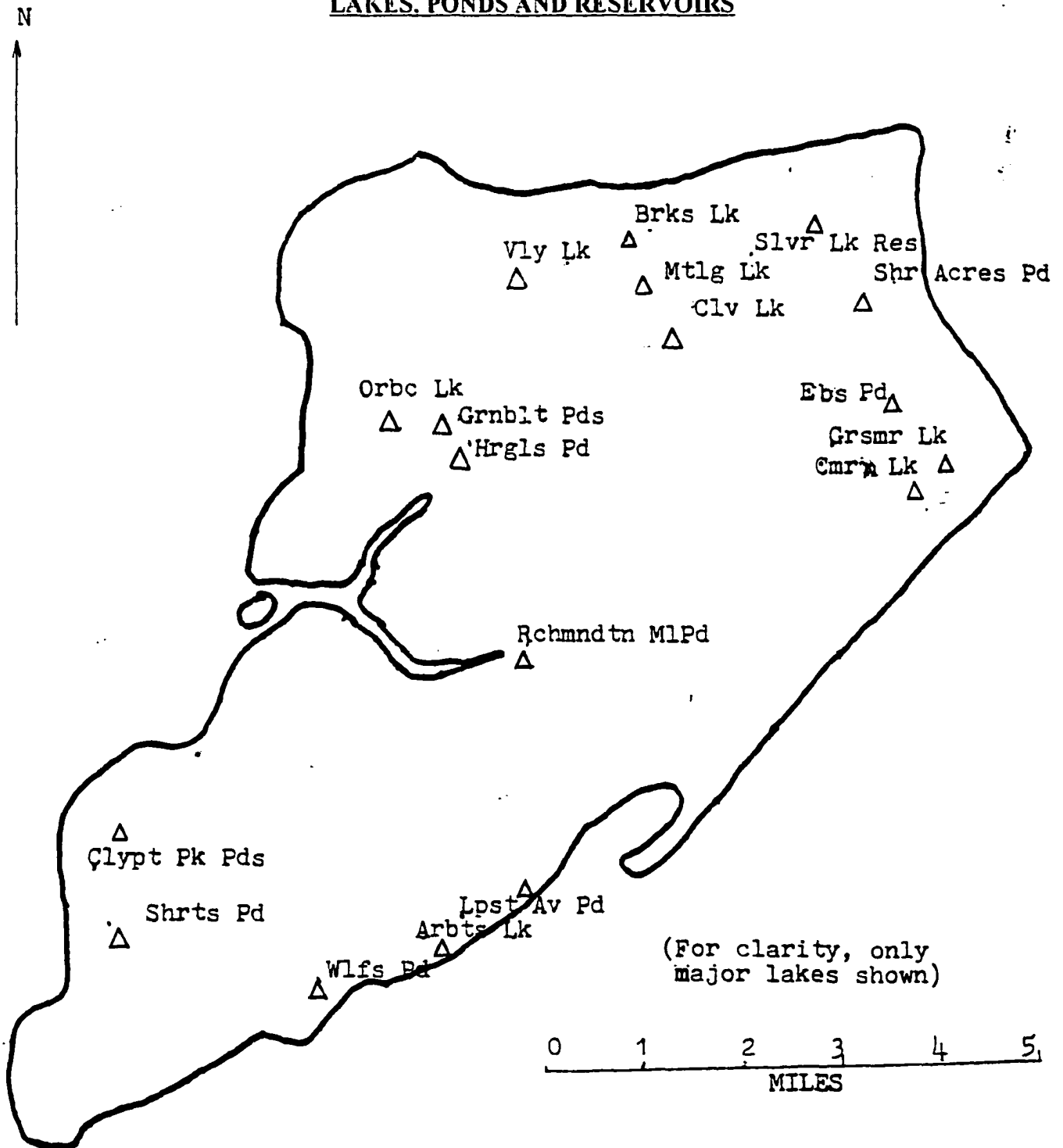


FIGURE 3.1- D

MAP OF QUEENS COUNTY SHOWING GENERAL LOCATIONS OF LAKES.

MAP OF STATEN ISLAND COUNTY SHOWING GENERAL LOCATIONS OF

LAKES, PONDS AND RESERVOIRS



bodies within city parks, such as the Central Park, Ridgewood and Silver Lake Reservoirs, once served as components of the municipal water supply system. Erosion caused by intensive use at the edges of many of the lakes and ponds, has created severe water quality problems (excessive sedimentation) in the lakes, which are already stressed by pollutants being conveyed by urban runoff and by acid rain. (New York City Department of Parks and Recreation 1990) Erosion in the watersheds (as discussed in Section 2.3) and in the tributary streams has also led to degradation of water quality in New York City's lakes and ponds.

3.2 - History, Description and Classification of Selected Lakes

As discussed in Section 1.2, (and as further discussed in Section 4.2), nine New York City lakes and ponds were selected for detailed analyses. This nine lake sample is considered generally representative of the New York City population of 134 lakes and ponds because like the population, the sample contains lakes:

- 1- That are located in areas ranging from sparsely developed to densely urbanized;
- 2- That range from virtually natural to completely artificial;
- 3- That have primary water input mechanisms that include impounded streams, groundwater seepage and the municipal water supply (as well as some degree of runoff);
- 4- That range in surface area from less than 2 acres to almost 90 acres (although the population is more skewed toward smaller surface areas than is the sample);
- 5- That are to a greater or lesser degree buffered against urban runoff by parkland or

other open space;

6- That are generally shallow (Ifcher 1996);

7- That have aquatic weed or algal problems (New York City Department of Parks and Recreation 1990, Lev 1989);

8- That originated as kettleholes (one or possibly two), thereby representing the kettle ponds located in Queens, Brooklyn and Staten Island.

However, it must be noted that the nine sample lakes were not selected through a purely random process. Rather, they are a component of a larger sample of 27 New York City lakes and ponds which were selected by The New York State Department of Environmental Conservation's Region 2 Water Unit as a component of a new rotating ambient water monitoring program. They tend to include the slightly more prominent lakes in the population, and accessibility was a factor in their selection. Additionally, the nine lake sample does not represent the four water supply distribution reservoirs which are included in the population. (Three of these reservoirs have been permanently taken off-line (Ridgewood, Central Park and Silver Lake). The Jerome Park Reservoir remains in service.)

The nine selected lakes, which have numbers assigned to them, based originally on the order in which they were sampled (but subsequently these numbers have been used as an auxiliary means of identification) include:

1- Wolfe's Pond

2- Richmondtown Millpond

3- Harlem Meer

4- Van Cortlandt Lake

5- Prospect Lake

6- Conselyea's Pond

7- Oakland Lake

8- Kissena Lake

9- Meadow Lake

A somewhat detailed description of each selected lake, along with a history follows.

Additionally, descriptions and histories of all the other lakes in Central Park, along with Willow Lake in Flushing Meadow Park are included because of the “flagship” status of these parks within the New York City Park System. Finally, in accordance with the criteria set forth in Section 2.4.2, each lake selected for detailed analysis is scored under each of the three proposed classification systems, namely; Water Input Mechanism, Degree of Artificiality, and Degree of Urbanization.

In scoring a given lake under each classification system, the primary descriptor (one of the averages (or an appropriate alternative within the designated range) proposed in Sections 2.4.2.1 through 2.4.2.3) in each system is determined by researching and evaluating the characteristics of the lake and its tributary watershed. Each descriptor is then adjusted in accordance with any modifying or otherwise complicating features in that lake or watershed. Examples of such procedures are as follows:

1- Water Input Mechanism System

If groundwater seepage is the primary input mechanism, its score of 3 might be reduced by 0.2 for each additional lower scored input to the lake (say a tributary surface

stream), and that score might be further reduced by, perhaps another 0.1 if that secondary source (the stream) is obviously afflicted by contaminant inputs like septic system overflow. However, if additional water inputs directly to the lake are severely contaminated (say with septic system overflow, and/or runoff from major traffic arteries, urban areas or severely eroded lands), judgment then dictates that our score of 3 should be reduced by as much as 0.5. In New York City, the score of 5 for municipal water supply as a lake feedstock is always reduced by 0.2 because of the addition of orthophosphates to the supply (See Section 3.3). Another example of scoring might include a lake fed by City water receiving direct inputs of polluted urban runoff, and also fed by a moderately polluted stream, where the initial score of 5 would be reduced by 0.2 for orthophosphate addition, by 0.4 for the polluted urban runoff and by 0.2 for the moderately polluted stream, for a cumulative score of 4.2. As still another example, at an impoundment of a moderately polluted perennial stream with low baseflow and a good vegetative buffer, the average score for a perennial stream of 1.5 might be increased by 0.5 for good vegetative buffer, and reduced by 0.1 for moderate pollution and then reduced further by 0.2 for low baseflow for a final score of 1.7. An alternative solution is to start with the average of 1.2 for all impounded streams, make no additions nor reductions for low baseflow, add 0.5 for good vegetative buffer, and then deduct 0.1 for moderate pollution for a score of 1.7.

Further Examples:

Renovated wastewater (filtration only), direct eroded land runoff, and seepage from densely developed residential area; (See Figure 2.1 - F)

3.6 (filtered wastewater) - 0.4 (eroded land runoff) - 0.2 (light to

moderately contaminated groundwater) = 3.0

Seepage Lake receiving runoff from degraded urban area, and inflow from an unpolluted tributary stream;

$$3 \text{ (groundwater)} - 0.5 \text{ (runoff from degraded urban area)} - 0.0 \text{ (unpolluted stream)} = 2.5 \quad (\text{Unpolluted streams can even raise scores.})$$

Alternatively, if groundwater is from under an intensely industrialized area; (See Figure 2.1 - E)

$$1.0 \text{ (polluted groundwater)} - 0.5 \text{ (runoff from degraded urban area)} + 0.2 \text{ (unpolluted stream)} = 0.7$$

An impounded ephemeral stream well buffered by vegetation, receiving a moderate amount of nonpoint source pollution; (See Figure 2.1 - C)

$$\text{Score} = 0.6$$

2- Degree of Artificiality System

A “bathtub lake” scored at 5 might have its score reduced by, perhaps 0.1 if a water body or a wetland previously existed on the site, and by another 0.1 if minor sources, in addition to totally anthropogenic sources help to maintain water levels. If more than a single descriptor applies, the cumulative score for the lake can be adjusted by adding a value of between 0.1 and 0.8 for each of the additional descriptors that may apply (depending on the extent of the deviation from natural conditions or the degree of complexity of the smaller enhancement(s)), to the largest descriptor. E.g., an “average” supplementary water addition (score of 1 - see Figure 2.2 - C) and an anthropogenically enhanced outlet yields a cumulative score of about 1.1. An additional example might

include an impounded stream, with a hardened shoreline, where the initial score of 4 (see Figure 2.2 - E) would be increased by 0.6 for the hardened shoreline for an adjusted score of 4.6. Still another example might be an excavated lake having stormwater diverted to it, where the initial score of 4 would be increased by 0.7 for the diverted stormwater.

Further Examples:

A natural lake (medium sized), supplemented by well water and dredged for maintenance and for more depth; (See Figures 2.2 - D and 2.2 - C)

$$0 \text{ (natural lake)} + 0.3 \text{ (for well)} + 0.5 \text{ (dredging)} = 0.8$$

Incorrect! First enhancement should be given full value;

$$2.5 \text{ (dredging a medium sized lake)} + 0.3 \text{ (for well)} = 2.8$$

A natural lake having its natural dam (lake formed by mass movement across an ephemeral stream) provided with a fairly complex enhancement, and also provided with supplementary water by a municipal water supply tap: (See Figures 2.2 - D and 2.2 - C)

$$3.2 \text{ (fairly complex dam enhancement)} + 0.1 \text{ (water supply tap)} = 3.3$$

3- Degree of Urbanization System

In this system, the evaluator's assessment of land use should be based on the factors presented with each descriptor in Figure 2.3. This assessment, in turn, should be substantially modified by the extent to which the lake or its tributary streams are buffered against contaminated runoff by parklands or other vegetative strips. These buffers can reduce the Degree of Urbanization score by up to 2.0 if erosion in the buffer is minimal. However, severely eroded buffers can increase the score by up to 0.5. E.g., a lake in an

intensely urbanized, partially degraded area (score about 4.7) is fairly well buffered by parkland (-1.0) which is subject to severe erosion (+0.5) is scored at 4.2. An additional example might be the scoring of a drainage area which consists of 25% parkland, 50 % suburban and 25% moderately urbanized. Here a weighted average of $(0.25)(0.3) + (0.5)(2) + (0.25)(3) = 1.8$ can be used. Another example might be a heavily urbanized area buffered by noneroding parkland, with no storm drains from city streets nor from the park's circulation system, where the initial score of 4 (for a densely urbanized area) is reduced by 2 (good vegetative buffer) for a cumulative score of 2.

Further Examples:

Suburbanized area well buffered by parkland, but fed by a stream passing through a moderately urbanized area; (See Figure 2.3 - A)

$$2 \text{ (suburbanized area)} - 2 \text{ (well buffered)} + \underline{0.4 \text{ (impact of tributary passing through more urbanized land)}} = 0.4$$

Incorrect! Must use the weighted average of land uses in the watershed to assess the impact of the stream passing through the more urbanized area.

Lake having "low end" intensely urbanized drainage area, slightly buffered by a greenbelt : (See Figure 2.3 - A)

$$3.8 \text{ (low end of intensely urbanized range)} - 0.4 \text{ (slight buffering)} = 3.4$$

3.2.1 - Wolfe's Pond

Many of the larger ponds on Staten Island are primarily artificial. (Leng and Davis 1930) Wolfe's Pond (located in southwestern Staten Island) was originally a small bay adjacent to the outlet of Wolfe's Creek, and it has this appearance on several maps

prepared during the 17th and 18th centuries. Surveys prepared between 1837 and 1839 are the first to show the Pond as being separated from Raritan Bay, and it is believed that the gradual silting of the mouth of the Creek probably led to the Pond's creation. However, there is some evidence that the pond may be partially artificial since a dam appears to have converted a marshy area into a pond, with the purpose of creating an ice pond (but evidence is lacking on this point). (Powell 1975) An alternative theory holds that Wolfe's Pond originated as a kettlehole. (New York City Department of Environmental Protection April 1999) The Pond has a clay bottom and is considered perched. There is a lack of shoreline vegetation due to heavy pedestrian usage which has led to an enhanced rate of shoreline erosion. The HEC-1 and HEC-2 hydrological and hydraulic mathematical models, respectively, which are being utilized by the New York City Department of Environmental Protection's consultants on the Staten Island Bluebelt Program, have indicated that the velocities generated by projected large future storm flows will not be high enough to cause bank and bottom erosion in the stream tributary to Wolfe's Pond.

Today, the Pond lies almost completely within Wolfe's Pond Park, but there is some residential development to the west. It continues to be separated from Raritan Bay by a fairly narrow berm which is occasionally overwashed during severe weather/tidal conditions. A sketch of Wolfe's Pond is found in Figure 3.2.

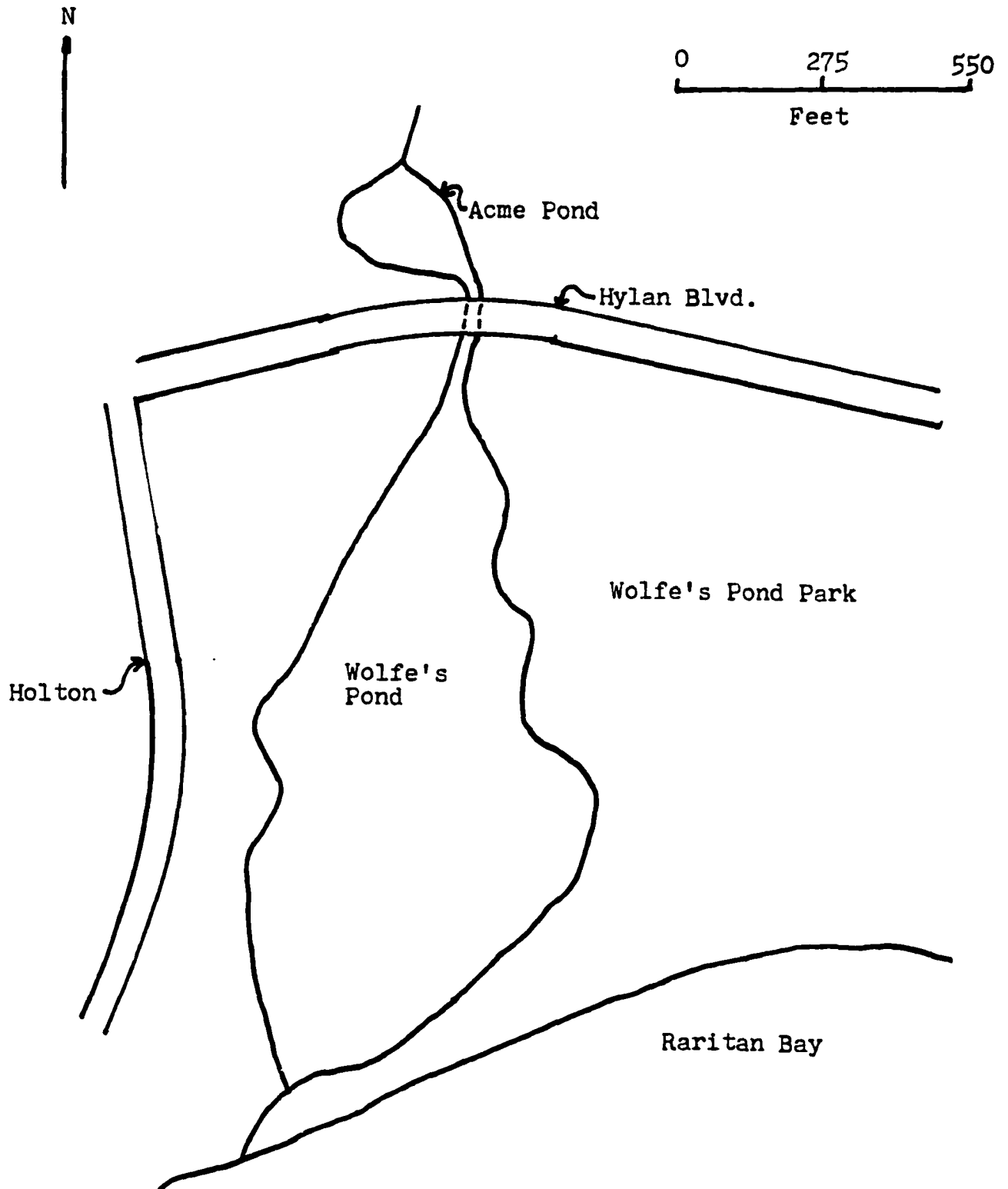
Classification System Scoring

Water Input Mechanism System

Wolfe's Pond is fed primarily by groundwater (Ifcher 1996, Khanbilvardi and

FIGURE 3.2

SKETCH OF WOLFE'S POND, STATEN ISLAND



Blatner 1991, New York City Department of Environmental Protection April 1999), but it also receives tributary flow (which receives a small amount of untreated sewage discharge) and suburban runoff. The groundwater score of 3 is therefore reduced to 2.7.

Degree of Artificiality System

According to one source (Powell 1975), Wolfe's Pond was created when a small embayment at the mouth of Wolfe's Creek was isolated from Raritan Bay by natural sedimentation processes. However, this natural dam appears to have been anthropogenically enhanced, while the outlet structure obviously was man-made. Wolfe's Pond is rated at 2.4.

Degree of Urbanization System

Wolfe's Pond is located in a lightly suburbanized watershed having minimal industry. The drainage area is mostly unsewered. It is characterized by failing on-site disposal systems and by a few illegal point sources. The Pond is buffered by parkland, except on the west where it is in close proximity to a few residential buildings served by on-site systems. Some sewerage is planned for the near future. Culverts are only used to pass the tributary stream under streets. A rating of 1.4 is assigned to Wolfe's Pond.

3.2.2 - Richmondton Millpond

This smallest of the nine lakes selected for detailed study is located in the historic Richmondton restoration site, which was initially settled in 1685, and which was established as the Richmond County Seat in 1728. The Millpond was probably established prior to 1770, when two grist mills were built. After the county seat was moved to St. George in 1898, Richmondton continued as a rural manufacturing center, with small

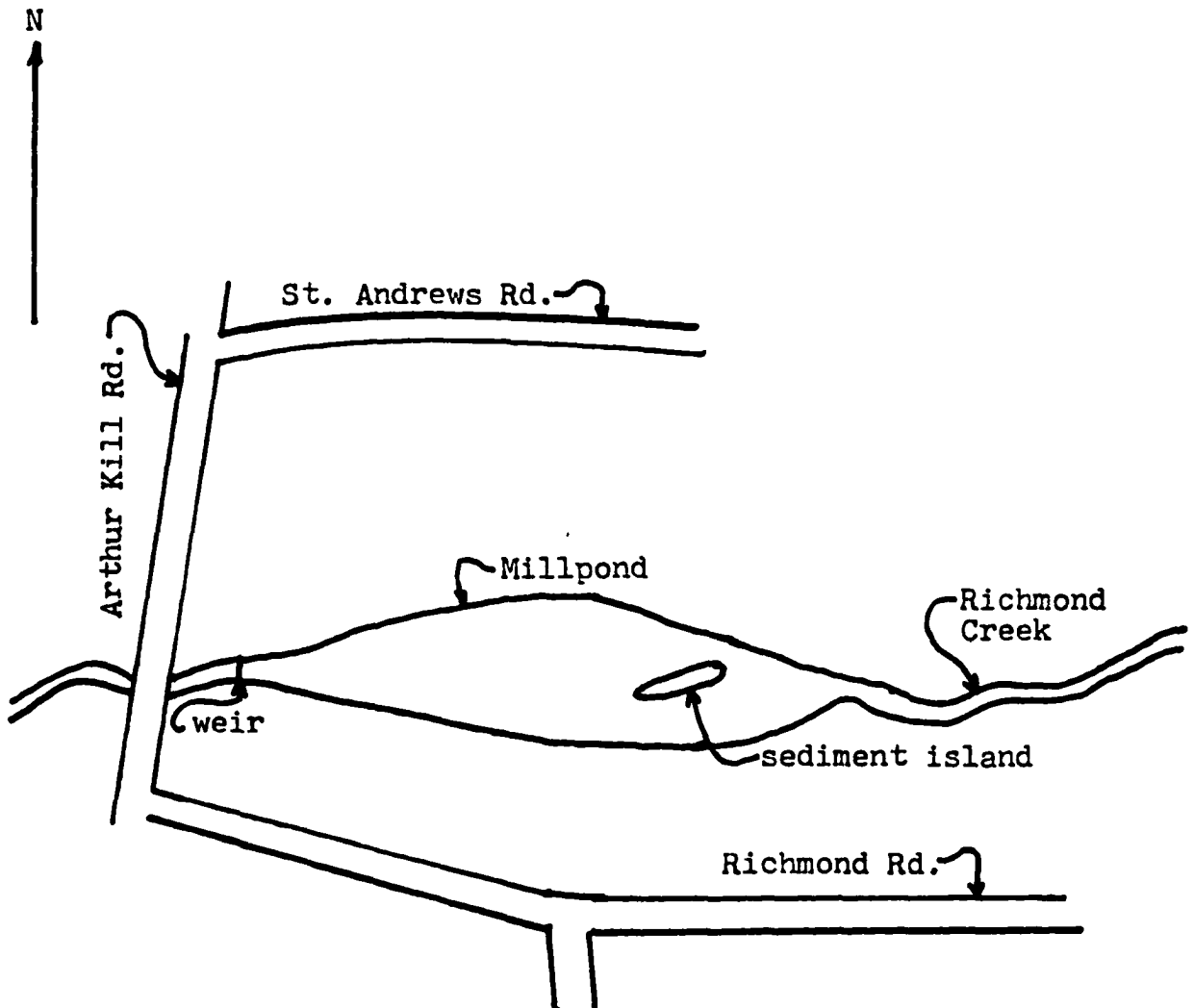
industries located around the Millpond. (New York City Department of Environmental Protection February 1997) Water quality in the Millpond is extremely poor, due to failing on-site disposal systems (a condition that might remind a student of New York City's history of the overflowing Manhattan privies of the early to middle nineteenth century (Goldman 1997)), to improper sanitary connections to storm sewers, and to high concentrations of waterfowl. Intense erosion along the tributary, Richmond Creek, and along the shore of the Millpond has led to severe sedimentation and substantial reduction in pond depth (from six feet to one foot). Fortunately, a multifaceted remediation program (including the provision of sanitary sewers, a dredging program designed to remove about 3000 cubic yards of sediment, and a host of erosion control measures along Richmond Creek and around the Millpond) is being implemented. (New York City Department of Environmental Protection February 1997) A sketch of the Richmondtown Millpond is found in Figure 3.3.

Classification System Scoring

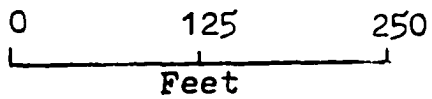
Water Input Mechanism System

The Richmondtown Millpond receives almost all its water from the tributary stream which is known as Richmond Creek. The tributary stream has a baseflow (score 1.5), but both the stream and the Millpond receive illegal sewage discharges (a sewer system designed to correct this situation is under construction), so the score is lowered to 1. (Berger and Associates 1988, New York City Department of Environmental Protection February 1997, New York City Department of Environmental Protection March 1997)

SKETCH OF RICHMONDTOWN MILLPOND, STATEN ISLAND



Historic Richmond Town



Degree of Artificiality system

The Richmondtown Millpond was created by impounding Richmond Creek with a man-made dam. It is scored at 4.

Degree of Urbanization System

Richmondtown Millpond and its tributary, Richmond Creek, are located in a lightly suburbanized drainage area characterized by failing on-site disposal systems and some illegal point sources. The catchment does contain some institutional facilities. Under New York City's Bluebelt Program, some improvements which are designed to reduce flooding and bank erosion have been implemented. Major sewerage of the watershed, which should drastically reduce pollution, is underway. Minimal parkland buffering is available. A score of 1.7 is assigned.

3.2.3 - Central Park

All the water courses within Central Park were designed by Olmsted and Vaux as part of their original planning effort. The lakes and ponds of Central Park are important because they function as a focal point for active and passive recreation for multitudes of visitors. They also serve as major components of the Park's drainage systems, since most of the storm runoff generated within the Park drains into these waterways. They also serve as habitats for many fish and wildlife (both aquatic and terrestrial species) living within the Park. Inflow to the water bodies consists of overland flow, stormwater from catch basins, and water from the municipal supply. The outflow from each water body ultimately flows into the municipal combined sewer system.

In 1984, all Central Park water bodies were classified under Carlson's Trophic

State Index as being hypereutrophic. These waters were ranked from the most hypereutrophic to the least in the following order: The Pool, Harlem Meer, The Pond, the Lake and Turtle Pond (formerly Belvedere Lake). (New York City Department of Parks and Recreation 1990)

The Pond is located in the southeastern corner of Central Park, near the intersection of 5th Avenue and Central Park South. Before the Park was created, the area possessed a varied landscape consisting of swampland, steep slopes and craggy outcrops, which was utilized for agricultural and industrial purposes. The swamp was excavated during park development in order to form a pond having a regular shoreline and a sandy beach at its southern end.

During its early years, the Pond was used for rowboats and swan boats in the summer and ice skating in the winter. The bottom of the Pond (as were the bottoms of all the Central Park water courses) was lined with concrete in 1903, while the shoreline was rip-rapped in 1928. In 1934, the Pond and promontory at the western edge was established as a bird sanctuary. In 1951, the eastern portion was filled in order to construct the Wollman Skating Rink. Finally, during late 1970s, the Pond was dredged and the existing rip-rapped shoreline was set with mortar, utilizing funds provided under Section 314 of the Federal Clean Water Act.

The outlet for the Pond, located at the Southwestern corner, consists of a stop-plank weir which drains directly into the municipal combined sewer system. Stop planks may be removed in order to raise or lower the water level. Additionally, an outlet pipe permits total draining. A city water line discharges to the Pond at its northeastern corner.

Four stormwater culverts also feed the Pond during wet weather.

Currently, the Pond is a popular lunchtime spot, probably because it is close to the most heavily utilized park entrance. Blooms of phytoplankton and duckweed, as well as fish kills have been observed during mid-summer. Cattails and the common reed (*Phragmites*), grow on areas of excess sedimentation at the northeastern end of the Pond. At this time, fish species include pumpkinseed, bluegill, golden shiners, brown bullheads, goldfish and guppy. (New York City Department of Parks and Recreation 1990)

The Lake, which is bounded on the north by a wooded hillside contains the vegetative communities known as the Ramble, Bethesda Terrace, and Cherry Hill on the south. It is the largest water body in Central Park (excluding the Central Park Reservoir), and is located at 79th Street. It is fed in part by a small stream within the Ramble called the Gill. Like the Pond, the Lake was constructed from a swamp. Originally, the Lake had an undulating shoreline with five coves that remain to this day. It also contained an island which has since eroded, and an extension of water known as Ladies Pond, which was filled over a half century ago. A boathouse was erected on the eastern shore for rowboats, and during the winter season, the water level was dropped to allow for ice skating.

The outlet structure for the Lake, which is located at the southeastern end, near the Loeb Boathouse, consists of a stop plank weir that drains into the City sewer system. Four arterial drainage systems, along with several smaller lines, convey stormwater to the Lake. Additionally, a second small stream flows under the West Drive and enters the Lake. Also, two municipal waterlines discharge to the Lake. One outlet is located at the

head of the Gill, while the other is at the northern end of the Lake.

Currently, the soil at numerous locations in the Ramble and on several slopes along the shoreline is severely eroded, resulting in massive siltation, and reeds have appeared in a silted cove near Cherry Hill. Intense duckweed and algae blooms now routinely occur in mid-summer. Fish species present in the Lake include: pumpkinseed sunfish, bluegill sunfish, and banded killifish, largemouth bass, and goldfish. (New York City Department of Parks and Recreation 1990)

The Harlem Meer is the second largest body of water in Central Park (again, excluding the Reservoir). Located in the northeastern corner of the Park, it is at the lowest point of elevation within the Park. Prior to the development of Central Park, the Meer constituted the westernmost edge of a large tidal marsh extending inland from the East River. After the Meer was constructed, its original shoreline included several coves and peninsulas, as well as two sandy beaches and an island. In 1941, the shoreline was smoothed, bounded by concrete (probably to control shoreline collapse and erosion resulting from overuse), and a boathouse was erected. The Meer was changed once more in 1966, when the Lasker Pool and Skating Rink were constructed directly over the mouth of the stream which flows from the Loch into the Meer. Currently, the stream is conveyed through a five foot culvert.

The drainage area serving the Meer is the largest in the Park, measuring 192 acres. A substantial portion of the vegetative ground cover has been lost, thereby drastically enhancing soil erosion at many locations. Severe erosion in this watershed is also a chronic problem because of the steep terrain in this portion of Central Park. The main

tributary to the Meer, the Loch, is now a muddy floodplain. (Mockler and Ippolito 1991) In 1984, it was estimated that as much as 186,000 cubic feet of sediment had accumulated at the bottom of the Meer over the previous 120 years.

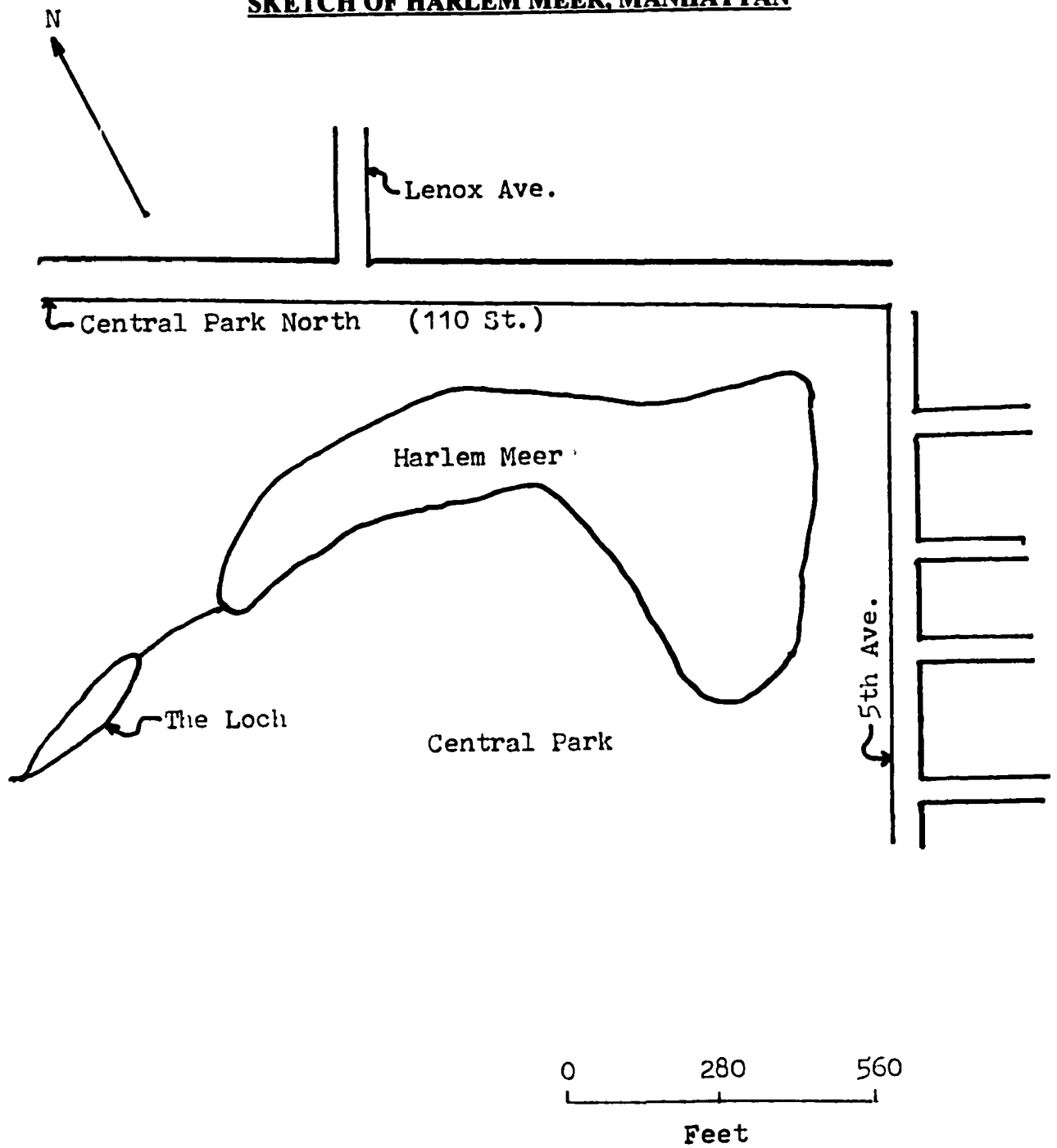
The outlet structure, which lies on the east shore, includes a weir that regulates the upper water level, as well as a 12 inch effluent line that is used to drop the water level about two feet during the winter. The structure also includes pipes which can drain the Meer completely. The main source of water for the Meer is the stream that originates at the Pool and that arrives by way of the Loch. Additionally, several culverts discharge stormwater to the Meer, and an eight inch pipe, located on the northwest shore, supplies municipal water.

In recent years, largemouth bass, pumpkinseed sunfish, bluegill sunfish, banded killifish, striped bass and carp have been collected from the Meer. The green algae, *spirogyra*, grows prolifically in the summer, sometimes in dense mats covering nearly 85% of the surface. (New York City Department of Parks and Recreation 1990) A sketch of the Harlem Meer may be found in Figure 3.4.

The Pool, which is located in the vicinity of 102nd Street and Central Park West, was created by damming and enlarging a stream known as Montayne's Rivulet. After passing over the dam, the stream, which known as the Loch in this reach, flows through a series of artificial waterfalls and then enters the Harlem Meer. In 1961, a nearby water main break set loose a torrent which flowed into Central Park and washed away the small island within the Pool. It also caused the complete siltation of the cove formerly located in the southwestern corner. The surrounding landscape appears natural and is not intensively

FIGURE 3.4

SKETCH OF HARLEM MEER, MANHATTAN



utilized. It generally experiences less soil erosion than other areas of the Park.

The outlet structure for the Pool is a rock dam that produces a waterfall. It also contains a pipe that is used to completely drain the Pool. Water is supplied by a municipal water line. Several storm water culverts, two arterial drainage systems, and a seep at the southeastern end of the Pool also supply water.

Severe algal blooms, as well as heavy growths of duckweed have been observed in the Pool, as have pumpkinseed sunfish, largemouth bass and goldfish. (New York City Department of Parks and Recreation 1990)

Classification System Scoring

Water Input Mechanism System

The Harlem Meer is supplied primarily by the New York City Water Supply. However, the Meer also receives some tributary flow, as well as runoff from eroding parkland and its associated circulatory system, and the municipal water supply is treated with orthophosphates (See Section 3.3), so the score of 5 is reduced to 4.4. (Ifcher 1996, New York City Department of Parks and Recreation 1990)

Degree of Artificiality System

The Harlem Meer was constructed on an old tidal marsh during the development of Central Park. The bottom is lined with concrete, as are the sides. The outlet discharges to the municipal combined sewer system (but alternatives are being considered in order to reduce hydraulic loading on the Wards Island Wastewater Treatment Plant). The Meer is scored at 4.8.

Degree of Urbanization System

The Harlem Meer is located in a very heavily urbanized area, some of which is degraded. However, it is strongly buffered by severely eroding parkland. A rating of 4.2 is assigned.

3.2.4 - Van Cortlandt Lake

Van Cortlandt Lake may be found in the northwestern section of Bronx County (within Van Cortlandt Park, the third largest of New York City's parks). (New York City Department of Parks and Recreation 1990) Throughout the year, the Park serves as a major regional open space in a densely urbanized area. It offers superlative natural, historical and cultural attributes, along with a wide variety of active and passive recreational features. (Baystate Environmental and Storch Associates June 1984)

Van Cortlandt Lake was established around 1699 when a dam was constructed on Tibbetts Brook by Jacobus Van Cortlandt, initially to energize his sawmill and subsequently, his grist mill. Prior to this impoundment, Tibbetts Brook was a tidal estuarine system, with short tributary streams. It ultimately discharged in a southerly direction to Spuyten Duyvil Creek and the Harlem River. The drainage basin lies in glacial till and in glaciofluvial or glaciolacustrine deposits. (Pearlmutter and Arnow 1953, New York City Department of Parks and Recreation 1990) Major alterations such as urban development and large scale construction projects (the railroad in the 1870s, the parade ground in 1889, two golf courses in 1895 and major highways (the Henry Hudson Parkway in the 1930s and the Major Deegan Expressway in the 1950s)) have been imposed on the watershed. The Lake was bisected by the currently abandoned railroad track, which was originally constructed as the Putnam Division of the New York Central

Railroad. The urbanization of the watershed (accompanied by such associated activities and occurrences as poor agricultural practices, filling, dumping, sedimentation, nutrient enrichment and the discharge of various urban pollutants) has almost certainly resulted in adverse impacts on the Lake. (New York City Department of Parks and Recreation 1990)

As Tibbetts Brook flows south from northern Yonkers, it cuts through soft Inwood marble. (Mockler and Ippolito 1991) Immediately after crossing into Bronx County, it passes through a series of wetlands, which are actually a series of interconnected lagoons created in the 1930s as sediment traps in association with the construction of the Henry Hudson Parkway. (Baystate Environmental and Storch Associates June 1984) These so called Henry Hudson Lagoons named (from north to south) Elm Lake, Maple Lake, Sycamore Lake and Birch Lake, are completely filled with sediment. Subsequently, Tibbetts Brook flows into Van Cortlandt Lake. Other sources of water for the Lake include direct precipitation, park and highway runoff, and groundwater seepage. Adjacent to the dam, a sluice gate directs the lake overflow to the municipal sewer system (and subsequently, to the Wards Island Wastewater Treatment Plant).

Land uses within the Van Cortlandt Lake drainage area include residential, commercial, industrial, transportation (the Major Deegan Expressway, the Mosholu Parkway Extension and the Henry Hudson Parkway), and parkland. The parkland contains mature forests, wetlands, pioneering forests, successional fields, meadows, lawns, golf courses, and paved surfaces.

In the past, ice skating was a very popular sport on Van Cortlandt Lake, and to accommodate the normal influx of skaters (up to 10,000 on weekends in 1889), a skate

house was erected circa 1902. (Baystate Environmental and Storch Associates June 1984)

Today the Lake is still used for skating, although for vastly smaller numbers, and no formal accommodations exist. Also, the Lake has not been completely freezing over in recent years, most likely due to an increase in total dissolved solids and to the lack of freezing temperatures.

Boating on the Lake was once a highly popular pastime, and postcards from the early 1900s depict several people either canoeing or rowboating. However, due to deteriorating water quality, rowboating on Van Cortlandt Lake was terminated in 1976. (Baystate Environmental and Storch Associates June 1984)

Active recreation that involves water contact has drastically declined as a direct result of water quality degradation in the Lake. Summer recreation (including the use of the adjacent municipal golf course (the first in the nation)) is especially hindered by the severe algal blooms which appear as early as May. However some use of the Lake for fishing continues, and passive recreational activities such as picnicking, nature study, bird watching, and hiking are conducted on the adjacent shoreline.

The NYSDEC has classified the waters of Van Cortlandt Lake as B, meaning that the best use of these waters is considered to be primary contact recreation. While there is anecdotal information about unsupervised swimming in the Lake during the 1800s, current NYC Parks Department policy does not allow for swimming in any lake or pond administered by that agency. Previous studies conducted on Van Cortlandt Lake and Tibbetts Brook include surveys by the New York State Department of Environmental Conservation (by and under the direction of the writer from 1975 through 1982), and by

Baystate Environmental Consultants (1985) under the Federal Clean Lakes Program.

Apparently, the Lake had ecological problems as early as 1893 when complaints were received about lake pollution attributed to cesspools in Yonkers. In 1903, the Lake was described as being filthy, and was further described by the Parks Department as “more of a semi-bog.” (Baystate Environmental and Storch Associates June 1984) During that year, efforts to improve the Lake were initiated and the original dam and sawmill were razed.

The construction of the Henry Hudson Parkway in the 1930s and the Major Deegan Expressway in the 1950s resulted in significant siltation and loss of wetlands associated with Van Cortlandt Lake. Large scale urbanization in the watershed, with its associated activities such as filling, dumping, sedimentation, nutrient enrichment and discharge of urban pollutants, has adversely affected the Lake.

Van Cortlandt Lake was dredged in 1903, when 30,000 cubic yards of contaminated material were removed, and again in 1935 (based on anecdotal evidence). A large portion of the original lake basins have been filled in as a result of sedimentation and have become freshwater wetlands. (Baystate and Storch 1984) In 1877, the Lake had a total surface area of about 38 acres, while in 1984 it only consisted of 15 acres of open water. Approximately 60% of the Lake has been lost to infilling or has succeeded to marshland over the last century (and possibly over the last half century, depending on the extent of dredging during the 1930s). Construction of a new spillway for the dam in 1934/1936 raised the water level in the Lake 1.5 feet and resulted in about 4.6 acres of additional open water. Another round of dredging has been recommended as part of a lake remediation program.

Intense algal blooms have often occurred in the past, sometimes causing fish kills (in 1961 and during the mid-1970s. Emergent macrophytes such as cattails, common reed, spatterdock, arrow arum, arrowhead, bullrush, pickerelweed and water willow, along with the white water lily (a rooted floating plant), grow thickly along the periphery of the Lake. The submergent macrophytes water weed and pondweed have also been observed. Duckweed and various species of algae dominate the open water during different seasons. The zooplankton are dominated by rotifers, clacocera and copepods. Pumpkinseed, blue gill and green sunfish, crappies, largemouth bass, yellow perch, shiners, goldfish and brown bullhead have been observed in the Lake, which was stocked with black bullhead by the Department of Environmental Conservation in 1978 and 1979 as part of an urban fishing program. (New York City Department of Parks and Recreation 1990) A sketch of Van Cortlandt Lake may be found in Figure 3.5.

Classification System Scoring

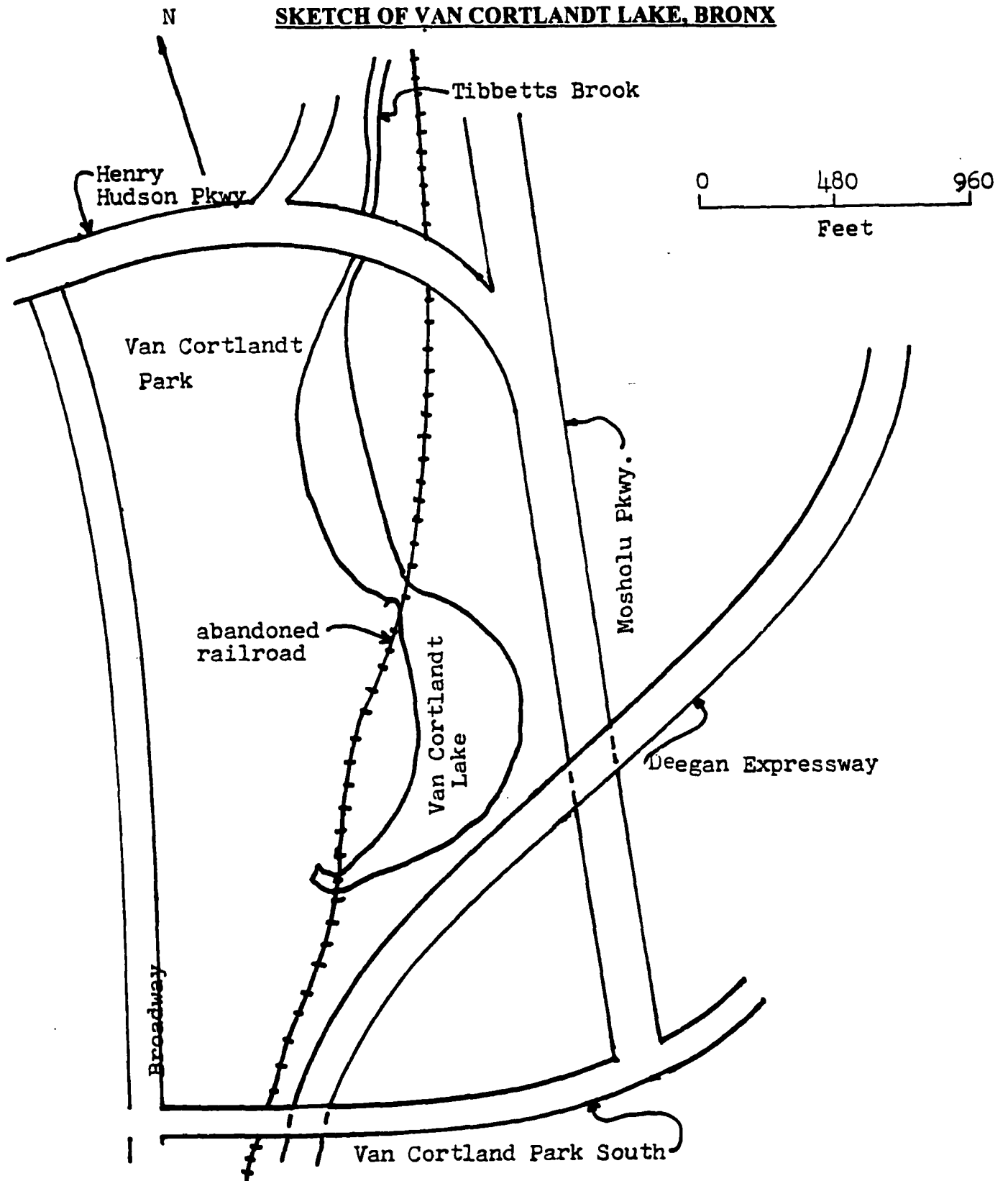
Water Input Mechanism System

Van Cortlandt Lake is supplied with water discharging from its tributary, Tibbitts Brook (which has baseflow). However the Lake also receives runoff from nearby highways carrying heavy traffic, as well as from Van Cortlandt Park and its circulatory system, and so its score is reduced from 1.5 to 1. (Baystate Environmental and Storch Associates May 1984, Baystate Environmental and Storch Associates June 1984, Ifcher 1996, New York City Department of Parks and Recreation 1990)

Degree of Artificiality System

Van Cortlandt Lake was created by impounding Tibbets Brook with a man-made

FIGURE 3.5



dam. It is given a score of 4.

Degree of Urbanization System

Van Cortlandt Lake and its tributary, Tibbets Brook, are located in a moderately urbanized drainage area. While the Lake and much of the Brook are buffered by parkland, they receive substantial quantities of urban runoff and drainage from major traffic arteries. A score of 2.7 is assigned.

3.2.5 - Prospect Lake

Prospect Lake is located at the southern end of Prospect Park, adjacent to Parkside Avenue, in central Kings County (the borough of Brooklyn). It is situated in the outwash plain, south of the terminal moraine formed by the Wisconsin glacier. The Lake was planned (in 1866) for the Park as the last of “three regions of distinct character” (the others being meadows and wooded hills) by the designers Frederick Law Olmstead and Calvert Vaux. They planned several of the Park’s features, collectively entitled the Watercourse, around the area’s glacial terrain (The entire park was designed by Olmstead and Vaux as a “celebration of nature” and as a “democratic Park,” but these goals were often frustrated when Brooklyn officials filled the “natural” landscape with busts of famous men and neoclassical pavilions and buildings, and local police arrested groups of Lower East Side immigrants seeking temporary relief from overcrowded tenements (Snyder-Grenier 1996)). The kettleholes of the terminal moraine evolved into the present Swan Boat Lakes; the course of glacial meltwater was enhanced to create the Ravine (which was originally designed to simulate an Adirondack stroll, with a steep and narrow brook bubbling over rocks, between pine covered cliffs (Walmsley 1981)); and the

outwash plain was excavated to form the Lake. (Mockler and Ippolito 1991) The Lake was actually created by digging a large basin from the outwash sand and gravel with pick and shovel. (New York City Department of Parks and Recreation 1990) During the 19th century, several bucolic shelters were erected along its shoreline, three of which remain today.

Around the turn of the century, the Swan Boat Lakes contained a water carousel of swan-shaped boats to amuse the Victorian population of that day. They were also the site of the August 27, 1776 Battle of Flatbush Pass, a significant component of the desperate Battle of Long Island, which was the first major land engagement fought by the newly self-declared independent United States in the American Revolution (and as stated by Sarah Comstock “where the Prospect Park Swan Boat now plies, the din of battle once was heard” (Comstock 1915)). In modern times the Lakes have become a recreational ground for frogs and birds who hide among the cattails and sedges that line their eroded shores. (Mockler and Ippolito 1991) Prospect Lake was originally designed for pastimes which included fishing, boating, ice skating and meditation.

Initially, the source of water for the lake system was a deep well from which it was pumped to a reservoir near the summit of Lookout Hill, to the east of where Smallwood’s Maryland Four Hundred stood against overwhelming British Forces in the aforementioned Battle of Long Island (the pump house still exists). However, the water is currently drawn from the municipal supply, which is introduced near the western end of Swan Boat Lakes. (In its never ending search for additional sources of municipal water supplies, New York City seriously considered the development of a substantial well field within Prospect Park

during the drought of the early 1980s (Holtzmacher, McLendon and Murrell 1982), but subsequent study, based on U.S. Geological Survey modeling of the Brooklyn-Queens Aquifer (which included an assessment of potential salt water intrusion), indicated that optimum well sites should be located farther east (Malcolm Pirnie 1998).) City water flows over Grotto Falls, through the Swanboat Lakes, through a swamp forest (the Ambergill, the Ravine and Pagoda Pond), through a ponded marsh (the Lullwater), and ultimately, into Prospect Lake. The outlet, located at the southwest corner of the Lake, discharges to the municipal sewer system.

Excavated by hand during the late 1860s, Prospect Lake now exhibits deep accumulations of organic sediments typical of a hypereutrophic lake. These sediments are anoxic and high in phosphorus concentrations. (American Lake and Wetlands Services, Inc. 1997) Dredging of these sediments has been recommended as a component of a lake remediation program. Erosion in the watershed is a problem. The current mean depth is 6 ft. and (according to Ann Wong of the Prospect Park Alliance) the original mean depth was about 8 ft. The open waters of the Lake have never been dredged (although the Lullwater, the only tributary to the Lake has been).

The watershed draining to the lake system contains various cover types, including wooded slopes, a cemetery, a picnic area, meadows, gardens, wetlands, an ice rink, a snack bar, and paved surfaces. Algae, duckweed, yellow water lily, water shield, arrow arum, cattails, and water willows thrive at various points around the periphery of Prospect Park Lake, while the open water is dominated by submergents such as muskgrass, coontail, water weed and water millfoil. This plant growth is so dense that it

requires mid-summer mechanical harvesting. The Lakes are populated by such fish species as largemouth bass, yellow perch, bluegill sunfish and catfish. (New York City Department of Parks and Recreation 1990) A sketch of Prospect Lake may be found in Figure 3.6.

Classification System Scoring

Water Input Mechanism System

Prospect Lake receives its water from the municipal supply, but it also receives runoff from parkland and nearby roads. Furthermore, the water supply is treated with orthophosphate and so the score is reduced from 5 to 4.7. (Ifcher 1996, New York City Department of Parks and Recreation 1990)

Degree of Artificiality System

Prospect Lake was created by excavating into glacial deposits. Water levels are maintained with City water. It was originally maintained using water from deep wells. The Lake drains to the municipal combined sewer system. Prospect Lake is rated at 4.4.

Degree of Urbanization System

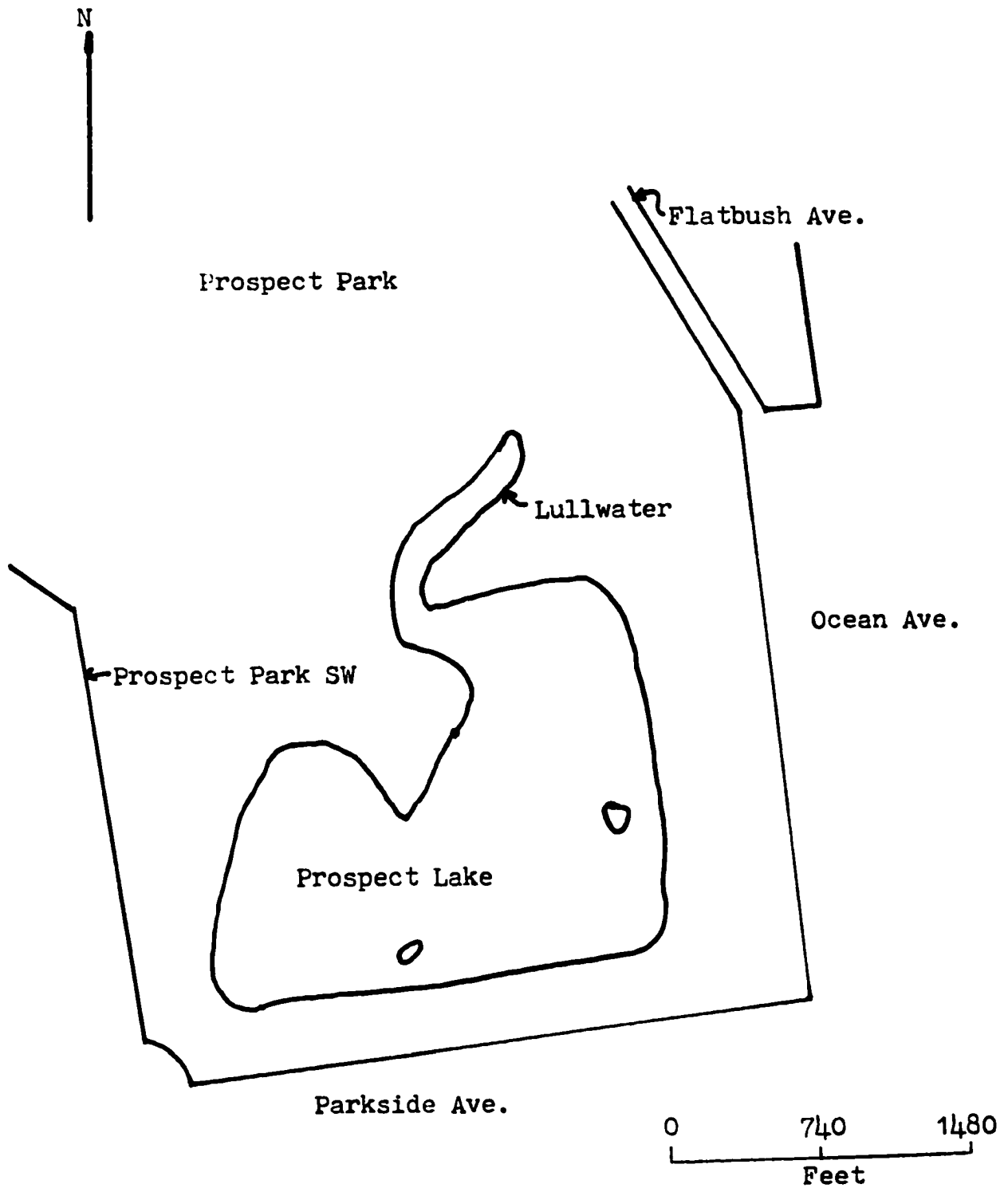
Prospect Lake is located in a fairly heavily urbanized watershed. It is strongly buffered by eroding parkland but runoff from some roadways is diverted to the Lake. A score of 3.5 is assigned.

3.2.6 - Conselyea's Pond

Conselyea's Pond, located within Brookfield Park in the Rosedale Section of southeastern Queens County, was created by impounding a small stream (Laurelton Creek) that first flows through a series of small upstream hypereutrophic impoundments

FIGURE 3.6

SKETCH OF PROSPECT LAKE, BROOKLYN



parallel to the Laurelton Parkway. Maps from 1918 and other sources (Bleyer 1998, Board of Water Commissioners 1867, Varona 1886) indicate that Laurelton Creek and the no longer existing Brookfield Pond (which was located a short distance upstream (north) of Conselyea's Pond) were part of the old City of Brooklyn Water Supply System, which originally consisted of sixteen ponds (Kirby et al. 1956) created by damming the small streams (between Jamaica and the Suffolk County Line) that flowed south across the outwash plain to the back bays, from the central ridge (terminal moraine) of Long Island. Later, when the ponds were threatened by urbanization, many were replaced by wells and infiltration galleries. (Citizens Union Foundation 1987) The ponds and their protected watersheds subsequently were utilized by former State Parks Commissioner Robert Moses as the base upon which he developed the now extensive State Park System in the southern portion of Long Island. (Caro 1994) Today, as the result of overpumping and loss of recharge due to intense urbanization (Buxton et al. 1981, Kimmel 1972, Spinello and Simmons 1992), Laurelton Creek no longer receives much baseflow and has thus been rendered virtually ephemeral. Its only significant source of freshwater flow is wet weather drainage from the Laurelton Parkway and from the adjacent street network.

Outflow from the Pond passes over a weir and into a tidally affected network of streams and wetlands associated with Jamaica Bay. When the writer visited the Pond in August of 1996, the weir appeared to be in a state of severe disrepair and was allowing substantial salt water inflow during periods of high tide. As is the case with many of the other New York City lakes, Conselyea's Pond appears to be undergoing severe eutrophication. It also exhibits a deep accumulation of organic, anoxic sediments.

Additionally, recent Parks Department data gathering efforts show high coliform counts in the Pond, indicating sewage discharges either directly into the pond from the adjacent pumping station, or into the tributary stream. (After subsequent investigations, these elevated readings were attributed by the New York Department of Environmental Protection to waterfowl.) A sketch of Conselyea's Pond may be found in Figure 3.7.

Classification System Scoring

Water Input Mechanism System

Conselyea's Pond is fed primarily by its much altered tributary, Laurelton Creek, which has little baseflow. The Creek flows are primarily urban and highway drainage, and the Pond receives substantial estuarine inflow due to a defective weir. A score of 0.5 is assigned to Conselyea's Pond, ironically by adding 0.1 to the ephemeral stream score of 0.4 as a result of some freshening due to saline water intrusion and to some minimal cleansing due to passage through a bit of degraded wetland.

Degree of Artificiality System

Conselyea's Pond was created by impounding Laurelton Creek with a man-made weir. It is given a score of 4.

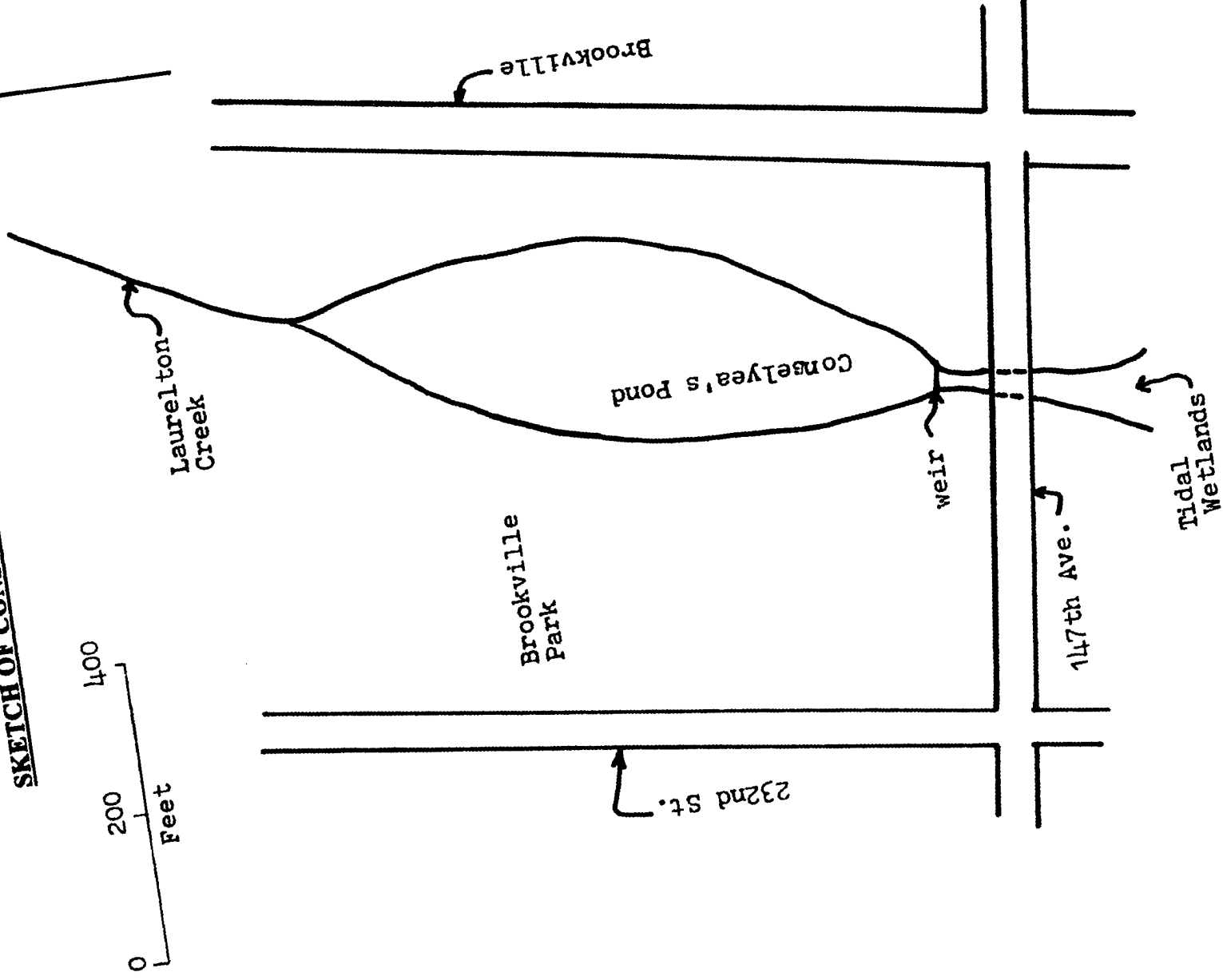
Degree of Urbanization System

Conselyea's Pond is located in a moderate to densely urbanized drainage area, having only minimal parkland buffering. Its tributary, Laurelton Creek also serves as the primary drainage system for a major traffic artery. A score of 3.8 is assigned.

3.2.7 - Oakland Lake

Oakland Lake is situated in northeastern Queens, west of Alley Creek. The Lake

FIGURE 3.7
SKETCH OF CONSELYEA'S POND, QUEENS



owes its existence to the formation of a kettlehole near the boundary between the terminal moraine and the ground moraine of the Wisconsin glacier. It was enhanced through the erection of a dam, between the Lake and Alley Creek in the 18th Century in order to drive a grist mill. The Lake, which was previously known both as Mill Pond and Douglas Pond, was utilized as a water supply for the Village of Flushing, where a pumping station existed until the 1930s. Debris, which had accumulated during a long period of neglect, was removed by a community-sponsored cleanup in 1969. In 1971, the 13 acres of Oakland Lake were circumscribed by rip-rap, while a path and a new drainage system were also completed. By the late 1970s, Alley Park had been severely impacted by large scale erosion, dumping, fires, and the die-off of many trees and shrubs. Additionally, substantial off-site construction had resulted in excessive lake siltation. The deterioration was reversed in the mid-1980s when landscape restoration was performed, the shoreline was re-vegetated, and the rip-rap was removed.

The Oakland Lake watershed currently includes a mix of park landscapes (containing old specimen trees, a ravine and a swamp), as well as the Queensboro Community College Campus and high density residential development. Area soils include Alton Stoney Loam, and numerous unconsolidated fill types. The Lake is primarily fed by springs, with some contributions of runoff from the adjacent residential areas. The outlet consists of a non-adjustable concrete weir that directs overflow into Alley Creek by way of the 46th Street storm sewer. New York State has designated the Lake as Class B waters, which means that the best usage is for any purpose other than as a potable water supply.

Macrophytes present in the littoral zone of Oakland Lake include emergents such as cattails, reeds, spatterdock, pickerelweed and arrow arum; rooted floating plants such as white water lily; and submergents such as naiads. Open water areas undergo heavy duckweed growths and severe algal blooms during mid-summer. Fish stocking was conducted by the State during the 1940s and again in 1970 with species such as carp, goldfish, golden shiners, brown bullhead, pickerel, yellow perch, pumpkinseed and blue gill sunfish, largemouth bass, white perch, American eel and black crappie. (New York City Department of Parks and Recreation 1990) A sketch of Oakland Lake may be found in Figure 3.8.

Classification System Scoring

Water Input Mechanism

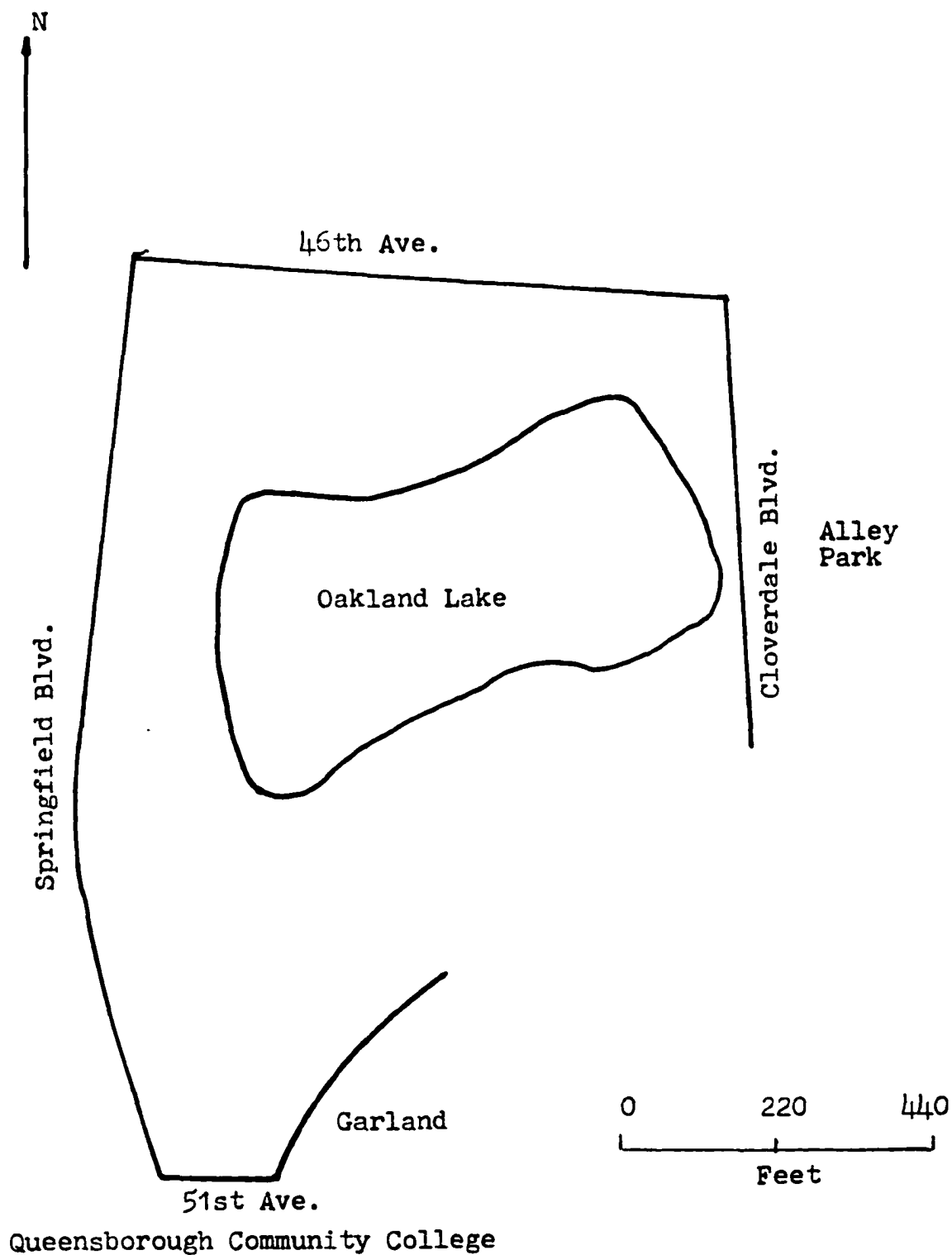
Oakland Lake receives most of its water from springs (groundwater), but it also receives substantial runoff from surrounding urban areas and eroding parkland. The groundwater score is therefore lowered from three to 2.5. (Ifcher 1996, New York City Department of Parks and Recreation 1990)

Degree of Artificiality System

Oakland Lake was created as a kettlehole pond, which was slightly altered by diverting urban runoff to it from the adjacent community (while the diversion of urban and park runoff to the Lake is considered a slight alteration under the proposed classification system, the associated but unconsidered sediment loading has a truly major impact), and by constructing an outlet that discharges to the local storm sewer system. It is scored at 1.2.

FIGURE 3.8

SKETCH OF OAKLAND LAKE, QUEENS



Degree of Urbanization System

Oakland Lake is located in a fairly intensively urbanized drainage area but is well buffered by eroding parkland. However, some urban runoff from land adjacent to the park is diverted to the Lake. A rating of 3.2 is assigned.

3.2.8 - Kissena Lake

Kissena Lake, which can be found within northeastern Queens, was originally created by damming Mill Creek in the early 1800s in order to provide power for a grist mill. The Creek flowed through the till associated with the ground moraine formed by the Pleistocene glaciers, which are responsible for much of the landscape of Long Island. Kissena Lake was once a part of a vast network of wetlands that traversed Queens County, from Flushing Bay to Jamaica Bay and reached as far east as Fresh Meadows. This is the bed of ancient Lake Flushing. (Titus 1998) During pre-revolutionary times, the surrounding land supported one of the earliest horticultural nurseries in the Americas, as well as an ice plant. During World War 2, the Works Progress Administration totally isolated the lake by draining it, dredging it, constructing a retaining wall around it (thereby converting it to a “bathtub lake”), and refilling it. A boathouse and playground were also constructed during this period. The years 1973 and 1983 saw further draining of the lake along with dredging.

The Kissena Lake watershed once consisted of a large tidal and spring-fed valley that was originally drained for agricultural purposes, and subsequently filled in order to create the existing park. Watershed and shoreline erosion are currently negligible sources of sediment since the entire shoreline is rimmed by concrete, and little soil compaction and

erosion occurs within the Lake's small and well manicured drainage area. Nearby soils include sandy and silty loams, and muck. While springs once fed Kissena Lake, water is now supplied by the municipal system at a rate of 100 gallons per minute. Excess water is removed through an outlet, which consists of a concrete weir embedded in the retaining wall, and is subsequently discharged into a nearby wetland.

Prior to the aforementioned 1983 dredging, the New York State Department of Environmental Conservation (NYSDEC) removed largemouth bass, pumpkinseed and bluegill sunfish, channel catfish, white perch, and American eel from Kissena Lake. The fish were subsequently restocked. Open-water aquatic vegetation includes the submergents water millfoil, coontail and water weed, along with the rooted floating plant white water lily. The emergent common reed may be observed within the shallow area adjacent to the southeast shore. By mid-summer, macrophyte growth is extremely dense and is removed by local volunteers with rakes. (New York City Department of Parks and Recreation 1990) A sketch of Kissena Lake may be found in Figure 3.9.

Classification System Scoring

Water Input Mechanism System

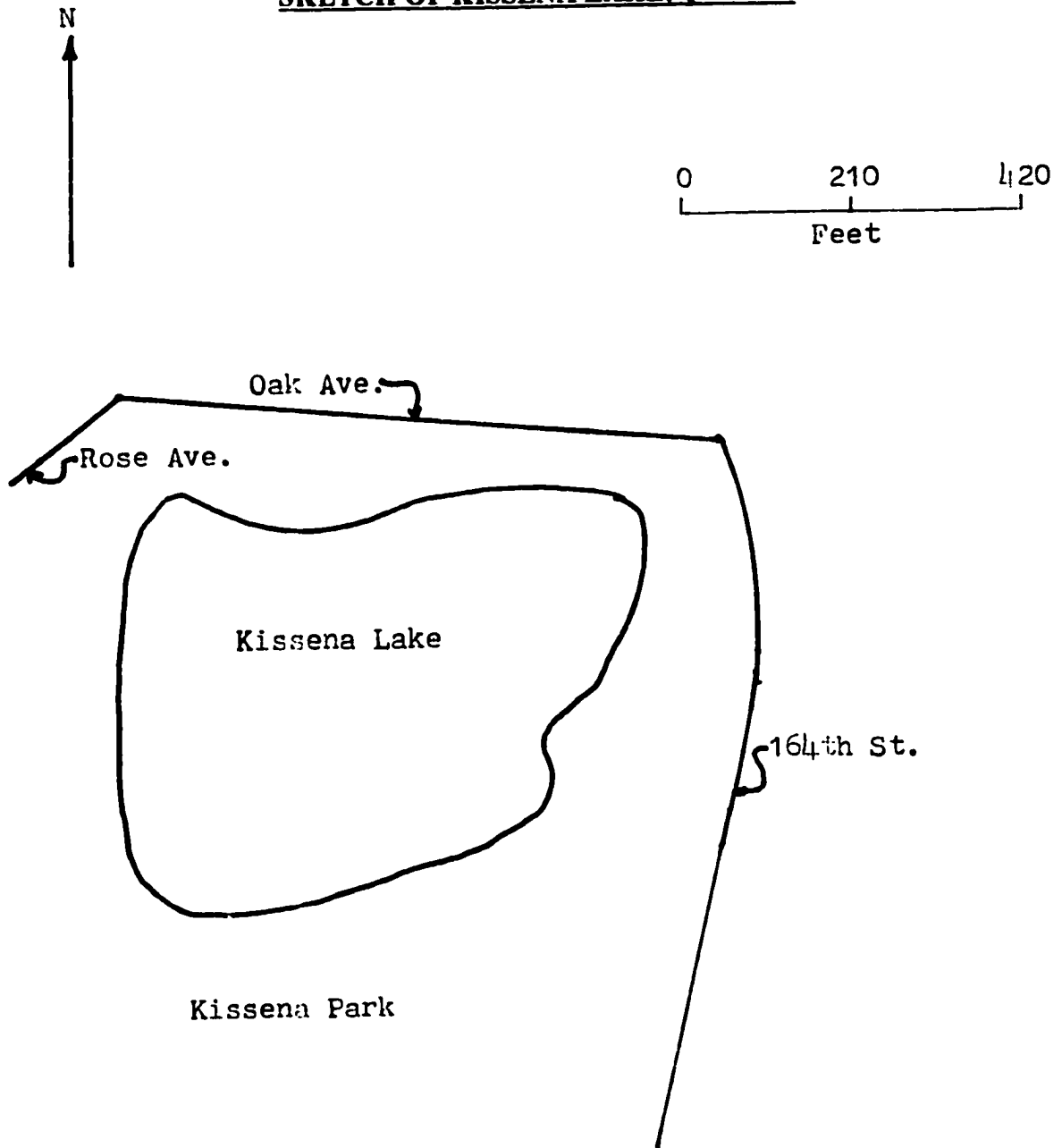
Kissena Lake is fed by the municipal water supply and some minimal parkland runoff. The municipal water is treated with orthophosphate, and so a score of 4.8 is assigned. (Ifcher 1996, New York City Department of Parks and Recreation 1990)

Degree of Artificiality System

Kissena Lake was originally created by impounding a small stream. Subsequently, it was further excavated and surrounded by a retaining wall. An outlet to the municipal

FIGURE 3.9

SKETCH OF KISSENA LAKE, QUEENS



sewer system was provided, and the water supply, which was once provided by springs, is now provided by the municipal system. Kissena Lake is scored at 4.6.

Degree of Urbanization System

Kissena Lake is located in a moderately to intensively urbanized watershed which has been subject to substantial filling (hydrological alteration). The Lake is well buffered by parkland, and a score of 2.6 is assigned.

3.2.9 - Meadow and Willow Lakes

Flushing Meadow Park was conceived during the LaGuardia administration by Robert Moses as part of a greenbelt to extend across northeastern Queens County along the Kissena Corridor. For 40 years prior to that time, the valley, within which a tidal stream once meandered through a marsh covered by salt hay (the bed of ancient Lake Flushing (Titus 1998), and an earlier channel of an ancestral diversion of the Hudson River via the Harlem River Channel (Buxton et al. 1981)), was landfilled with ashes by the Brooklyn Ash Removal Company. This “reclamation” of this “swampy meadow” had local denizens referring to Flushing Meadows as the “Valley of the Ashes.” (Oats 1980)

Meadow and Willow Lakes, located within Flushing Meadow Park, were constructed in the 1930s prior to the opening of the first New York City World’s Fair in 1939. Between 1940, when the first fair closed and 1962, when construction of the second fair was underway, almost no maintenance was performed on the Lakes. During that time, they had become severely eutrophic, with heavy concentrations of weeds around the shorelines and extensive algal blooms. Because major exhibits were planned to be located immediately adjacent to the Lakes, a program to control algae was initiated in

1962 and continued through 1965, when the fair closed. (Lawler, Matusky and Skelly Engineers 1987) This control program consisted of the following components:

- 1- Copper sulfate addition to reduce algal densities;
- 2- Chemical addition, along with harvesting, to control macrophytes; and
- 3- Groundwater pumping, utilizing four deep wells, in order to increase the flow (and concurrently decrease the hydraulic residence time (lake overflow passes over a weir and into Flushing Creek)) and reduce lake temperature below the optimum for algal growth.

These management approaches, while extremely expensive, apparently made the Lakes aesthetically pleasing for the duration of the fair. Since treatment and flushing have not been provided since 1965, as anticipated, algal blooms and aquatic weed growth have returned, creating an aesthetically unappealing condition in two of New York City's largest lakes.

Phosphorus and other nutrients that foster algal growth usually enter ponds and lakes via precipitation, direct surface runoff, tributary stream inflow and groundwater seepage. Based on hydrological balances, stormwater runoff (from the Park and from adjacent highways) and precipitation appear to be relatively minor sources of water compared with groundwater seepage (78% of the total inflow). The groundwater, having passed through the underlying nutrient-laden salt marsh which was excavated in order to create the Lakes, then imparts 58,000 lbs of total phosphorus per year to the Lakes. The bottom sediments release another 2,500 lbs per year. Sediment cores taken in 1986 showed a top sediment (black mud high in water and copper (from the aforementioned

copper sulfate treatment conducted during the second fair)) depth of 1.3 feet above the salt marsh sediment in Meadow Lake. (Lawler, Matusky & Skelly Engineers 1987) A sketch of Meadow Lake may be found in Figure 3.10.

Classification System Scoring

Water Input Mechanism System

Meadow Lake is fed mainly by groundwater, but it also receives runoff from nearby major traffic arteries. It also receives substantial saltwater inflow from Flushing Creek due to defective outlet controls. Meadow Lake is assigned a score of 2.6 (no credit for any freshening effects for saltwater intrusion here due to the degraded state of Flushing Creek). (Lawler, Matusky and Skelly Engineers 1987)

Degree of Artificiality System

Meadow Lake was created by excavating into the water table, through an old ash fill overlying a salt marsh, and by constructing a tide gate to prevent salt water inflow from Flushing Creek. It is given a rating of 4.

Degree of Urbanization System

Meadow Lake is located in a fairly intensely urbanized drainage area which is only moderately buffered by parkland. It also receives drainage from two adjacent major traffic arteries. A score of 3.9 is assigned.

A summary of some key morphometric features of the nine lakes selected for detailed study may be found in Table 3.2. A summary of the three proposed classification system scores for the nine New York City lakes selected for detailed study can be found in Table 3.3.



FIGURE 3.10

SKETCH OF MEADOW LAKE, QUEENS

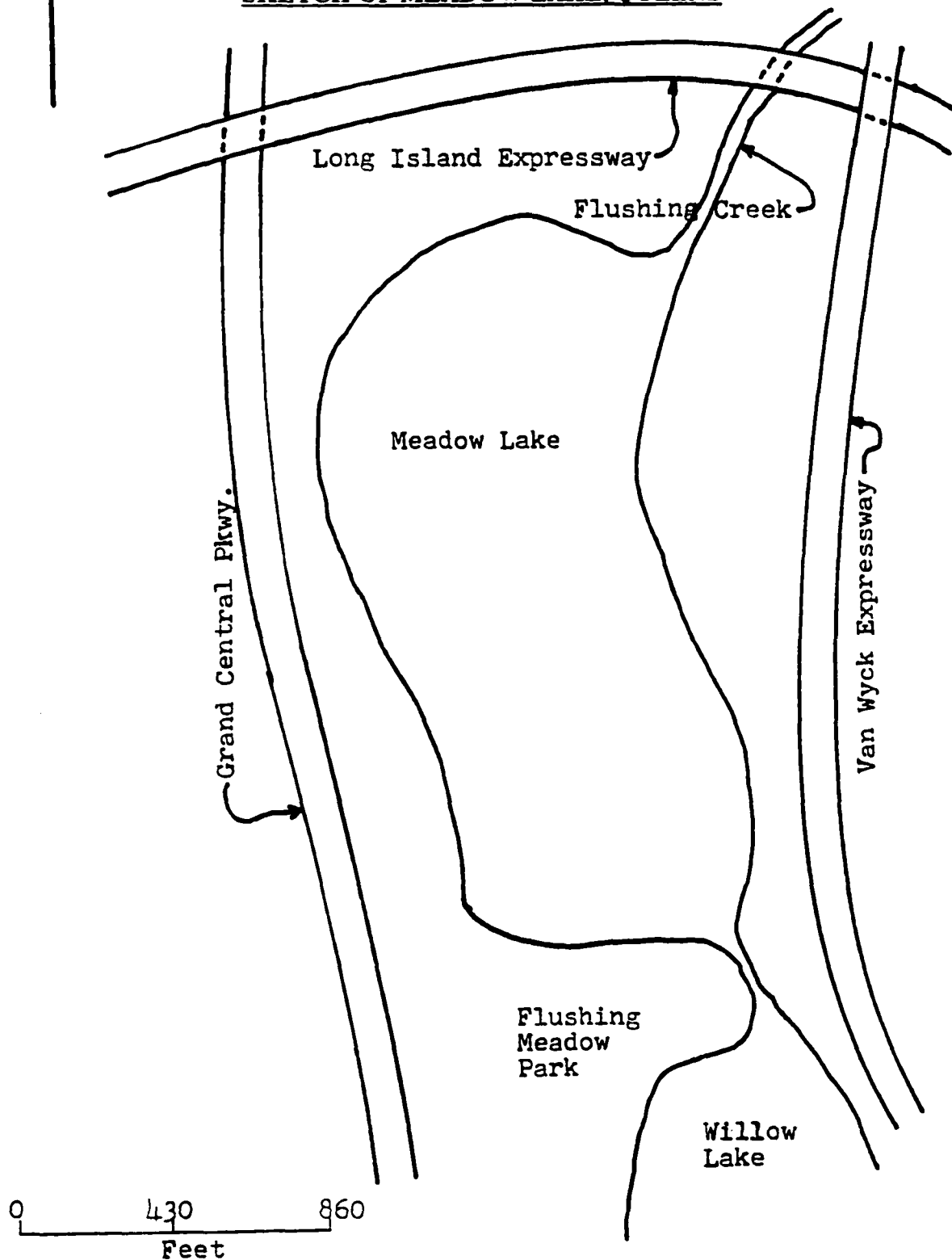


TABLE 3.2							
LAKE MORPHOMETRY							
Lake	Location	Area (acres)	Mean Depth (ft)	Volume (ft ³)	Outflow (ft ³ /sec)	Flushing Rate (yr ⁻¹)	Hydraulic Retention Time (yrs)
Wolfe's Pond	South-western Staten Island	15.4 **	4.0 **	2.68x10 ⁶	0.45	4.5 - 6.0 *****	0.19
Richmond Town Millpond	Central Staten Island	1.0 ****	1.0 ****	4.35x10 ⁴	1.8 *****	1299	7.7x10 ⁻⁴
Harlem Meer	Central Manhattan	10.6 **	3.7	1.71x10 ⁶	0.03	5.5 ***	0.18 ***
Van Cortlandt Lake	North-western Bronx	12.8 **	3.0	1.67x10 ⁶	5.3	91.9 ***	0.01 ***
Prospect Lake	Central Brooklyn	50.7 **	6.0 **	13.2x10 ⁶	0.72	1.73 ***	0.58 ***
Conselyea's Pond	South-eastern Queens	4.3 **	4.0	7.49x10 ⁵	0.5 *	21.28	0.047
Oakland Lake	North-eastern Queens	13.0 **	7.9	4.47x10 ⁶	0.62	4.35 ***	0.23 ***
Kissena Lake	North-eastern Queens	7.7 **	5.5	1.84x10 ⁶	0.15	2.62	0.38
Meadow Lake	North Central Queens	84.0 *****	4.8 *****	17.7x10 ⁶ *****	4 *****	7.3 *****	0.14 *****

* USGS 1997

** NYC Parks Dept. (Ifcher 1996)

*** NYC Parks Dept Limnological Survey 1990 (Effect of municipal water supply may not be included at Harlem Meer, Prospect Lake and Kissena Lake)

**** Bluebelt Study (New York City Dept. of Environmental Protection 1997)

***** Lawler et.al. 1987

***** Low flow values (1964) supplied by USGS; No permanent USGS gaging stations exist on this stream (USGS 1987)

***** Groundwater refill rate (Khanbilvardi 1991)

TABLE 3.3 CLASSIFICATION SYSTEM SCORES FOR NEW YORK CITY LAKES SELECTED FOR DETAILED STUDY			
LAKE	WATER INPUT MECHANISM SCORE	DEGREE OF ARTIFICIALITY SCORE	DEGREE OF URBANIZATION SCORE
Wolfe's Pond	2.7	2.4	1.4
Richmondtown Millpond	1.0	4.0	1.7
Harlem Meer	4.4	4.8	4.2
Van Cortlandt Lake	1.0	4.0	2.7
Prospect Lake	4.7	4.4	3.5
Conselyea's Pond	0.5	4.0	3.8
Oakland Lake	2.5	1.2	3.2
Kissena Lake	4.8	4.6	2.6
Meadow Lake	2.6	4.0	3.9

3.3 - Recent Municipal Water Supply Treatment Enhancements

New York City water is soft and generally low in mineral content, including alkalinity (salts of weak acids such as bicarbonates and carbonates) and is therefore weak in buffer capacity. Chlorination and fluoridation of the drinking water tends to drive the pH into the acid range, thereby rendering it severely corrosive relative to lead and copper, under the American Society for Testing Materials' (ASTM) monitoring procedures. (Mastronardi 1993, Sawyer 1960) Furthermore, acid precipitation tends to render a water supply more aggressive relative to lead and copper unless it is neutralized

naturally or by treatment. (Sheehan 1998, Steele 1993)

Potential public health hazards associated with the first draw of residential drinking water (after the water has been in continuous contact with copper or lead piping or fixtures throughout the previous night), and the need to control copper and other metals in both wastewater treatment plant effluent discharges to the New York Harbor Estuary and in sewage sludge, resulted in the development and implementation of a water supply corrosion control program. This involves the addition of both sodium hydroxide (to adjust pH to 7.2) and calcium-based “blended” orthophosphate (to create a thin protective (passivation) film of calcium orthophosphate which will act to inhibit the establishment and maintenance of a corrosion cell). (Mastronardi 1993) However, since the municipal water supply is utilized as a primary source of water for many of the lakes and ponds in New York City, there is concern that the corrosion control program will intensify the already hypereutrophic condition of these waters. (Matsil 1994) This is especially true since it is the orthophosphate form of phosphorus that is the most bioavailable to algae and to aquatic macrophytes. This orthophosphate load must be added to any that is drawn into the water supply when utilizing intakes located in reservoir hypolimnions during anoxic conditions when reservoir sediments are cycling orthophosphates back into the water column.

CHAPTER 4

FIELD PROGRAM

4.1 - Objectives

The primary objectives of the field program were to assess the trophic state and general water quality of the nine selected lakes and ponds, as well as to determine the impacts of urban runoff on these systems. Another objective was to acquire sufficient information to determine whether the three proposed classification system scores assigned to each of the lakes could be related to water quality characteristics. Finally, it was also an objective to generally assess the somewhat unique problems of urban lakes and to gather enough insight to develop both general and site-specific remedial suggestions.

4.2 - Field Program Design

This study has identified 134 lakes, ponds and reservoirs (both active and decommissioned) within the boundaries of New York City, with most lying partially or totally within the boundaries of New York City Parks. Since one of the overall objectives of this project was to determine whether lake water input mechanism affects the trophic states and water quality of the lakes, the nine lakes selected for detailed investigation were broken into three sets of three lakes each, with one set (Wolfe's Pond, Oakland Lake and Meadow Lake) having groundwater seepage as their primary source of water, a second set (Richmondtown Millpond, Van Cortlandt Lake and Conselyea's Pond) being fed mainly by impounded tributaries, and the third set (the Harlem Meer, Prospect Lake and Kissena

Lake) wherein the municipal water supply was the most significant source. It should be understood that the aforementioned input mechanisms are not the sole sources of water to the lakes, only the primary sources.

In order to account for seasonal variation, each of the nine lakes was visited for sampling, as well as for in-situ measurements and observations during the Fall of 1997, the Spring of 1998 and the Summer of 1998. Due to severe resource limitations, only a one day visit per lake per season was conducted, and only a single horizontal sampling and measurement location for each lake was occupied. In an ideal limnological experimental design of this type, additional spatial and temporal replication would be highly desirable in order to properly assess the variability of water quality parameters within each lake and within each season.

By utilizing only New York City lakes, this study utilizes the concept of a lake district which hypothesizes that lakes within the same geographical area will have similar climate, soil and vegetation. In other respects such as depth, size and fertility, lakes within such a district can be quite different (Horne and Goldman 1994). However, New York City is large enough to allow for some variation in local climate (Henderson-Sellers and Robinson 1989) due to the urban heat island effect, varying urban albedo, and the varying proximity of the different lakes to large open water bodies. Additionally, above and beyond the limnological concept of a lake district, the use of only New York City lakes means that the study would require interaction with only a single governmental jurisdiction (although others were actually involved).

4.3 - Qualitative and Quantitative Parameters Evaluated at Each Study Lake

In order to determine the trophic state of each lake, measurements were taken for secchi transparency, nutrient (nitrogen and phosphorus) species and chlorophyll pigments. For northern temperate lakes, where transparency is controlled by algae concentrations, Carlson proposed the following response models to relate total phosphorus, chlorophyll *a*, and secchi depth:

$$\text{chlorophyll } a = 0.068 P^{1.46}$$

$$\text{secchi depth} = 7.7 \text{ chlorophyll } a^{-0.68}$$

where chlorophyll *a* concentration is in parts per billion, ambient total phosphorus concentration (P) is also in parts per billion, and secchi depth is in meters. Also, 0.068 and 7.7 are empirical coefficients in units of (parts per billion)^{-0.46} and meters(parts per billion)^{0.68}, respectively. (North American Lake Management Association 1988)

Carlson's Trophic State Index (a commonly used measure of the degree of eutrophication of a lake) can be expressed as functions of secchi depth, chlorophyll *a* concentration or ambient total phosphorus concentration by means of the following relationships:

$$TSI_{SD} = 60 - 14.4 \ln \text{ secchi depth}$$

$$TSI_{Chl} = 9.8 \ln \text{ chlorophyll } a + 30.6$$

$$TSI_{TP} = 14.42 \ln P + 4.15$$

where:

TSI_{SD} = Carlson's Trophic State Index based on secchi transparency,

TSI_{Chl} = Carlson's Trophic State Index based on chlorophyll *a* concentration,

TSI_{TP} = Carlson's Trophic State Index based on lake total phosphorus concentration,

$\ln$ = natural logarithm, and

60, 14.41, 9.81, 30.6, 14.42, and 4.15 are dimensionless empirical constants.

Ideally, these TSIs will all be equal, but practically, variation in any one parameter may be large enough at any lake to cause significant variation in the TSI. These relationships are based on data for lakes across the United States, and since they are based on averages, they may not apply exactly to lakes at a given location. Also, the relations only apply to lakes having less than 30 color units. (New York State Department of Environmental Conservation and the Federation of Lake Associations, Inc. 1990) Secchi transparency, chlorophyll *a* and total phosphorus can also be related to each other and to Carlson's Trophic State Index graphically by means of the nomograph in Figure 5.1. (North American Lake Management Society 1988) This index extends from 20 at the extreme oligotrophic end of the continuum, to 80 at the extremely hypereutrophic end.

The assessment of the impact of urban runoff was conducted by collecting lake samples to be analyzed for turbidity, as a surrogate for the light fraction of sediment (Sawyer 1960). Additionally, this impact was assessed by performing analyses for the metals most often found in urban runoff (copper, zinc, cadmium and lead), occasionally in excess of recommended aquatic life criteria. (Schueler 1987)

While no raw sewage outlets, combined sewer outlets nor wastewater treatment plant outlets are known to discharge directly into the lakes nor into their tributaries (with the exception of the Wolfe's Pond and Richmondtown Millpond systems), it appeared

necessary to examine a few sanitary parameters such as fecal coliform, fecal streptococcus, and total organic carbon in order to assess possible impacts of failing on-site disposal systems, sewer leakage, animal wastes in urban runoff, and contributions from flocks of waterfowl. (While the ratio of fecal coliform to fecal strep is no longer considered to be a reliable mechanism for differentiating between human fecal contamination and that from other warm-blooded animals because of the variable decay rates of the various fecal strep species (American Water Works Association, American Public Health Association and Water Environment Federation 1995), the ratios may still be valid over small areas without multiple sources (Van Orden 1998, Van Orden 1990).)

In order to determine the extent of thermal stratification, if any, vertical profiling of temperature, pH, conductivity and dissolved oxygen was conducted with a Hydrolab Reporter Water Quality Multiprobe, in association with a Hydrolab Scout 2 Display Unit at the deepest point of each lake, which was located by means of soundings with the secchi disk along several transects, as indicated on Page 12 of Appendix G. All sampling, vertical profiling, and other measurements and observations were conducted during mid-day (never earlier than 9:30 AM and never later than 3:00 PM - one logistical limitation was the need to bring all water samples to the laboratories by 4:00 PM) from a canoe by the writer and trained technical staff. The exception was at the Richmondtown Millpond where lack of depth and difficult access required that these activities be conducted just upstream of the outlet weir. The locations of all sampling points may be found on the nine lake sketches at the end of Appendix G.

For each seasonal visit to each lake, a water sample was collected for the chemical

and physical analyses with a Lab-Line (Poly Pro) water sampler (a point sampler, as opposed to a depth-integrating sampler) at a depth of one foot (0.3 meters) below the surface, and also at one foot above the bottom (for nutrients and oxidation-reduction potential (ORP or Eh) only). Bacterial samples were collected directly with appropriate sterilized sample bottles at one foot below the surface. Analyses were performed for color to assess the validity of using the Carlson's Trophic State Index (low color is needed for valid results (North American Lake Management Society 1988)), and for hardness to determine the toxicity of the metals to aquatic life (Schueler 1987).

As an afterthought, during the third seasonal set (summer of 1998), samples were collected for toxicity testing, using the Microtox Test (which utilizes luminescent microorganisms (reduction in light emission is proportional to the toxicity of the sample)). (New York State Department of Environmental Conservation March 18&19, 1997)

Visual observations (present and previous weather, appearance of the lake, activities on and adjacent to the lake, vegetation) were made during each visit using the general protocols used in New York's Citizens State Lake Assessment Program (New York State Federation of Lake Associations and Department of Environmental Conservation 1996, and direct observation of the citizen training process by the writer). All water quality analyses not performed in-situ with the Hydrolab equipment were performed by outside laboratories.

Secchi transparency was determined by lowering the disk and recording the depth at which it disappeared and then raising it and recording the depth at which it reappeared. These two values were then averaged.

The Hydrolab multiprobe was calibrated in the office in accordance with the operating manual prior to each field visit. At each lake, temperature, pH, conductivity (and salinity), and dissolved oxygen concentrations (and percent saturation) were recorded at one foot below the surface, one foot above the bottom (and at mid-depth at the deeper lakes). A summary of the water quality parameters evaluated and the reasons for their evaluation are as follows:

Air Temperature - To assess the effect on water temperature.

Secchi Transparency - To assess the trophic state of the lake.

Water Temperature - To assess microbiological and chemical kinetics and to assess the extent (if any) of thermal stratification.

Conductivity, Salinity and Chlorides - To assess the extent of chemical stratification (if any), and the extent of any salt water intrusion (where applicable). Also, salt water holds less dissolved oxygen than does fresh water.

pH - To assess trophic state, toxicity of ammonia nitrogen, chemical kinetics, and possible impacts of acid rain.

Dissolved oxygen - To assess trophic state, habitat quality, stratification, and phosphorous kinetics at the water-sediment interface.

Eh - To assess chemical kinetics in general and phosphorous kinetics at the water-sediment interface in particular.

Color - To assess the validity of using the most commonly used lake response models (Carlson).

Turbidity - Also to assess the validity of using Carlson's model; additionally to assess the impact of urban runoff.

Hardness - To assess the toxicity of metals.

Metals (Pb, Cu, Zn, and Cd) - To assess the impact of urban runoff, which can be a source of toxicity.

Nutrients and Chlorophyll Pigments - To assess the trophic state of the lake.

Fecal coliform and fecal streptococcus - To assess the sanitary quality of the lake and possible contamination sources.

Microtox - Proprietary bioassay to assess chronic and acute toxicity; summer only.

Total Organic Carbon - To assess the extent of organic loading of the lake.

Preservation and analytical procedures utilized in this field effort may be found in Table 4.1. All sample containers were iced to maintain a temperature below 4 degrees C. and the holding times were limited by the bacterial samples which had to be in the laboratory within six hours of collection. The toxicity samples taken during the summer round had to reach the upstate (Hale Creek) laboratory within 48 hours (coolers containing the iced samples were sent by overnight mail). All containers used to deliver samples for physical, chemical, microbiological and toxicity analyses were plastic.

<u>TABLE 4.1</u> <u>PRESERVATION AND ANALYTICAL PROCEDURES FOR</u> <u>FIELD PROGRAM</u>		
PARAMETER	PRESERVATION	ANALYTICAL PROCEDURES
Metals (Total) Lead, Copper, Cadmium, Zinc	HNO ₃	Perkin-Elmer Model 3030 Graphite Furnace Atomic Absorption Spectrophotometer using EPA Methods 239.29(Pb), 220.2(Cu), 213.2(Cd), 289.2(Zn)
Chloride		Titration against a standard solution of silver nitrate using potassium chromate indicator. Standard Methods (SM) 18 th Edition (4500-Cl-B)
Oxidation-Reduction Potential (Eh or ORP)		Orion ORP electrode in accordance with Orion Instruction Manual
Hardness		Titration with a standard solution of EDTA as per SM 18 (2340C)
Turbidity		Turbidimeter as per SM 18 (2130B)
Color (Apparent)		Spectrophotometer as per SM 18 (2120C)
Chlorophyll a, b, c		Spectrophotometer using trichromatic procedure as per SM 18 (10200H)
Fecal Coliform		Most Probable Number (MPN) using Multiple Tube Fermentation Technique as per SM 18 (9221C)
Fecal Streptococci		MPN using Multiple Tube Fermentation Technique as per SM 18 (9230B)
Ammonia Nitrogen		Distillation followed by titration procedure as per SM 18 (4500-NH ₃ E)
Total Kjeldahl Nitrogen (TKN)		Macro-Kjeldahl Method in accordance with SM 18 (4500-N _{org} B)

TABLE 4.1 (Continued)

PRESERVATION AND ANALYTICAL PROCEDURES FOR
FIELD PROGRAM

Nitrate and Nitrite Nitrogen	H ₂ SO ₄ added at lab after portion for nitrite analyses is removed.	Analyzed as per SM 18 (4500-NO ₃ -E (Cadmium-Reduction)) and (4500-NO ₂ -B (colorimetric)) procedures respectively
Orthophosphate		Analyzed by direct colorimetry measuring color formation with vanadomolybdophosphoric acid, as per SM 18 (4500-P-C)
Total Phosphorus		Measured after all phosphorus components in the sample were fully oxidized by above colorimetric method (SM 18 (4500-P-A))
Total Organic Carbon		Combustion and infrared analysis as per SM 18 (5310B)
Toxicity		Bioassay, using luminescent microorganisms and Microtox Model 500 Analyzer

CHAPTER 5

SAMPLING RESULTS AND STATISTICAL ANALYSES

5.1 - Field Measurements and Analytical Results

All sampling data and field measurements are displayed in Appendix A1 (Access Database), Appendix B (Excel Workbook), and Appendix D (WinSTAT Workbook). The original laboratory data sheets may be found attached to Appendix G.

The first of the field measurements taken was maximum lake depth (See Appendices A1, B, D, and Table 5.1). The results indicate that all nine lakes are relatively

<u>TABLE 5.1</u>	
<u>MAXIMUM DEPTHS OF LAKES SELECTED FOR DETAILED STUDY</u>	
LAKE	MAXIMUM DEPTH (METERS)
Wolfe's Pond	1.5
Richmondtown Millpond	0.3
Harlem Meer	2.2
Van Cortlandt Lake	1.2
Prospect Lake	2.3
Conselyea's Pond	1.4
Oakland Lake	3.3
Kissena Lake	2.0
Meadow Lake	1.1

shallow, with only one having a depth greater than 2.3 meters (7.6 ft.) (Oakland Lake at

3.3 meters (10.9 ft.)). This would place the selected lakes toward the shallow end of the urban and suburban lake spectrum (although these depths are not unusual for artificial lakes and ponds (Debo August 1977, U.S. Department of the Interior 1967)), and would explain why so many tend toward the hypereutrophic end of the trophic state continuum. (Burden and Malone 1984) Vertical profiling each season at each lake with the Hydrolab Multiprobe revealed that the lack of depth at all but Oakland Lake appeared to preclude any long term thermal stratification. The eight shallow lakes and ponds appear to be holomictic (mixing from top to bottom), since only very deep or chemically stratified lakes are meromictic, and polymictic (mixing many times through the year), since they did not thermally stratify and were all exposed to wind (the primary driving force for lake mixing). Oakland Lake does thermally stratify and appears to be holomictic and dimictic (mixing twice per year), or more likely, monomictic (mixing once per year), depending on whether the lake surface freezes over during the winter months, which in recent years is unlikely. The overall shallow depths of these lakes makes them prone to eutrophication, since shallower depths lead to greater depth-averaged light intensities and greater sediment/water contact area per volume for enhanced nutrient recycling (Burden and Malone 1984, North American Lake Management Society 1988).

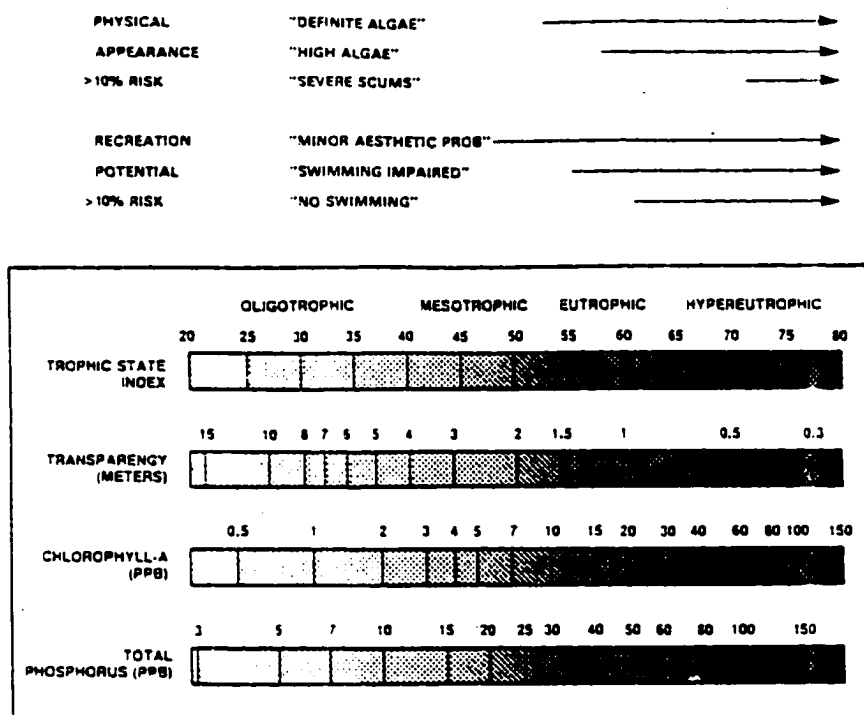
Water transparency measurements indicated fairly low secchi depths (low water clarity), with only one lake exceeding two meters (6.6 ft.) and three additional lakes exceeding one meter (3.3 ft.) during the fall survey, one lake exceeding two meters and two other lakes exceeding one meter during the spring survey, and only two lakes exceeding a secchi depth of one meter during the summer survey (although the disk could

be seen on the bottom at the very shallow Richmondtown Millpond during the Spring and Summer surveys). Use of the Carlson Trophic State Index nomograph (See Figure 5.1 (North American Lake Management Society 1988)) would place all lakes (except for the Richmondtown Millpond) into the eutrophic or hypereutrophic state during the summer.

In general, water temperature tracked air temperature as would be expected in shallow holomictic, polymictic lakes. The one exception is the somewhat deeper Oakland Lake, which does thermally stratify during the summer, and which revealed a hypolimnetic temperature of 13 degrees F. (7.9 degrees C.) below that of the epilimnion (which did track air temperature).

During the fall survey, pH ranged from 7.11 to 8.99, and during the spring, it ranged from 7.11 to 9.88. However, during the summer survey, pH ranged more widely, from 6.72 to 10.44. The only readings below 7.00 occurred during the summer survey at thermally stratified Oakland Lake, below the thermocline, where decomposition and respiration rates exceeded photosynthetic rates. Decomposition and respiration add carbon dioxide to the water column (which yields an acidic reaction), while photosynthesis removes carbon dioxide from the water column (leading to a basic reaction). Given the trophic states of the lakes, it is not surprising that the pH readings at the lakes during daylight hours are on the high side (See Table 5.2). This photosynthetic-driven diurnal elevation of pH appears to overwhelm any tendency toward low water column pH caused by acid precipitation (the pH of precipitation in the New York City Area is between 4.3 and 4.4 (Horne and Goldman 1994)). Runoff resulting from this unbuffered acidic precipitation may also may be neutralized by its passage through each lake's watershed).

FIGURE 5.1
CARLSON'S TROPHIC STATE INDEX NOMOGRAPH



(From North American Lake Management Society, 1988)

Conductivity, salinity and chloride readings all indicate substantial estuarine water intrusion into Conselyea's Pond and into Meadow Lake. This is due to defective outlet

<u>TABLE 5.2</u> <u>SUMMER SURFACE VALUES OF TROPHIC STATE, pH</u> <u>AND DISSOLVED OXYGEN (from Appendix B)</u>			
LAKE	TSL _{chl}	pH	Dissolved Oxygen (mg/l)
Wolfe's Pond	65	7.72	7.21
Richmondton Millpond	34	7.18	6.69
Harlem Meer	54	9.77	15.52
Van Cortlandt Lake	72	9.47	13.65
Prospect Lake	68	10.22	14.8
Conselyea's Pond	60	7.69	12.49
Oakland Lake	54	7.64	15.15
Kissena Lake	80	10.44	14.3
Meadow Lake	80	10.07	12.26

structures at both lakes. Two of the three lakes fed by City water (Prospect Lake and Kissena Lake) have the lowest conductivity, salinity and chloride readings in the set. The third lake fed by City water (the Harlem Meer) is also fed by small underground (buried and culverted) streams, which probably account for its higher readings. Wolfe's Pond, immediately adjacent to Raritan Bay, which is fed primarily by groundwater seepage, and secondarily by a tributary which receives small point discharges and overflow from on-site disposal systems, shows remarkably low readings (given its origin as an indentation in the shoreline of the Bay, and anecdotal information about occasional

breaching and overwashing of the berm separating the Lake from the Bay during intense storms).

Hardness in water, a measure of soap consuming capacity to the layman, and of the scaling problem in hot water pipes and boilers to the engineer, is caused by the presence of such divalent cations as calcium, magnesium, strontium, ferrous and manganous, and is largely derived from contact of the water with soil and rock formations. It was measured in this study in order to assess the toxicity of heavy metals on aquatic life (hardness is protective (Schueler 1987, Kuzia and Dean 1978)), and tends to be highest in the lakes afflicted by estuarine water intrusion, and lowest in lakes fed by City water. Of the uncontaminated (by salt) groundwater fed lakes, Oakland Lake, located in the ground moraine, which may be locally underlain by outwash sands (which is further underlain by the Magothy and Raritan formations deposited during the Cretaceous Period) (Pearlmutter and Arnow 1953) has a far higher hardness than does Wolfe's Pond, which is located in the terminal moraine (also underlain by the Magothy and Raritan formations). Between the tributary supplied lakes uncontaminated by saltwater, the Richmondtown Millpond, which is fed by Richmond Creek after it flows through the ground moraine underlain by Staten Island Serpentine, has a higher hardness (surprisingly) than does Van Cortlandt Lake which is fed by Tibbetts Brook after it flows through a valley containing local outwash sediments underlain by Inwood Marble. See Table 5.3 for summer values of lake hardness (and Appendices A1, B and D for other seasonal hardness values).

Turbidity in the lakes ranged from 4 to 17 Nephelometric Turbidity Units (NTU) and averaged 7.9 during the fall survey, while it ranged from 2.4 to 30 and averaged 9.5

during the spring. During the summer, turbidity readings ranged from 3.5 to 25 and averaged 12.9. These are relatively low values and may indicate that runoff

TABLE 5.3	
SELECTED LAKE SUMMER HARDNESS VALUES (from Appendix B)	
LAKE	HARDNESS (mg/l as CaCO₃)
Wolfe's Pond	63
Richmondton Millpond	242
Harlem Meer	76
Van Cortlandt Lake	135
Prospect Lake	32
Conselyea's Pond	3100
Oakland Lake	226
Kissena Lake	23
Meadow Lake	1140

(urban, suburban and parkland) is not conveying a heavy sediment load (at least not the light fraction (colloidal, clay and silt)) to the lakes, or it means that the parklands adjacent to the lakes are functioning as an effective buffer in spite of the storm drains that occasionally penetrate these buffers and discharge pavement runoff to the lakes. It also means that the low secchi depth readings are caused by algal growth rather than by non-chlorophyll particles.

Color readings averaged 72 color units during the fall survey and ranged from 30 to 180. During the spring survey the readings averaged 31.5 and ranged from 5 to 80, while during the summer they averaged 148 and ranged from 40 to 280. During the

summer survey the color readings tracked both chlorophyll *a* and secchi depth quite well (see Figure 5.2). Surprisingly, two of the lakes (Prospect and Kissena) fed almost solely by City water (which has very low color readings) had very high values (240 and 280 respectively). However, the surprise vanishes when the laboratory advised, long after the field work was completed, that it had reported apparent color (which includes the effects of suspended matter in addition to those of colloidal matter) rather than true color.

During the summer survey, daytime dissolved oxygen (DO) readings near the water surface were in the supersaturated range (except at Wolfe's Pond and at the Richmondtown Millpond) due to vigorous photosynthetic activity. However, at thermally stratified Oakland Lake, DO values in the hypolimnion were extremely low. Similarly, DO readings near the bottoms of unstratified Kissena Lake and Conselyea's Pond were extremely low (clinograde profile). Similar gradients were observed at several other lakes, but they were not as severe. During the spring survey, DO readings were far more vertically uniform, with several of the lakes in the supersaturated range. Likewise, during the fall survey, no substantial vertical DO gradient could be discerned, and two lakes (Meadow Lake and Conselyea's Pond) had readings in the supersaturated range (these are the lakes with the severe saltwater intrusion problems, although the problem was less severe by far at Meadow Lake during the fall survey). See Figures 5.3-A and 5.3-B for selected profiles. This apparent anomaly (of high DO near the bottoms of the two lakes having among the lowest secchi transparencies) could be due to instrument inadequacy (the DO detection system was difficult to stabilize in the more ionized waters (salinity up to 5.4 ppt in Meadow Lake and up to 18.4 ppt in Conselyea's Pond)), or possibly to the

SUMMER VALUES OF COLOR, CHLOROPHYLL A, AND SECCHI

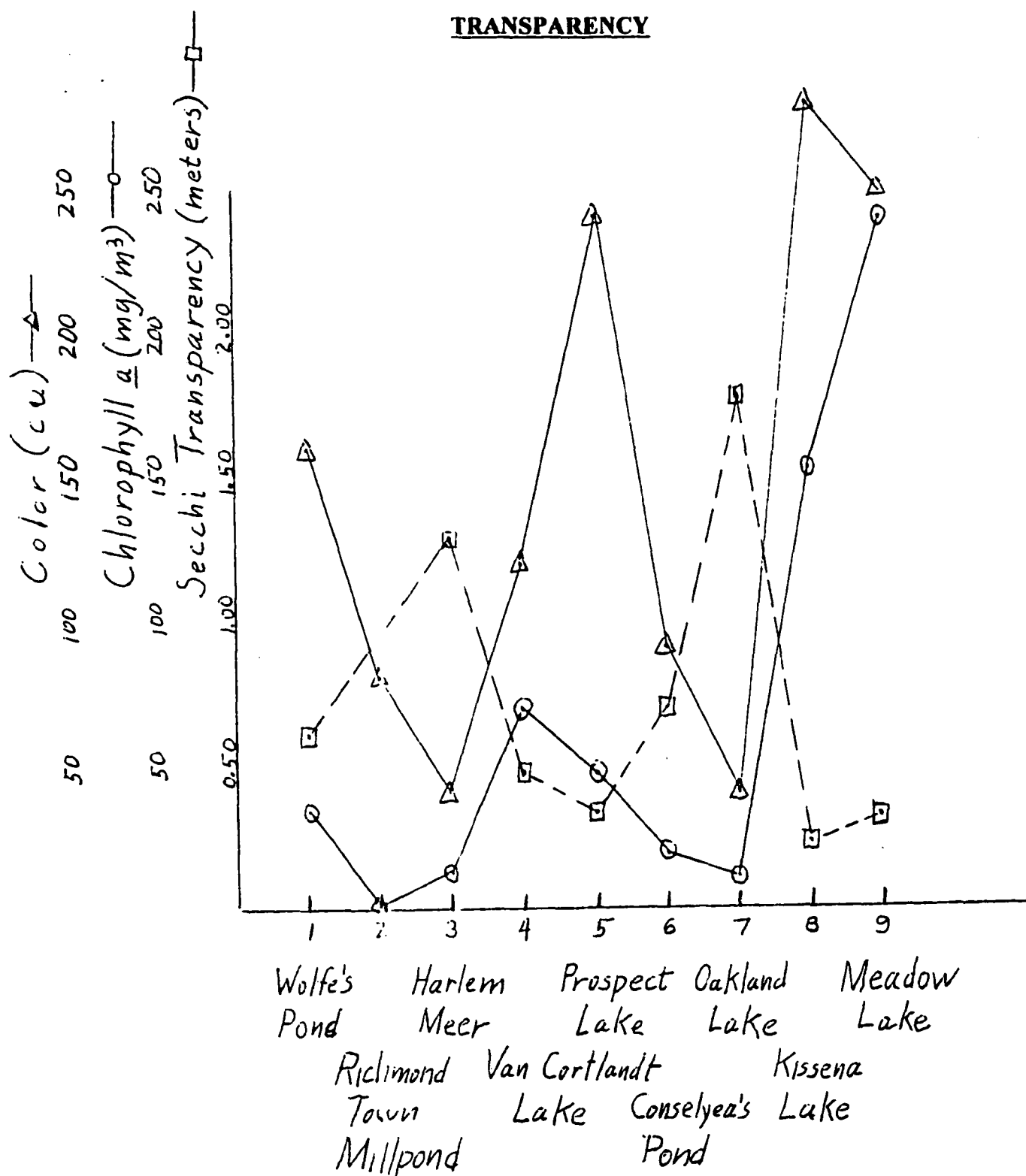


FIGURE 5.3-A

SELECTED VERTICAL PROFILES-OAKLAND LAKE

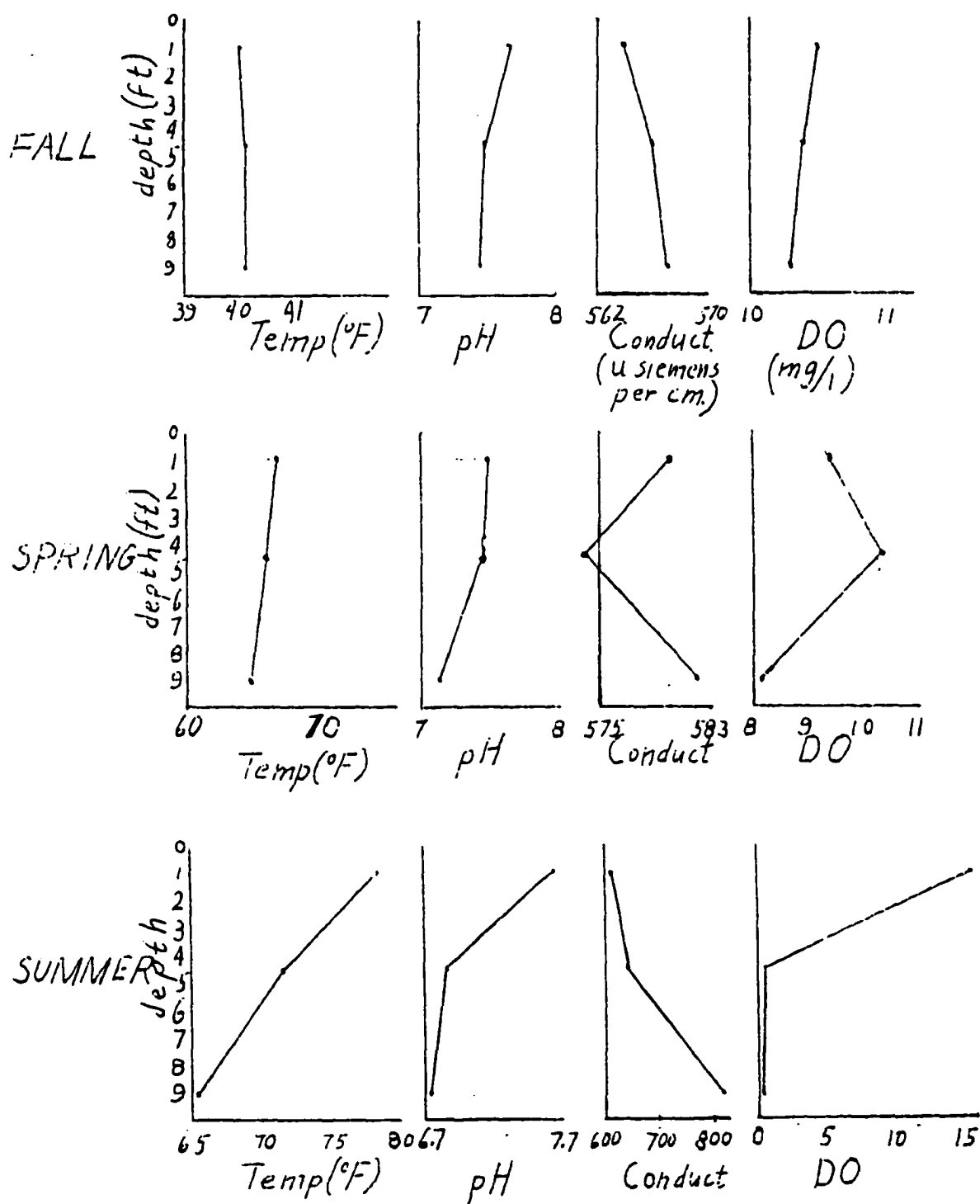
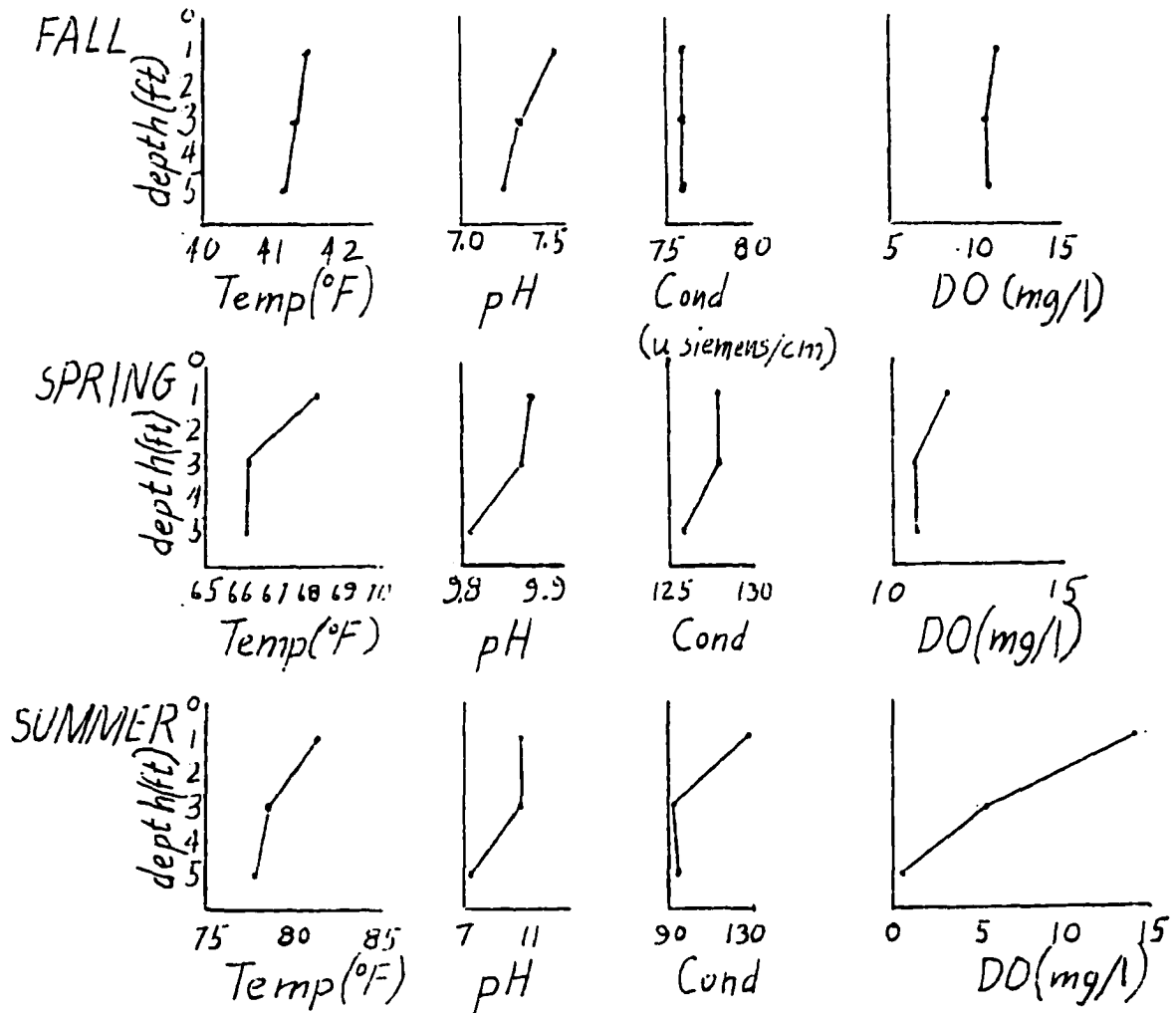


FIGURE 5.3-B

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SELECTED VERTICAL PROFILES-KISSENA LAKE



fact that chlorophyll a and total chlorophyll were higher in these lakes than in any of the other seven during the fall survey (chlorophyll b and chlorophyll c gather light in dimly illuminated portions of the water column, where chlorophyll a does not absorb light, thereby allowing for additional algal cell growth and DO production at the lower depths (Horne and Goldman 1994)), or merely due to extremely vigorous vertical mixing which could convey highly oxygenated water to the lower portions of the lakes. The summer DO gradients in the unstratified lakes were due to the vigorous sunlight-driven photosynthetic activity near the surface, along with the substantial (but unmeasured) sediment oxygen demand (SOD) being imposed on the lower portions of the water column by the decomposing benthic organic deposits observed at many of the lakes. At thermally stratified Oakland Lake, the problem was compounded by the absence of wind-driven and convective mixing (nocturnal sinking of cooler water) across the thermocline to bring DO to the hypolimnion, with only the weaker mechanism of diffusion available for this purpose.

Chlorophyll a readings (a measure of algal biomass) during the summer survey were at levels associated with eutrophic or hypereutrophic conditions (based on the Carlson's Trophic State Index nomograph (North American Lake Management Society 1988)), except at the polluted Richmondtown Millpond where the hydraulic residence time at this smallest of the lakes (which has also been subjected to severe sedimentation (historic depth was six feet but is now between one and two feet, with a sediment island having been formed (New York City Department of Environmental Protection February 1997))) is probably too brief to allow phytoplankton to develop. The highest

concentrations of chlorophyll a during the summer survey were at Meadow Lake, Kissena Lake, Van Cortlandt Lake and Prospect Lake. During the spring survey, the highest concentrations were at Meadow Lake, Conselyea's Pond and Prospect Lake, while the fall survey revealed the highest concentrations at Meadow Lake, Conselyea's Pond and Kissena Lake. Chlorophyll b, an accessory pigment, was always high at Meadow Lake and occasionally high at other lakes such as Conselyea's Pond. Oddly, the Richmondtown Millpond shows a remarkably high chlorophyll b level during the summer survey (while the chlorophyll a and c concentrations were two orders of magnitude lower).

Oxidation-reduction potential (ORP or Eh) imperfectly tracked DO concentrations during this study. Eh should be high in an oxidizing environment (high DO in an aquatic system), where metals and nutrients are most thermodynamically stable in their most oxidized form. (Horne and Goldman 1994) Under these conditions, iron in the form of undissolved ferric oxides strongly sorbs phosphorus and removes it from the water column. (Drever 1988) In a reducing environment (low or zero DO (hypoxic or anoxic respectively) in aquatic systems), metals and nutrients are most thermodynamically stable in their most reduced form. In this environment, the ferric oxides are reduced to species such as Fe^{2+} , FeS , or FeCO_3 , and phosphorus is released into the water column and becomes available to phytoplankton. Similar sorption-desorption reactions occur with a wide variety of inorganic and organic particles. Also, but less importantly, insoluble ferric phosphate in the sediments is converted to the soluble form under low Eh conditions and released to the water column. Eh did track DO well at Conselyea's Pond during the summer survey, where the only negative Eh reading observed in this study corresponded

with the only location where the odor of H_2S was present, and at Oakland Lake where a low DO corresponded with a low but not negative Eh reading. At other locations, anomalously higher Eh readings were observed near the bottom of the water column than near the top during the spring and summer surveys.

All metals readings (See Appendix B, columns T, U, V and W) were below “EPA Trace Metal Criteria for Urban Runoff Exposure - Ambient Life Criteria for Intermittent Exposure”, for “Threshold Effect” (See Table 5.4), indicating only minimal impact of urban runoff on the selected lakes (Schueler 1987). However, the significant metals in urban runoff (zinc, copper, lead and cadmium; those that are most often found in urban ambient samples and which were evaluated in this study) are often sorbed onto particulate matter which could have rapidly settled out thereby escaping detection, since it was the total (unfiltered) concentrations of metals that were measured. Metals tend to be most bioavailable and toxic to aquatic life when they are free or in weak inorganic complexes. They are also present in stormwater in nonbioavailable organic complexes. (Paulson and Amy 1993) Seasonal total metals concentrations are also found in Tables 5.5, 5.6 and 5.7.

Where the total phosphorus readings are useful (in about 70% of the samples (see section 5.3 for discussion of problems)), they indicate that the lakes are in the hypereutrophic state according to Carlson’s Trophic State Index. Under Liebig’s Law of the Minimum, the productivity of aquatic systems is controlled by the nutrient that is in lowest supply relative to the nutritional requirements of algae and other aquatic vegetation. This nutrient is considered the limiting nutrient. (American Lake & Wetlands

Services, Inc. 1997, New York Federation of Lake Associations and Department of Environmental Conservation 1990, Water Pollution Control Federation 1991) Waters

TABLE 5.4				
EPA TRACE METAL CRITERIA FOR URBAN RUNOFF EXPOSURE				
Trace Metal Contaminant	Water Hardness (mg/l as CaCO ₃)	Human Ingestion (ug/l)	Ambient Life Criteria for Intermittent Exposure (ug/l) - Threshold Effect	Ambient Life Criteria for Intermittent Exposure (ug/l) - Significant Mortality
Copper	50	-	20	50-90
	100	-	35	90-150
	200	-	80	120-350
Cadmium	50	10	3	7-160
	100	10	6.6	15-350
	300	10	20	45-1070
Lead	50	50	150	350-3200
	100	50	360	820-7500
	200	50	850	1950-17850
Zinc	50	-	380	870-3200
	100	-	680	1550-4500
	200	-	1200	2750-8000
Nickel	-	13.4	-	-

(From Schueler, T. R., *Controlling Urban Runoff: A Practical Manual for Planning and Urban BMPs*, Prepared for the Washington Metropolitan Water Resources Planning Board, July 1987.)

where total nitrogen (TN) to total phosphorus (TP) ratios are below 10 are nitrogen limiting, while those having TN to TP ratios above 17 are phosphorus limiting. Ratios between 10 and 17 means that aquatic plant growth may be limited by nitrogen and/or

<u>TABLE 5.5</u>				
<u>FALL LAKE METALS CONCENTRATIONS (ug/l)</u>				
Lake	Pb	Cu	Zn	Cd
Wolfe's Pond	6.1	7.8	6.0	<1
Richmondton Millpond	11.5	14.3	10.2	<1
Harlem Meer	9.9	9.5	3.6	<1
Van Cortlandt Lake	20.2	13.1	5.8	<1
Prospect Lake	8.2	2.0	12.0	<1
Conselyea's Pond	7.3	1.7	9.6	<1
Oakland Lake	<1	<1	1.0	<1
Kissena Lake	1.6	<1	1.3	<1
Meadow Lake	8.8	1.8	2.2	<1

<u>TABLE 5.6</u>				
<u>SPRING LAKE METALS CONCENTRATIONS (ug/l)</u>				
Lake	Pb	Cu	Zn	Cd
Wolfe's Pond	7.6	4.2	3.3	<1
Richmondton Millpond	6.3	9.8	4.4	<1
Harlem Meer	16.6	<1	5.7	<1
Van Cortlandt Lake	20.2	1.3	3.9	<1
Prospect Lake	17.1	<1	<1	<1

TABLE 5.6 (Continued)				
<u>SPRING LAKE METALS CONCENTRATIONS (ug/l)</u>				
Conselyea's Pond	<1	11.9	23.9	<1
Oakland Lake	6.7	5.0	2.1	<1
Kissena Lake	3.0	13.9	1.9	<1
Meadow Lake	22.1	6.6	3.0	<1

TABLE 5.7				
<u>SUMMER LAKE METALS CONCENTRATIONS (ug/l)</u>				
Lake	Pb	Cu	Zn	Cd
Wolfe's Pond	11.4	1.8	3.4	<1
Richmondton Millpond	8.5	5.4	9.1	<1
Harlem Meer	5.8	6.4	6.8	<1
Van Cortlandt Lake	6.4	2.6	5.2	<1
Prospect Lake	1.5	1.1	2.6	<1
Conselyea's Pond	<1	2.7	7.1	<1
Oakland Lake	3.4	1.8	3.6	<1
Kissena Lake	3.1	<1	<1	<1
Meadow Lake	<1	3.0	<1	<1

phosphorus. During the summer survey, the TN to TP ratios indicate that nitrogen was the limiting nutrient, while the ratios for the spring indicate that phosphorus was limiting (See Appendix B column AM, and Table 5.8). During the fall survey, the ratios for most lakes fell in the range between 10 and 17. Based on the high Total Kjeldahl Nitrogen

(TKN) results relative to the other nitrogen species, most of the nitrogen is in the organic form. Since the major component of TN in this study was organic nitrogen, most of the lakes would almost always be nitrogen limiting if, as some suggest (American Lake & Wetlands Services, Inc. 1997), the ratio of available nitrogen (ammonia and nitrate) to available phosphorus (which correlates well with total soluble phosphorus, which at normal lake ranges of pH is in the form of orthophosphate (Horne and Goldman 1994))

<u>TABLE 5.8</u>			
<u>SEASONAL RATIOS OF TOTAL NITROGEN TO TOTAL</u>			
<u>PHOSPHORUS</u>			
LAKE	FALL	SPRING	SUMMER
Wolfe's Pond	12.1	70.3	0.8
Richmondtown Millpond	6.3	80.7	21.0
Harlem Meer	18.6	33.2	5.2
Van Cortlandt Lake	10.8	45.4	5.6
Prospect Lake	15.0	55.6	16.4
Conselyea's Pond	20.7	64.0	22.0
Oakland Lake	19.9	37.7	2.1
Kissena Lake	4.4	14.0	1.8
Meadow Lake	16.8	34.6	6.8

were used.

Fecal coliform concentrations during the spring survey met water quality standards for primary contact recreation at all lakes except for the Richmondtown Millpond (which

is still afflicted by small point sources (mostly illegal sewage connections to storm sewers) and failing on-site disposal systems. Swimming is not a use of these waters permitted by the New York City Department of Parks and Recreation, but the State Department of Environmental Conservation classified most of the lakes at the B level to comply with Title 3, Article 17 of the Environmental Conservation Law, which requires this level of protection for streams located in residential areas where “there is a potential exposure of population to the surface waters.” During the summer survey, only Conselyea’s Pond showed fecal coliform levels in excess of B level standards, while the fecal streptococcus concentration at this location was elevated. The fall survey brought forth coliform exceedences at Wolfe’s Pond (point sources and on-site disposal systems), the Richmondtown Millpond, the Harlem Meer (no known sources other than waterfowl and other animals), and Van Cortlandt Lake (major sources were corrected almost two decades ago; minor sources may remain). Elevated strep levels were recorded at the Harlem Meer, Van Cortlandt Lake, Prospect Lake, Conselyea’s Pond, and Oakland Lake indicating possible animal sources. While fecal coliform (bacteria originating in the gut of warm-blooded animals) and total coliform densities may serve as adequate indicators where sewage from sources such as combined sewer overflows and storm sewers with cross-connections contaminates surface waters, they are not considered adequate for assessing health threats associated with contamination by separate storm sewer discharges. If the stormwater has not mixed with sewage, then the traditional coliform indicators may not properly represent the disease potential of this source and may lead to premature beach closures and the unnecessary adoption of costly control measures. Additionally, a

large portion of swimming-related illnesses involve infections of the eyes, ears, upper respiratory tract and skin which are caused by non-enteric pathogens for which coliforms would serve as a poor indicator. (O'Shea and Field 1992, Henderson 1968) However, others have highlighted studies indicating that swimming in waters contaminated with urban stormwater runoff resulted in a 50% to 100% increase in illness rate, and have called for more research on the concentrations of microbial pathogens or pathogen indicators in urban and suburban stormwaters and the risk that they represent to public health. (Mahin and Pancorbo 1999) Still others have observed pathogens and indicators in urban runoff and in artificial lakes surrounded by Texas woodlands. (Environmental Protection Agency November 1976)

As discussed in Section 2.4.1, several lake classification systems currently exist. Based on the results of this field program, Table 5.6 shows the classification of the nine selected New York City study lakes under three of these existing systems.

5.2 - Statistical Analyses

Field Measurements and laboratory data were evaluated using simple (only two variables involved) regression analyses, and one-way analyses of variance (ANOVA) with Tukey's w-procedure (or honestly significant difference procedure) at the 95% level of significance. (Steel and Torrie 1960) Regression analyses were used to evaluate the existence of any relationships among a variety of water quality parameters, as well as between classification system scores and water quality parameters. The analyses of variance were used in an attempt to detect whether lake water quality was affected by

water input mechanism (i.e., groundwater, tributary or municipal water supply), unrefined by scoring.

Both analyses were performed by utilizing the WinSTAT Statistics Program for Windows. For any set of data, in the simple regression analysis, WinSTAT selects the best relationship (from among the alternatives of linear, power, exponential, logarithmic,

<u>TABLE 5.9</u>			
<u>CLASSIFICATION OF SELECTED LAKES, THREE EXISTING SYSTEMS</u>			
LAKE	NATURAL ORIGIN	TROPHIC STATE	THERMAL MIXING PATTERN
Wolfe's Pond	Sediment deposition at mouth of stream	Hypereutrophic	Holomictic, polymictic
Richmondtown Pond	None	Hypereutrophic	Holomictic, polymictic
Harlem Meer	None	Eutrophic	Holomictic, polymictic
Van Cortlandt Lake	None	Hypereutrophic	Holomictic, polymictic
Prospect Lake	None	Hypereutrophic	Holomictic, polymictic
Conselyea's Pond	None	Eutrophic	Holomictic, polymictic
Oakland Lake	Glacial (kettle)	Eutrophic	Holomictic, monomictic
Kissena Lake	None	Hypereutrophic	Holomictic, polymictic
Meadow Lake	None	Hypereutrophic	Holomictic, polymictic

and three forms of hyperbolic) between the independent and dependent variables under consideration. The selected relationship is that having the highest coefficient of correlation (r) and the associated highest coefficient of determination (r^2). The WinSTAT Program produces the appropriate coefficients and exponents for the selected function (as

well as for the six alternative functions), along with the coefficients of correlation and determination. It also superimposes the best regression curve on a scatterplot of the data pairs (See Appendix E for Seasonal WinSTAT Regression Equations, Correlation and Determination Coefficients and Regression Curve Plots. Also, see Appendix C for a more limited seasonal selection of Excel Scatter Plots).

Seasonal Regression Analyses were performed between the following pairs of water quality variables:

- 1- pH vs Eh near lake bottoms to assess stability of various chemical constituents in aqueous solutions as well as water itself (the stability of water and common aquatic substances is often plotted on Eh - pH diagrams, with the upper and lower stability limits for water as parallel lines with slopes of -1) (Drever 1988, Environmental Protection Agency 1974),
- 2- DO vs Eh near lake bottoms, since hypoxic conditions should be associated with reducing conditions (low Eh),
- 3- DO vs chlorophyll a near the surface, since high algal biomass should yield supersaturated DO conditions during daylight hours due to intense photosynthetic activity,
- 4- Turbidity vs chlorophyll a to determine if the turbidity is due to algal growth or whether it is primarily due to stormwater conveyance of sediment (at least the light fraction thereof) into the lakes and can, therefore, serve as a surrogate for the light fraction of sediment import,
- 5- Turbidity vs Secchi Depth as a follow-up to "4" to determine whether transparency

is controlled primarily by algal growth (as required by Carlson's Lake Response Model (North American Lake Management Society 1988)) or whether fine particles of organic or inorganic material are having an effect, and

6- Copper vs Turbidity to assess whether copper, as a representative of metals most often found in urban runoff is associated with light particulate matter in the lakes.

A surprisingly low number of water quality variable pairs displayed relationships having correlation coefficients above 0.5 (and there would be fewer still if only linear correlation was being assessed), generally indicating less than perfect correlation between the selected variable pairs (See Table 5.10). This implies highly variable seasonal conditions at the selected lakes. DO always correlated well with chlorophyll a (high algal densities should always yield high or supersaturated DO), but secchi depth should always correlate with turbidity (it did not in the Fall), and the failure of chlorophyll a to correlate with turbidity in the Summer may mean that during that season, the turbidity may be more associated with sediment inputs (the light fraction) than with the density of algal cells. The failure of Eh to always correlate positively with DO can not be explained. The failure of copper to correlate with turbidity, counter to expectations, probably means that the copper is mainly sorbing onto a somewhat heavier fraction of the sediment load, and is generally avoiding detection by settling out. As discussed earlier, though there is no effort in this study to correlate surface pH with surface DO, they do track each other as expected.

Seasonal Regression analyses were also performed for the assigned scores under the three proposed classification systems (Degree of Urbanization, Degree of Artificiality,

and Water Input mechanism) against Carlson's Trophic State Index (based on chlorophyll a (which should be the same as the Index based on secchi depth), turbidity, copper, lead, zinc, fecal coliform, hardness and pH. See section 6.2 for a discussion of the results of these analyses.

Additionally, seasonal analyses of variance were performed with primary water input mechanisms as the three treatments, the lakes as the experimental units (three lakes for each treatment) and a series of water quality parameters (fecal coliform,

TABLE 5.10 REGRESSIONS WITH $r > 0.5$ WATER QUALITY VARIABLE PAIRS			
VARIABLE PAIR	SEASON	BEST RELATIONSHIP	r
DO vs Chlorophyll <u>a</u>	Spring	linear	0.697
Chlorophyll <u>a</u> vs Turbidity	Spring	logarithmic	0.916
Secchi depth vs Turbidity	Spring	hyperbolic	0.851
Eh vs DO	Summer	hyperbolic	-0.858
DO vs Chlorophyll <u>a</u>	Summer	hyperbolic	0.681
Secchi depth vs Turbidity	Summer	hyperbolic	0.957
Copper vs Turbidity	Summer	hyperbolic	0.558
Eh vs pH	Fall	linear	-0.718
Eh vs DO	Fall	hyperbolic	0.864
DO vs Chlorophyll <u>a</u>	Fall	hyperbolic	0.867
Chlorophyll <u>a</u> vs Turbidity	Fall	logarithmic	0.760

orthophosphate, total Kjeldahl nitrogen (organic plus ammonia nitrogen), zinc, lead, hardness, pH, turbidity, Carlson's Trophic State Index (based on secchi depth), color and chlorophyll a) as the effects to be measured.

The results of the 33 analyses of variance indicated that there was no significant difference between any of the three treatments (water input mechanisms) for any of the measured effects. The tabulated value of F (5.4) at a probability level of 0.05 (95% level of significance) was always greater than the calculated values. In fact, the calculated values of F were often less than unity. This basically meant that the variability of the measured effects within treatments (lakes having the same water input mechanism) was so great, that the variability between treatments had to be very large in order to demonstrate a significant difference between the effects caused by the three water input mechanisms. This will be discussed further in section 5.3, but at this point it should be stated that some of the within treatment variability is due to differences in the nature and size of the watersheds resulting in urban runoff of varying character, to the fact that no attempt was made to score the water input mechanisms (i.e., to account for combinations of water input mechanisms and runoff), and to the impact of salt water intrusion.

5.3 - Problems and Weaknesses

As discussed within Chapter 4, efforts were made to control variability by utilizing the concept of the lake district. Nevertheless, substantial variability was introduced as the result of a mix of water sources to each lake, variation in urban runoff quality and quantity due to the great variation in buffering by parkland which totally or partially surrounds the

lakes (but which is often penetrated by storm sewers draining varying areas of urban or suburban streets, or the park's circulation system). Scoring water input mechanism and degree of urbanization respectively was an attempt to compensate for this variability. However, attempting to statistically relate classification system scores to water quality was probably too ambitious, due to the presence of a multitude of other factors that affect water quality.

In performing the analyses of variance for primary water input mechanism (as well as the regression analyses for scored water input mechanism), additional within-treatment sources of variability included salt water intrusion, the presence of a nutrient-laden marsh beneath one of the lakes, and varying baseflows (or the absence thereof) in the tributaries. Other sources include varying hydraulic retention time, the intermittent presence of extensive flocks of waterfowl, and varying degrees of wastewater management. These varying levels of wastewater management focus on sewered areas, as well as, areas afflicted by failing on-site disposal systems and small point sources. Even in sewered areas, subtle or overt interconnections can develop between combined or sanitary sewers, and lakes or ponds. These interconnections can be direct or indirect via storm sewers. Past examples of such interconnections include Martling's Pond (sewer break), Rattlesnake Creek (direct interconnection between a combined sewer and the portion of the Creek placed in a culvert), Conselea's Pond (suspected leakage), McLean Avenue, Yonkers (interconnections between storm and sanitary sewers, and direct sanitary connections between apartment houses and storm sewers resulting in sanitary discharges to Tibbetts Brook (tributary to Van Cortlandt Lake)).

Additional sample replication would have allowed for better definition of average conditions and variability at each lake, a better understanding of water quality relative to weather conditions, and more degrees of freedom (and lower variance) in statistical analyses. However, it should be noted that the dissertation proposal indicates that the data collected in this study will be considered along with data gathered in other efforts, and subsequent comparisons (Section 6.2) do not indicate major differences between the data collected in this study and the data collected in surveys conducted by others. As noted in Section 4.2, resource and logistical limitations severely restricted the within-season collection of spatial and temporal replicate samples, a truly important element of good experimental design (Herricks 1998). It may have been more appropriate to visit each lake four or five times during each season while reducing the number of lakes visited in order to assess “normal” conditions at a lake or to overcome the impact of a faulty single seasonal sample. However, since one purpose of this exercise was to assess the impact of water input mechanism, and to assess the extent of variability within each of the three input mechanisms (groundwater, municipal water and surface tributary), three lakes in each category was considered a minimum. The resource and logistical limitations also foreclosed the possibility of performing measurements and collecting samples at predetermined times relative to substantial rainfall events.

In highly productive urban lakes such as most of those in our nine lake sample, an ideal sampling program would involve collecting samples over a diel cycle, which includes the lighted portion of the day (diurnal) and unlighted (nocturnal) portion. Generally, the parameters that would vary with the diel cycle would include dissolved oxygen, carbon

dioxide, pH, temperature and nutrients, depending on depth, season, latitude and trophic state. During those portions of the daylight hours, when solar energy is most intense, algae produce such large quantities of oxygen near the water surface while conducting photosynthesis, that the upper portion of the water column becomes extremely supersaturated in oxygen (to values of 250 percent in some tropical lakes). Concurrently, free carbon dioxide, which is consumed in photosynthesis, is drastically reduced and closely related pH is elevated. During nocturnal hours, photosynthesis ceases and plant and invertebrate respiration, along with bacterial decomposition of organic matter reduces oxygen concentrations and increases carbon dioxide concentrations (which has an inverse relation to oxygen). In an extreme example of this diel variation, sewage oxidation ponds, can reach supersaturated oxygen levels during the daytime and zero at night.

Photosynthesis in productive water is directly affected by solar energy availability. This fact has been used to model photosynthesis, using only solar energy intensity and chlorophyll concentration. (Horne and Goldman 1994) Enough is now known about the diel variations in productive lakes so that in most cases, only diurnal samples need be taken to fairly comprehensively characterize a particular lake. Additionally, sampling programs identified in Appendix G (pages 9 and 10) and other lake sampling programs discussed subsequently in Section 6.2 generally did not involve nocturnal sampling.

A major project limitation turned out to be the high method detection limit utilized by the outside laboratory for nutrients. About 30 percent of the total phosphorus results were reported as being less than 0.1 mg/l (in the Carlson Trophic State Index System 0.1 mg/l falls in the hypereutrophic range), requiring that chlorophyll *a* and secchi depth alone

be used to assess trophic state. Fortunately, the Carlson response models independently relate each of these three parameters to Trophic State Index, and to each other. (North American Lake Management Society 1988) It is also fortunate (for this study) that most of the lakes are indeed hypereutrophic, thereby rendering about 70 percent of the total phosphorus data (which consisted of readings at or in excess of 0.1 mg/l) useful.

Another problem with regard to laboratory communication involved the water quality variable color. True color should have been reported in order to validate the use of the Carlson Trophic Index Models but unfortunately, it was apparent color that was reported. Apparent color includes suspended matter and can, therefore, be substantially higher in value than true color. As discussed earlier in this chapter, the high values of color obtained in this project closely tracked the high values of chlorophyll *a* and obviously included fine suspended algae.

In retrospect, the list of water quality parameters should have included alkalinity (or acid neutralizing capacity). Also, in view of increasing use impairments in New York State lakes which are associated with nuisance aquatic weeds, perhaps this study should have included a macrophyte survey at each lake. However, such a survey would have required talent that was unavailable for the current ambient monitoring program.

CHAPTER 6

DISCUSSION

6.1 - Conditions of the Lakes

Based on Carlson's Trophic State Index, eight of the nine lakes chosen for detailed analyses are either eutrophic or hypereutrophic. The exception is the Richmondtown Millpond which has too short a retention time to allow for the development of substantial quantities of phytoplankton. The lakes all appear to be afflicted by severe sedimentation due to erosion in their watersheds (several of the parks have severe erosion problems (Baystate and Storch June 1984, Baystate and Storch May 1984, Dinkle et al., New York City Department of Parks and Recreation 1990)), washoff of particulate matter from impervious surfaces, streambank erosion (New York City Department of Environmental Protection February 1997), and deposition of phytoplankton subsequent to die-off. During summer conditions, decomposing organic sediments appear to be imposing a substantial oxygen demand on lower portions of the water columns at several of the lakes (while upper portions were supersaturated during daylight hours). The eutrophic conditions seem to have multiple causes including shallow depths, low flushing rates (high hydraulic retention times), and importation of substantial nutrient loads.

The severe eutrophic conditions cited above have resulted in degraded aesthetic and ecological conditions. During my visits of 1997 and 1998, the waters of all the lakes almost always had an unappealing murky gray or green color, with numerous clusters, filaments or mats of algae, either floating or neutrally buoyant. Dense growths of

submergent, floating and emergent macrophytes were almost always present. During the summer survey of 1998, Meadow Lake was experiencing a severe fishkill, and the odor of hydrogen sulfide was detected at Conselyea's Pond. NYC Parks Department officials were advised not to engage in fish stocking projects until remediation programs were implemented (American Lake & Wetland Services 1997). The occasional presence of large flocks of waterfowl undoubtedly added a nutrient burden to the lakes (Zafer 1994) and rendered the shorelines at several of the lakes aesthetically unappealing. (Revkin 1998)

The occasional elevated fecal coliform concentrations at several of the lakes were of some concern, since their presence could not always be explained. The ever decreasing unsewered areas of Staten Island have long been known for large numbers of failing on-site wastewater disposal systems (due to the presence of a surficial lens of clay in the soil horizon), and for numerous illicit small point sources (thereby explaining exceedences at Wolfe's Pond and at the Richmondtown Millpond). Exceedences at other locations are probably caused by waterfowl or urban runoff. While fecal coliform levels in these lakes should consistently be kept below 200 colonies (or most probable number (MPN)) /100ml. in order to avoid exposure of the public, unexplained exceedences are not excessive, and the health effects of elevated coliform levels in water uncontaminated by sewage (ie, separate storm runoff) are not clear. (O'Shea and Field 1992)

The relatively high pH observed at most of the lakes during the daylight hours, which was caused by the consumption of CO₂ during vigorous photosynthetic activity, probably poses a threat to aquatic fauna in that ammonia under these conditions exists in

the toxic undissociated NH_4OH form. (Horne and Goldman 1994, Matsil 1998)

However, there is some question as to whether NH_4OH truly exists in nature. These pH and temperature dependant reactions can be expressed in two forms:



Using the second equation, toxic, undissociated (free) ammonia is calculated by means of:

$$[\text{NH}_3][\text{H}^+]/[\text{NH}_4^+] = K,$$

where;

$$K = (5.7)(10^{-10}) \text{ at } 25 \text{ degrees C.}$$

and K, the equilibrium constant, varies directly with temperature in accordance with;

$$\ln K_T - \ln K_{25} = \Delta H_R / R (1/T_{25} - 1/T) \quad (\text{Drever 1988})$$

where;

K_T = equilibrium constant at any other temperature,

ΔH_R = standard enthalpy of the reaction in kilojoules/mol,

R = gas constant = 8.3143 Joules/mol degree Kelvin, and

T_{25} and T are in degrees Kelvin.

The reaction moves far to the right (toward the formation of more toxic NH_3) as temperature and pH increase. This is a significant problem in highly productive lakes during photosynthesis, when CO_2 is removed from upper portions of the water column. The calculated values of the toxic undissociated form of ammonia from the summer survey are found in table 6.1.

TABLE 6.1				
SUMMER VALUES OF TOXIC UNDISSOCIATED AMMONIA				
LAKE	TEMPERATURE DEGREES C	pH	AMMONIA NITROGEN mg/l	FREE AMMONIA mg/l
Wolfe's Pond	26.8	7.72	0.14	0.0038
Richmondtown Millpond	20.8	7.18	0.20	0.0012
Harlem Meer	25.8	9.77	0.28	0.20
Van Cortlandt Lake	26.9	9.47	0.42	0.24
Prospect Lake	26.1	10.22	0.14	0.12
Conselyea's Pond	32.5	7.69	0.10	0.0038
Oakland Lake	25.7	7.64	0.10	0.0023
Kissena Lake	27.3	10.44	0.10	0.092
Meadow Lake	28.4	10.07	0.42	0.38

Even in the absence of global warming, the ever increasing impact of the urban heat island effect as urban sprawl continues, will likely result ever warmer shallow urban lakes with ever higher levels of toxic free ammonia. A mitigating effect in New York City is that most lakes and ponds are partially or totally surrounded by parkland or other types of undeveloped land which tend to have far cooler microclimates (as the result of evapotranspiration) than do the surrounding urban areas. (Henderson-Sellers and Robinson 1986) NASA's recent Urban Heat Island Pilot Project, using an Airborne Thermal/Visible Land Application (ATLAS) Sensor, which sees in six visible light channels, two near infrared channels and six in the thermal infrared band, has indicated

that urban temperatures are rising faster than are the planetary temperatures (rooftops and other structures are reaching temperatures of 160 degrees F in Salt lake City, while vegetation is between 85 and 97 degrees F near celestial noon in July). (National Aeronautics and Space Administration 1998)

A general relation between city size and heat island intensity is as follows:

$$T (\text{urban} - \text{rural}) = P \log p \text{ (Henderson-Sellers and Robinson 1989)}$$

where:

p = population, and

P is a constant of proportionality, which differs between European and North American Cities

The Urban Heat Island Effect is believed to result from:

- 1 - Decreased loss of sensible heat due a to reduction of wind speed in the canopy;
- 2 - Decreased evaporation (loss of latent heat flux) due to removal of vegetation
(the surface of the city has been “waterproofed”);
- 3 - Anthropogenic heat from building sides;
- 4 - Greater daytime heat storage due to the thermal properties of urban materials
and its nocturnal release;
- 5 - Increased counter radiation due to absorption of outgoing long wave radiation
and re-emission by the polluted urban atmosphere;
- 6 - Decreased net longwave radiation loss from canyons (tall buildings and narrow
sidewalks) due to reductions in their sky view factors by buildings (a
smooth surface radiates more than does a rough surface);

7 - Heating of the canopy by exhausts. (Henderson-Sellers and Robinson 1989)

NASA's Urban Heat Island Pilot Project (UHIPP) has indicated that as urban sprawl increases, urban temperatures should continue rising faster than general planetary temperatures. The aforementioned NASA thermal images indicate that urban streams having vegetated shorelines appear as cool fingers penetrating the urban heat islands, whereas streams that have lost their vegetative buffers display no such cooling characteristics.

It would appear that the nine selected lakes are generally protected (in some cases to a substantial degree) from the more severe effects of urban runoff (such as high importation of substances such as metals, oils and floatables) by being partially or totally surrounded by parkland. While this buffer system is penetrated to varying degrees at most of the lakes (and more frequently along tributaries) by storm sewers draining adjacent streets and park roads, the effect of this buffer appears to render the watersheds far less urban (in terms of water quality impacts) than would normally be the case in such densely developed locations. Nevertheless, this system of parkland buffers did not prevent the importation of limiting nutrients in amounts capable of rendering the lakes highly productive.

It is the writer's observation that maintenance of the lakes, while better than during the City's fiscal crisis of the 1970s, still leaves room for improvement. Ecology-altering saltwater intrusion into Conselyea's Pond and Meadow Lake might be reduced or eliminated by repairing the outlet works (although given the lack of baseflow in Laurelton Creek, it's possible that there may be inadequate freshwater input to keep the Pond filled

at all times). Additionally, sediment import to Van Cortlandt Lake and Conselyea's Pond could be reduced by maintaining (dredging and cleaning) the upstream Henry Hudson Lagoons and unnamed impoundments along Laurelton Creek, respectively. However, aquatic weed harvesting has rendered some of the flagship lakes minimally aesthetically adequate to support designated uses such as passive shoreline recreation, sport fishing and boating.

A toxicity condition (detected by the aforementioned Microtox Test) of unknown origin and nature was observed at the Richmondtown Millpond during the summer survey of 1998 (nothing obvious was revealed by the other data gathered at this site during the summer survey). This observation requires further investigation, including a priority pollutant scan followed by a field survey.

6.2 - Sampling Data Collected in Other Studies

In 1987, the Natural Resources Unit of the New York City Department of Parks and Recreation conducted a limnological survey of six lakes located within New York City parks. The results of this survey, based on monthly samples collected at a depth of one foot between May 8 and October 28 (sampling began at Prospect Lake on June 24) are displayed in Table 6.2.

TABLE 6.2							
LIMNOLOGICAL SURVEY OF NEW YORK CITY LAKES AND PONDS							
Lake	pH	Alkalinity (mg/l as CaCO ₃)	Ammonia (mg/l)	Nitrite (mg/l)	Nitrate (mg/l)	Orthophosphate (mg/l)	Chlorophyll a (ug/l)
Harlem Meer			0.13			0.071	
Prospect Lake	7.0-8.9	< 60	0.06 - 0.13	0.004 - 0.010	0.10 - 0.50	0.026 - 0.090 avg = 0.056	14.6 - 111.4 avg = 49.09
Kissena Lake	6.8-7.5	< 60	0.04 - 0.16	0.003 - 0.006	0.00? - 0.13	0.026 - 0.090 avg = 0.065	3.0 - 11.8 avg = 5.99
Oakland Lake	7.0-9.5	>60, <100	0.09 - 1.05	0.002 - 0.037	0.10 - 0.20	0.010 - 0.054 avg = 0.037	26.5 - 108.8 avg = 71.35
Van Cortlandt Lake	7.0-8.9	> 60	0.00? - 0.42	0.015 - 0.068	0.20 - 0.90	0.057 - 0.490 avg = 0.214	21.1 - 141.8 avg = 76.5

Additional data for Prospect and Van Cortlandt Lakes are as follows:

LIMNOLOGICAL SURVEY OF NEW YORK CITY LAKES AND PONDS						
(continued)						
Lake	BOD (mg/l)	Total Coliform (MPN/100ml)	Fecal Coliform (MPN/100ml)	Secchi Transparency (ft)	Total Suspended Solids (mg/l)	Total Dissolved Solids (mg/l)
Prospect Lake	4.4	421	154	3.6	10.9	86.5
Van Cortlandt Lake	7.5	210	429	1.9	19.8	439.7

(From New York City Department of Parks and Recreation 1990)

The Bluebelt Study, which is being conducted for the New York City Department of Environmental Protection by a consortium of consultants, gathered both wet and dry weather sampling data near the inlet to Wolfe's Pond and near the outlet of the

Richmondtown Millpond (among many other locations in southwestern Staten Island) for the purpose of calibrating the AESOP water quality model, as developed by the USEPA.

The data (6 to 8 samples for each location, including both wet and dry periods), which had to be picked off a series of plots wherein sampling data is superimposed on values calculated by the model, are displayed in Table 6.3.

TABLE 6.3				
BLUEBELT WATER QUALITY DATA				
	Wolfe's Pond		Richmondtown Millpond	
Water Quality Parameter	Wet Weather	Dry Weather	Wet Weather	Dry Weather
Fecal Coliform (MPN/100ml)	1.1x10 ¹ (fall) - 7x10 ⁴ (summer)	1.8x10 ² (spring) - 4x10 ⁴ (summer)	1.0x10 ¹ (fall) - 7.0x10 ³ (fall)	1.2x10 ³ (spring)
BOD₅ (mg/l)	7 (fall) - 10 (summer)	6 (spring) - 14 (summer)	1.7 (spring) - 8.0 (fall)	1.7 (spring) - 14.0 (fall)
Dissolved Oxygen (mg/l)	5 (summer) - 9 (fall)	2 (summer) - 10 (fall)	4.0 (fall) - 5.1 (fall)	3.2 (fall) - 3.7 (fall)
NH₃ (mg/l as N)	0.2 (fall) - 1.1 (summer)	0.3 (spring) - 1.1 (summer)	0.4 (fall) - 0.6 (fall)	0.3 (spring) - 1.4 (fall)
NO₂ + NO₃ (mg/l as N)	0.5 (summer) - 0.6 (summer and fall)	0.2 (all seasons)	0.6 (fall) - 1.6 (fall)	0.8 (spring) - 1.3 (fall)
Total Nitrogen (mg/l as N)	1.6 (fall) - 2.6 (summer)	1.6 (spring) - 3.0 (summer)	1.7 (spring) - 2.4 (fall)	1.8 (spring) - 5.8 (fall)
Orthophosphate (mg/l as P)	0.00 (summer) - 0.28 (summer)	0.38 (summer)	0.11 (spring) - 0.48 (fall)	0.19 (spring) - 0.82 (fall)
Total Phosphorus (mg/l as P)	0.2 (fall) - 1.1 (summer)	0.2 (spring) - 0.6 (summer)	0.3 (spring) - 2.8 (fall)	0.3 (spring) - 3.5 (fall)

(From New York City Department of Environmental Protection April 1999 and New York City Department of Environmental Protection February 1997)

There do not appear to be any obvious differences between the dry and wet weather data. If anything, the dry weather values tend to be slightly elevated, with rainfall tending to slightly dilute the known dry weather sources (failing septs and illicit sanitary discharges) in these two drainage areas. This is tending to mask any scouring of deposited contaminants from the land surface and from drainage conduits by runoff (first flush).

As part of a program to correct water quality problems in the lakes in Flushing Meadow Park, the consultant for the New York City Department of Environmental Protection, Lawler, Matusky and Skelly Engineers, sampled the water column at several points in Willow and Meadow Lakes in 1985. Table 6.4 only displays the data collected at station MLS (the closest station to the writer's sampling station).

TABLE 6.4			
MEADOW LAKE SURVEY			
Parameter	May 28, 1985 5:15PM	August 15, 1985 2:10 PM	September 19, 1985 1:15 PM
Sample Depth (ft)	2	3	3
DO (mg/l)	18.4	12.9	13.7
Temp (deg C)	21.0	28.0	21.6
Specific Conductance (umhos/cm)	8500	4900	4500
pH		8.9	9.3
BOD ₅ (mg/l)	15.3	>24.7	12.0
Suspended Solids (mg/l)	43.1	29.3	26.6
Total Coliform (#/100ml)	600	300	1000

TABLE 6.4 (Continued)			
MEADOW LAKE SURVEY			
Ammonia (mg/l)	0.44	2.43	1.15
NO ₂ NO ₃	1.80	0.13	<0.05
Chlorophyll <u>a</u> (mg/m ³)	68.40	513.73	153.70
Orthophosphate (mg/l)	<0.01	<0.01	<0.01
Total Phosphorus (mg/l)		0.30	0.19

(From Lawler, Matusky and Skelly 1987)

In 1983 and 1984, Baystate Environmental Consultants, in cooperation with Storch Associates, as consultants to the New York City Department of Parks and Recreation, conducted extensive water quality sampling in Van Cortlandt Lake as part of a diagnostic study which was funded in part by EPA under the Clean Lakes Program (Section 314) of the Federal Clean Water Act. Part of the data set, based on 16 visits, for Station 3 (the point closest to the writer's sampling station) is displayed in Table 6.5, as follows:

TABLE 6.5	
VAN CORTLANDT LAKE SURVEY (Station 3)	
Parameter	Range
Temperature (degrees C.)	1.0 - 27.9
Dissolved Oxygen (mg/l)	6.2 - 19.8
Conductivity (umhos)	440.0 - 890.0
Alkalinity (mg/l as CaCO ₃)	40.0 - 100.0

TABLE 6.5 (Continued)	
VAN CORTLANDT LAKE SURVEY (Station 3)	
pH	5.6 - 9.8
Total Phosphorus (ug/l)	51.6 - 358.5
Soluble Reactive Phosphorus (ug/l)	5.5 - 45.0
Ammonia Nitrogen (mg/l)	0.038 - 0.300
NO ₂ + NO ₃ Nitrogen (mg/l)	0.01 - 1.91
Total Kjeldahl Nitrogen (mg/l)	0.30 - 1.77
Chloride (mg/l)	90.0 - 200.0
Lead (mg/l)	-----
Cadmium (mg/l)	-----
Total Organic Carbon (mg/l)	4.2 - 15.6
Oil and Grease (mg/l)	-----
Total Suspended Solids (mg/l)	1.8 - 27.2
Chlorophyll <u>a</u> (ug/l)	2.9 - 251.1
Fecal Coliform (n/100 ml)	11.0 - 930.0

(From Baystate and Storch 1984)

As part of a Diagnostic/Feasibility Study of Prospect Lake conducted for the Prospect Park Administrative Office, and funded by the Prospect Park Alliance, the consultants (American Lake & Wetlands Services) performed water quality sampling four times during 1996 at three sites. Their Site 1 is closest to the writer's Prospect Lake sampling point, and the limited quantity of their data made available is displayed in Table 6.6, as follows:

TABLE 6.6	
PROSPECT LAKE DIAGNOSTIC/FEASIBILITY STUDY	
Parameter	Range
Temperature (degrees C)	10.0 - 25.9
pH	6.76 - 10.42
Dissolved Oxygen	1.7 - 13.1
Secchi Transparency (meters)	1.2 - bottom

(From American Lake and Wetlands Services, Inc. 1997)

Between August and December of 1996, as part of the Oakland Ravine Study, the Gaia Institute (under the direction of Dr. Julie Mankiewicz), pursuant to its contract with URS, the prime consultant to the New York City Department of Environmental Protection, performed an intensive water quality sampling program at Oakland Lake in order to develop a "Baseline Ecological Assessment." The data is not yet organized and is, therefore, considered to be raw. Ten stations (1 through 10) were created for vertical profiling for temperature, total dissolved solids, pH and dissolved oxygen, as well as for secchi transparency, while three other stations (A through C) were created for evaluation of chlorophyll a, bacterial counts (not counts as generally used in sanitary characterization of a waterway but rather, to be correlated with chlorophyll), and phytoplankton and zooplankton enumeration. Additionally, samples were collected for nutrient analyses at the three stations. At stations 1 through 10, measurements were taken at the surface and at every foot of depth, while at stations A through C, samples were collected at the surface and at depths of 3 feet, 6 feet and 9 feet (where available). The data for Stations 8 (at 1 ft of depth) and B (at the surface), the closest locations to the writer's sampling

station are displayed in Table 6.7, as follows:

TABLE 6.7 WATER QUALITY SURVEY OF OAKLAND LAKE		
<u>Parameter</u>	<u>Station</u>	<u>Range</u>
Temperature (degrees F)	8 - 1	40.5 - 80.3
pH	8 - 1	7.25 - 8.36
Total Dissolved Solids (ppm)	8 - 1	129 - 251
Dissolved Oxygen (ppm)	8 - 1	6.7 - 13.9
Secchi Transparency (ft)	8 - 1	0.5 - 7.0
Chlorophyll <u>a</u> (ug/l)	B	6 - 86
Alkalinity (mg/l as CaCO ₃)	B - 0	136 - 164
Nitrate N	B - 0	< 0.25
Nitrite N	B - 0	< 0.1
Ammonia N	B - 0	< 0.25
Orthophosphate	B	< 1.0

(From Gaia Institute 1996, 1997, 1997)

Note that the Gaia Institute had difficulties with nutrient method detection limits, as did this study (as discussed in Section 5.3).

A comparison of selected water quality data collected in this study, as compared with data gathered in the aforementioned other surveys, is displayed in Table 6.8, as follows:

TABLE 6.8						
WATER QUALITY COMPARISONS, NEWMAN VS OTHER STUDIES						
Lake	Survey	pH	Ammonia nitrogen (mg/l)	Orthophosphorus (mg/l)	Chlorophyll <i>a</i> (mg/meter ³)	Fecal coliform (#/100ml)
Wolfe's Pond	Newman	7.18 - 7.93	0.12 - 0.21	<0.10 - 0.12	13.0 - 32.3	<1 - 1800
	Bluebelt	---	0.2 - 1.1	0.00 - 0.38	-----	1.1x10 ¹ - 7x10 ⁴
Richmond-town Millpond	Newman	7.18- 7.87	0.12 - 0.20	<0.10 - 0.25	<1.0 - 3.6	<1 - TNTC
	Bluebelt	---	0.3 - 1.4	0.11 - 0.82	-----	1.0x10 ¹ - 7.0x10 ³
Harlem Meer	Newman	7.11 - 9.77	0.10 - 0.28	<0.10 - 0.13	3.8 - 11.2	<1 - 400
	NYC Parks	----	0.13	0.071	-----	-----
Van Cortlandt	Newman	7.29 - 9.47	<0.10 - 0.42	<0.10 - 0.13	1.8 - 69.6	16 - 800
	NYC Parks	7.0 - 8.9	0.00? - 0.42	0.057 - 0.490	21.1 - 141.8	429
	Baystate & Storch	5.6 - 9.8	0.038 - 0.300	0.005 - 0.045	2.9 - 251.1	11.0 - 930
Prospect	Newman	7.36 - 10.22	<0.10 - 0.28	<0.10	12.8 - 59.9	<1 - 8
	NYC Parks	7.0 - 8.9	0.06 - 0.13	0.026 - 0.090	14.6 - 111.4	154
Oakland	Newman	6.87 - 7.66	<0.10 - 3.22	<0.10	7.6 - 10.7	<1 - 68
	NYC Parks	7.0 - 9.5	0.09 - 1.05	0.010 - 0.054	25.5 - 108.8	-----
	Gaia Institute	6.17 - 8.69	<0.25	<1.0	6 - 86	-----
Kissena	Newman	7.23 - 10.44	<0.10 - 0.56	<0.10 - 0.41	22.2 - 152.8	<1 - 41

TABLE 6.8 (Continued) WATER QUALITY COMPARISONS, NEWMAN VS OTHER STUDIES						
	NYC Parks	6.8 - 7.5	0.04 - 0.16	0.026 - 0.090	3.0 - 11.8	-----
Meadow	Newman	8.66 - 10.13	0.12 - 0.42	<0.10	70.4 - 240.5	<1 - 18
	Lawler	8.9 - 9.3	0.44 - 2.43	<0.01	68.40 - 513.73	-----

With a minimal number of exceptions, the data from the various surveys are almost interchangeable, and provide similar pictures of a system of lakes which, while differing in many features, generally have poor water quality and display severe symptoms of eutrophication or hypereutrophication.

6.3 - The Influence of Weather on Sampling Results

Prior weather was noted for each sampling event in the ninth field (page 4) of the three seasonal Access Databases displayed in Appendix A1. Additionally, the writer downloaded historic climatological data, as compiled by the National Oceanographic and Atmospheric Administration's National Climatic Data Center for November 1997, December 1997, May, 1998, June 1998, July 1998, and August 1998, which may be found in Appendix A2. It should be noted that the field sampling conducted under this study was scheduled as follows (based on staff, laboratory and canoe availability):

Fall Survey	1 - Nov. 10, 1997	(Wolfe's Pond and Richmondtown Millpond)
	2 - Nov. 12, 1997	(Harlem Meer and Van Cortlandt Lake)
	3 - Nov. 25, 1997	(Prospect Lake and Conselyea's Pond)

	4 - Dec. 4, 1997	(Oakland Lake, Kissena Lake and Meadow Lake)
Spring Survey	1 - May 26, 1998	(Wolfe's Pond and Richmondtown Millpond)
	2 - June 4, 1998	(Harlem Meer and Van Cortlandt Lake)
	3 - June 8, 1998	(Prospect Lake and Conselyea's Pond)
	4 - June 9, 1998	(Oakland Lake, Kissena Lake and Meadow Lake)
Summer Survey	1 - July 29, 1998	(Wolfe's Pond and Richmondtown Millpond)
	2 - Aug. 3, 1998	(Harlem Meer and Van Cortlandt Lake)
	3 - Aug. 5, 1998	(Prospect Lake and Conselyea's Pond)
	4 - Aug. 10, 1998	(Oakland Lake, Kissena Lake and Meadow Lake)

This means that the aforementioned monthly climatological data provides all relevant weather information for at least one week prior to each sampling event.

The Bluebelt Program considers any samples taken after at least three consecutive dry days to be a dry weather sample. We will consider any rain in excess of 0.03 inches during the three days preceding a sampling event (along with the day of sampling if an adequate amount of rain occurred that day prior to the actual sampling activity) to cause a sample to be considered a wet weather sample. Under this definition, the following of the aforementioned sampling events are considered wet weather events: Nov. 10, 1997, Nov. 12, 1997, Nov. 25, 1997, Dec. 4, 1997, May 26, 1998, June 4, 1998 and Aug. 3, 1998. In reality, over 0.1 inch of rain fell during the three days prior to each of the identified wet

weather events.

As indicated in Chapter 4, our primary surrogate for urban runoff is the metals group. It was also intended that turbidity was to be a surrogate for the impact of this phenomenon, but turbidity is often caused by high algal densities rather than the light fraction of sediment input to our lakes. In order to assess the impact of urban runoff on the lakes, dry weather concentrations of the metals are compared with wet weather concentrations in Table 6.9. It should be noted that since the cadmium concentrations are always less than 1 ug/l, they are not included. Also, since the second visit of each seasonal survey (Harlem Meer and Van Cortlandt Lake) always yielded wet weather samples, these sites are not included. Wet weather and dry weather samples were each averaged at each lake, and the raw metals data may be found in fields 26, 27 and 28 in the three seasonal databases that make up Appendix A1 or in the laboratory data sheets at the end of Appendix G.

TABLE 6.9 COMPARISON OF THE INFLUENCE OF WET AND DRY WEATHER ON METALS CONCENTRATIONS						
	WET WEATHER			DRY WEATHER		
Lake	Pb (ug/l)	Cu (ug/l)	Zn (ug/l)	Pb (ug/l)	Cu (ug/l)	Zn (ug/l)
Wolfe's Pond	6.8	6.0	4.6	11.4	1.8	3.4
Richmond - town Millpond	8.9	12.0	7.3	8.5	5.4	9.1
Prospect Lake	8.2	2.0	12.0	9.3	1.0	1.8

TABLE 6.9 (Continued) COMPARISON OF THE INFLUENCE OF WET AND DRY WEATHER ON METALS CONCENTRATIONS						
Conselyea's Pond	7.3	1.7	9.6	<1.0	7.3	15.5
Oakland Lake	<1.0	<1.0	1.0	5.0	3.4	2.8
Kissena Lake	1.6	<1.0	1.3	3.0	7.4	1.4
Meadow Lake	8.8	1.8	2.2	11.6	4.8	2.0

These results are totally contrary to expectation. It was anticipated that antecedent rainfall would induce metal-enriched urban runoff to elevate metals concentrations in the lakes. Yet with a few notable exceptions (such as copper at Wolfe's Pond and at the Richmondtown Millpond, zinc at Prospect Lake, and lead at Conselyea's Pond), the dry weather concentrations tend to be greater than the wet weather concentrations. Possible explanations include:

- 1 - Inadequate sample replication;
- 2 - Buffering of the lakes by parklands; or
- 3 - The fact that total (unfiltered) metals concentrations were reported by the laboratory, and the portion of the metals loading associated with particulate matter rapidly settled to the bottom after the storm event and escaped detection. This means that the storm event may have functioned as a dilution phenomenon rather than as a concentration phenomenon with regard to what the sampling activity "saw." Direct sampling of the runoff,

rather than of the lake water column, might have yielded a completely different picture.

6.4 - Responses to Classification Systems

In suggesting the three classification systems assessed in this study, it was hoped that they would possess both an intrinsic value for use in the science of limnology and a quantitative relationship with water quality. It was anticipated that the classification system having the best quantitative association with water quality would be the “Degree of Urbanization System,” since relationships between several general land uses and pollutant export have already been developed (American Water Works Association Research Foundation 1991, Feth 1973, Novotny 1995, Novotny 1992, Pitt 1992, Pitt and Field 1990, Pitt and McLean 1992, Pitt et al. 1993, Schueler 1987, Schueler 1990). It was further anticipated that the “Degree of Urbanization System” would be closely followed by the “Water Input Mechanism System” since these input mechanisms possess varying degrees of protection against pollutants (e.g., impoundments would be subjected to pollutant inputs to their urban tributaries from urban runoff, compounded by loss of vegetative buffer strips resulting from “stream improvements”; groundwater seepage would be somewhat more protected by the filtering action of soils; and municipal water supplies would offer the most protection against pollutants since this water would be obliged to meet rigorous quality standards). Finally, it was expected that water quality would be least sensitive to the “Degree of Artificiality Classification System,” since only a few components of this system such as deepening a lake or adding additional sources of

water can be considered to have a direct effect on water quality.

By developing quantitative scales for each of the classification systems, and scoring each lake in accordance with those scales and with suggested (and ever more refined) protocols, it was hoped that quantitative responses of selected water quality variables to the classification system scores could be established. Unfortunately, this study was not able to develop statistically valid relationships. As discussed in sections 5.2 and 5.3, seasonal analyses of variance (with lakes as the experimental units, unscored water input mechanisms as the treatments, and 11 different water quality variables as the measured responses) revealed no significant differences between any of the treatments (water input mechanisms) at the 95% level of significance. Furthermore, the seasonal regression analyses revealed only a small number of regression curves having correlation coefficients with values above 0.5 (See Table 6.10). While a close quantitative response of numerous water quality parameters to proposed classification system scores has not been established by studying the nine lakes utilized within this project, the results of the seasonal regression analyses are such that they suggest that with somewhat more

TABLE 6.10 REGRESSIONS WITH $r > 0.5$ WATER QUALITY VARIABLE VS CLASSIFICATION SCORE			
WQ Variable vs Classification Score	Season	Best Relationship	r
Carlson Trophic Index vs Degree of Urbanization	Fall	hyperbolic	0.592
Fecal Coliform vs Degree of Urbanization	Fall	hyperbolic	0.859
Copper vs Degree of Artificiality	Fall	hyperbolic	0.524
Lead vs Degree of Artificiality	Fall	hyperbolic	-0.850

TABLE 6.10 (Continued) REGRESSIONS WITH $r > 0.5$ WATER QUALITY VARIABLE VS CLASSIFICATION SCORE			
Zinc vs Degree of Artificiality	Fall	hyperbolic	0.730
Fecal Coliform vs Water Input Mechanism	Fall	hyperbolic	0.536
Hardness vs Water Input Mechanism	Fall	hyperbolic	0.911
pH vs Water Input Mechanism	Fall	hyperbolic	0.710
pH vs Degree of Urbanization	Spring	hyperbolic	0.626
Turbidity vs Degree of Artificiality	Spring	hyperbolic	0.691
pH vs Degree of Artificiality	Spring	hyperbolic	-0.531
Lead vs Water Input Mechanism	Spring	hyperbolic	-0.847
Zinc vs Water Input Mechanism	Spring	hyperbolic	0.914
Fecal Coliform vs Water Input Mechanism	Spring	hyperbolic	0.939
Hardness vs Water Input Mechanism	Spring	hyperbolic	0.797
pH vs Water Input Mechanism	Spring	Linear	0.719
Lead vs Degree of Urbanization	Summer	hyperbolic	0.862
pH vs Degree of Urbanization	Summer	hyperbolic	0.540
Turbidity vs Degree of Artificiality	Summer	hyperbolic	0.682
Fecal Coliform vs Degree of Artificiality	Summer	hyperbolic	0.728
pH vs Degree of Artificiality	Summer	linear	0.508
Copper vs Water Input Mechanism	Summer	hyperbolic	0.595
Zinc vs Water Input Mechanism	Summer	Logarithmic	-0.543
pH vs Water Input Mechanism	Summer	Linear	0.732
Hardness vs Water Input Mechanism	Summer	Hyperbolic	0.859

refinement in establishing the classification scales and in scoring the particular lakes and ponds, statistically valid quantitative responses of urban lake water quality variables to the proposed classification system scores can be established (at least for water input

mechanism and degree of urbanization). Such refinements would include more precisely accounting for parkland buffering, eliminating or controlling for sources of variance such as salt water intrusion, lack of baseflow in tributaries, varying quality and quantity of urban, suburban and parkland runoff, nutrient-laden marshland underlying an excavated lake, varying proportions of water input mechanisms at each lake, and varying lake morphometry.

Additionally, the database must be drastically expanded to provide far more degrees of freedom. This could be accomplished by sampling each lake at least five times each season and occupying two to three locations during each visit to establish average conditions and variability at each lake. Furthermore, the number of lakes sampled in each primary water input mechanism should be increased to about nine or ten, and detailed water budgets should be established for each lake. Finally, sampling should be planned to take place both immediately after wet weather and after substantial antecedent dry weather.

CHAPTER 7

SUGGESTED REMEDIAL ACTIONS

7.1 - Ongoing Efforts

Several of the nine lakes studied within this project have previously been or are currently being evaluated by the New York City Departments of Environmental Protection, and Parks and Recreation and their consultants for the purpose of developing corrective action programs. These include Wolfe's Pond, the Richmondtown Millpond, Van Cortlandt Lake, Prospect Lake, Oakland Lake, and Meadow Lake.

Wolfe's Pond and the Richmondtown Millpond have been evaluated within the Department of Environmental Protection's Bluebelt Program, a watershed level facility planning effort designed to manage stormwater and wastewater in the southwestern, relatively undeveloped portion of Staten Island. The objectives of this effort are to avoid the usual New York City practice of imposing a gridiron street pattern (along with associated utilities (water mains, storm sewers, sanitary sewers, etc.)) on the existing topography and drainage patterns, and to utilize existing waterways and wetlands to the maximum extent possible for stormwater management. Concurrent objectives include the elimination of flooding, erosion and sedimentation, loss of wetlands and other habitats, and pollution resulting from failing on-site disposal systems, uncontrolled point sources, improper cross-connections, and poorly functioning package (temporary) wastewater treatment plants serving private, commercial and institutional facilities. This is all to be accomplished by providing best management practices for stormwater management, and a

well planned sanitary sewer system (the necessary intercepting sewer system, which must function as the spine for this sanitary collection system, was completed in 1993).

The Wolfe's Pond Plan calls for the completion of the sanitary sewer system by installing about five miles of conduit to accommodate current and projected flows, and the use of best management practices (BMPs) to treat stormwater (to remove pollutants and to attenuate flow) at the points where it is discharged to natural waterways. A shallow marsh wetland will be installed at one discharge point, and a high and low marsh will be constructed at the other. Both will be preceded by stilling basins (which will allow for sediment and debris removal). A third BMP involves stabilizing the outlet works at the pond, which has been partially breached. Additionally, tributary streambanks are to be stabilized with rock toe planting, and boulder clusters will be installed in the stream beds to reduce velocities. (New York City Department of Environmental Protection April 1999)

The Richmond Creek Plan (which includes the Richmondtown Millpond) recommends completion of the sanitary sewer system in the drainage area to accommodate present and projected flows with about ten miles of conduit. BMPs will be installed at all points of storm water entry (via storm drains) into the natural waterways. These BMPs include stilling basins, wetland creation (the ability of wetlands to remove biochemical oxygen demand, suspended solids, nutrients, and metals from aqueous flows is well known (Reimold and McBrien 1997, National Small Flows Clearinghouse 1998, Boutista and Geiger 1993, Carter 1996)), wetland enhancement, a sand filter, and an extended detention pond (that is controversial because it will cause the loss of some

mature trees which are intolerant of extended saturation periods) with an associated wetland system. The plan also recommends stream stabilization using such bioengineering techniques as branch packings and brush mattresses to prevent erosion and sedimentation, and several culvert enlargements to pass larger storm flows through the system without causing flooding. Finally, the Millpond will be dredged to historic depths; the overflow weir will be replaced and lengthened; and the shoreline will be planted with native wetland flora to discourage human passage and the presence of feeding waterfowl, thereby minimizing erosion and insults to water quality. (New York City Department of Environmental Protection February 1997, New York City Department of Environmental Protection March 1997)

Diagnostic and feasibility studies on Van Cortlandt Lake, which were performed for the Department of Parks and Recreation, indicate that 90 percent of phosphorus in the lake must be removed to shift its trophic state from hypereutrophic to mesotrophic. To accomplish this goal, both in-lake and watershed management approaches were proposed. (Baystate and Storch June 1984, Baystate and Storch May 1984) The watershed management recommendations include diversion of highway drainage around the lake to avoid shock loads of toxics and sediment (which are causing severe shoaling), control of erosion within Van Cortlandt Park, reconstruction and expansion of the lagoon system upstream of the Lake to more effectively remove sediment and associated phosphorus (which is currently being scoured into the lake), dredging and stabilization of Tibbetts Brook, removal of a salt pile and improperly stored hazardous materials from a nearby maintenance yard, and removal of macrolitter such as abandoned automobiles, TV sets

and washing machines strewn about the park landscape (this condition has improved since the feasibility report was drafted). The in-lake remedial recommendations include dredging of the lake to remove organic sediment and to restore additional open water, and the use of weed harvesting and nutrient inactivation (utilizing a chemical such as alum) as maintenance measures subsequent to dredging.

The Diagnostic/Feasibility Study Report for Prospect Lake (American Lake and Wetlands Services Inc. 1997) also recommends the implementation of a series of in-lake and watershed measures to reverse the hypereutrophic state of the Lake. The in-lake techniques include water level drawdown, sediment removal (dredging), and aquatic weed harvesting to address symptoms of high productivity and to restore favorable habitat, while the proposed watershed measure involves treatment of lake inflows to remove up to 99 percent of incoming phosphorus using dissolved air flotation.

At Oakland Lake, problems include deteriorated water quality in the Lake and in nearby Alley Creek, high rates of combined sewer overflow (CSO) into Alley Creek, sewer system flooding along nearby streets, erosion in Oakland Ravine (adjacent to Oakland Lake), reduction of water available in Oakland Ravine to support ecosystems because of the alteration of surrounding areas resulting from development, and severe sediment accumulation in Oakland Lake. To address these problems, the New York City Department of Environmental Protection's consultant (URS Griener) has recommended diversion of stormwater (in one case before it reaches the combined sewer system) to Oakland Ravine for treatment using plunge pools with rock cascades for energy dissipation, rock check dams with rock channels for velocity attenuation and habitat

improvement, pools for collecting sediment, floatables, oil and debris, creation or restoration of wetlands for stormwater treatment, and planting and to stabilize ravine and park slopes. (Dinkle et al. 1998)

In the face of a perceived overwhelming source of phosphorus (groundwater seeping into Meadow Lake (and adjacent Willow Lake) through the underlying tidal marsh) and a perceived inadequate arsenal of remedial tools, NYCDEP's consultants have recommended a minimal control program. This program includes no action to control the severe algal problem and the use of herbicides to control aquatic macrophytes. (Lawler, Matusky & Skelly 1987)

It should be noted that the Oakland and Meadow Lakes Studies were ancillary to the East River and Flushing Bay Combined Sewer Overflow Abatement Projects, respectively.

7.2 - Recommended Additional Efforts

Eutrophication tends to intensify as a lake becomes more shallow and as its hydraulic residence time decreases (for a given phosphorus loading, a lake with a long residence time can accommodate the loading without adverse impacts better than a lake with one that is shorter (New York Federation of Lake Associations and Department of Environmental Conservation 1990, North American Lake Management Association 1988)). However, lakes with longer residence time have more opportunity for water-sediment reactions, and lakes with very short residence times (one to two weeks) don't allow for adequate time for algae to respond to incoming nutrient supply.

Dredging an urban lake may be expensive but it provides several benefits. These include rendering the lake less prone to eutrophication, extending the life of the lake (all lakes are subject to some rate of sedimentation which eventually leads to their extinction), and removing the source of sediment oxygen demand (SOD) and toxics. Dredging also removes the primary source of phosphorus (contained in decomposing organic matter, sorbed onto inorganic sediment materials such as ferric hydroxide, and contained in inorganic compounds such as ferric phosphate) which is recycled back into the water column during reducing (hypoxic or anoxic) conditions at the water-sediment interface. However, dredging will not have a lasting effect unless it is accompanied by an intense program of erosion control in the watershed. Almost all the nine lakes selected in this project for detailed study have erosion problems in their watersheds, and/or in the beds and/or banks of their tributary streams. In situ capping or treatment (such as sediment phosphorus inactivation using hypolimnion aluminum salt injection (Environmental Protection Agency 1995) can prevent the release of toxics and phosphorus, (Hartig et al. 1999) and the exertion of SOD, but it would do little to void the problems associated with very shallow depths, and it would not have the same impact as dredging with regard to extending the life of the lake.

The concept of flow augmentation to wash out algal cells, to reduce the time of water sediment contact and to dilute phosphorus concentrations has been used elsewhere (Zafer et al. 1994) and can be effective. However, the use of City water for this purpose is only being considered herein because most of the lakes and ponds under study are relatively small, and because the use of the municipal supply as the primary source of

water for some of New York City's lakes is already being practiced. It runs counter to the concept of not wasting a higher quality resource (water supply) to enhance lower priority uses (secondary contact recreation, aesthetics, and improvement of a degraded ecological system). (Baystate and Storch May 1984) Additionally, given the history of a high level of demand on the New York City water supply (prior to the reductions brought about by the imposition of recent conservation measures such as sonic leak detection, universal metering, water audits, plumbing inspections, and magnetic hydrant locking) relative to the safe yield of the system (1290 million gallons per day), increased use of the water supply for these lakes is questionable. Furthermore, the addition of orthophosphates to the water supply to render it less aggressive toward the distribution system, service connections and plumbing systems adds a requirement of phosphate removal before it can be used for flow augmentation in the lakes. (Matsil 1994, American Lake and Wetlands Services Inc. 1997) The writer would be very reluctant to recommend use of City water for flow augmentation.

Flow augmentation alternatives include the use of well water and the recycling of lake water. The use of groundwater would have to be examined in the context of the possible induction of saltwater intrusion into the aquifer system, and the possibility of introducing groundwater high in phosphorus to the lake, as was the case at Prospect Lake. (American Lake & Wetlands Services Inc. 1997) Costs for recycling lake water are high (Lawler, Matusky & Skelly Engineers 1987) but may be worthwhile in some cases if a major shift in trophic level can be achieved. Two stage filtration, with alum or ferric chloride coagulation is a proven treatment technology for this purpose.

Since runoff from impervious urban surfaces of various kinds contributes a wide variety of pollutants to urban waterways (Novotny 1995, Novotny 1992, Novotny 1991, Pitt and Field 1990, Pitt et al. 1993, Schueler 1987, Schueler 1990, Palmer et al. 1984), such flows should be diverted around urban lakes. Alternatively, they should be provided with treatment or with the application of best management practices designed to remove nutrients, sediment, metals, oil, and debris.

Nearly all the selected lakes suffer from severe soil erosion in their watersheds, primarily as the result of over-utilization of this land by the huge population of New York City, leading to excessive sedimentation and rapid eutrophication caused by the sediment and the associated nutrients. It would appear that some form of bioretention (Murfee, Scaief and Whelan 1997) or other vegetative buffer (Christen 1998) should be provided around the lakes, along their tributaries, and at any inlets to conduits draining to the lakes.

Given the foregoing, the following measures are suggested as part of this study for remediating the nine lakes selected for detailed study:

1- Wolfe's Pond

The Bluebelt recommendations should be implemented and the Pond should be dredged. If these measures do not shift the trophic condition of the Pond to the mesotrophic range, flow augmentation designed to wash out algal cells, to reduce time of water-sediment contact, and to dilute phosphorus concentrations (Zafer et al. September 1994), using either well water or recycled lake water should be considered. Recycled lake water should be treated to remove solids and phosphorus.

2- Richmondtown Millpond

No recommendations are advanced beyond those included in the Bluebelt Plan.

That plan should successfully eliminate water quality and sedimentation problems in the Millpond.

3- Harlem Meer

Substantially improve erosion control in the watershed through planting, slope stabilization and maintenance of these measures. Dredge the Meer and divert storm runoff from park roads around the Meer. If these measures are inadequate to shift the trophic state of the Meer to the mesotrophic range, provide flow augmentation by recycling the water in the Meer at a high rate, with enhanced treatment (Zafer et al. September 1994) so as not to place an increased hydraulic burden on the municipal water supply system, or on the wastewater collection and treatment system. Consider in situ phosphorus deactivation with alum as an alternative to removal of phosphorus from water supply inputs.

4- Van Cortlandt Lake

The Diagnostic and Feasibility Reports submitted by Baystate Environmental Consultants Inc. and Storch Associates to the NYC Department of Parks and Recreation is ambitious and should succeed in moving the trophic state of the Lake to the mesotrophic range (and should also move its contour configuration back to that of 1877. The writer strongly supports this approach and offers no additional recommendations. It should be noted, however, that elements of the State Department of Environmental Conservation have objected to the loss of marshland

(formed by neglect) in exchange for the gain in open water (strongly favored by the writer) that these recommendations will bring about.

5- Prospect Lake

The Diagnostic/Feasibility Study Final Report recommendations should be implemented. Additionally, road drainage should be diverted away from the Lake and a vigorous erosion control program consisting of planting and slope stabilization should be implemented in the watershed. The Report's goal of 99% removal of phosphorus from lake water inputs is extremely ambitious. If these measures fail to reverse the trophic state of the Lake back to the mesotrophic range, one should consider flow augmentation, to be accomplished by means of recycling lake water.

6 - Conselyea's Pond

The Pond outlet works should be repaired in order to eliminate saltwater intrusion. Also, municipal water or, preferably, pumped groundwater should be provided to restore baseflow to Laurelton Creek. Eventually, the Brooklyn/Queens Aquifer system should be properly managed to provide a supplementary municipal water supply, and to provide baseflow in currently ephemeral streams (where any remain), while precluding both subsurface flooding and saltwater intrusion. This should help to freshen the waters of the Pond and the upstream impoundments. Additionally, the Pond and all upstream impoundments should be dredged and cleared of debris. Diversion of street and highway runoff is probably not an option, since Laurelton Creek was "improved" to function as the primary drainage

system for the Laurelton Parkway. It should be noted that Laurelton Creek, along with Brookfield Pond (which was located several blocks to the north of Conselyea's Pond but no longer exists) was once part of the City of Brooklyn's water supply. One should also consider restoring the wetland located between Laurelton Creek and the Pond to function as a runoff treatment unit, and re-assessing the possibility of leakage from adjacent sewers into the Pond. If the aforementioned measures fail to substantially improve the degraded condition of Conselyea's Pond, consideration should be given to in-lake aeration. Also, substantially improve maintenance of Laurelton Creek and the adjacent shoreline, and consider opening this shoreline to the public as a true greenway (Environmental Protection Agency and U. S. Department of the Interior 1980). Finally, consider measures to restore the stream to the maximum extent possible by removing culverting and concrete lining.

7- Oakland Lake

The recommendations of the Oakland Ravine Project should be implemented. Such implementation should result in substantial improvement to water quality. Additionally, dredging the Lake to historic depths is recommended in order to achieve still further improvement.

8 - Kissena Lake

The Lake should be dredged. Phosphorus should be removed from the City water used to supply the lake. If these measures fail to move the trophic state of the Lake to the mesotrophic range, flow augmentation by means of recycling lake

water should be considered. Alternatively (or additionally), phosphorus can be inactivated by alum addition to the lake. Also, the concrete bulkhead around the lake should be removed to create a more natural setting.

9 - Meadow Lake

The outlet works should be repaired to prevent the inflow of polluted saline water from Flushing Creek into the Lake. The Lake is currently overwhelmed by the inflow of groundwater having a very high phosphorus content as the result of its being constructed in an old tidal marsh. However, because it is the focus of a major park in Queens County, correction should not merely take the form of the “band-aid” approach recommended by New York City’s consultants. Rather, it should involve dredging to remove surficial nutrient and copper-laden (due to past copper sulfating operations) organic sediments, and to deepen the lake.

Additionally, an impervious liner should be installed to prevent the infusion of phosphorus saturated groundwater from the underlying tidal marsh. Water input could then be provided by deep wells into the Upper Glacial Aquifer or the underlying Jameco Gravel Aquifer (which in this area fills the erosion channel of an ancient diversion of the Hudson River (Buxton et al. 1981)). However, this alternative must be managed with care and coordinated with any potential Brooklyn/Queens Aquifer Management scenarios because intensive long term groundwater pumping might induce saltwater intrusion into the aquifer system. To minimize stress on such a deep well system, lake water should be reused after appropriate treatment. Highway drainage should be diverted around the Lake.

Finally, waterfowl at all the lakes should be monitored, and when the numbers grow excessive, their presence should be discouraged (by means of pyrotechnics, harassment by dogs, netting, and the passage of local laws prohibiting the feeding of waterfowl) in order to minimize water quality impacts, degradation of aesthetic conditions along the shorelines, and potential health hazards. Urban runoff and a large waterfowl population at Green Lake in Seattle (which is visited by millions of residents and tourists each year) have been found to be major sources of nitrogen and phosphorus, with phosphorus functioning as the limiting nutrient. (Zafer et al. 1994)

CHAPTER 8

APPLICATION OF CLASSIFICATION SYSTEMS TO OTHER URBAN AREAS

The three proposed classification systems developed through this study and applied to nine New York City lakes and ponds, if viable, should be applicable to other urban and suburban areas of the United States and to other developed parts of the world. These systems may not, however, be fully applicable to unsewered urban areas of developing nations where increasing population has led to shanty towns without sanitation, and large scale homelessness. This in turn has led to higher levels of diffuse pollution (Novotny 1995) than is the case in the western nations. In this chapter, the proposed classification systems will be applied to lakes and ponds in urban and suburban areas of Middlesex County New Jersey, San Diego County California, DeKalb County (Metropolitan Atlanta) Georgia, and Palm Beach County Florida.

8.1 - Middlesex County, New Jersey

Middlesex County, New Jersey is located in the Metropolitan Area of New York City and lies to the immediate southwest of Staten Island, astride the mouth of the Raritan River. It is heavily industrialized and is mainly covered by several older urban foci and newer suburban sprawl. The most southerly townships of the County are still characterized by some remaining (but rapidly vanishing) undeveloped forests and active farmland. The two lakes under consideration herein are located in this southern portion of the County, and were created through the construction of two dams on Manalapan Brook,

a tributary of South River, which in turn is a tributary of the Raritan. These two impoundments are named Manalapan Lake and DeVoe or Mill Lake and are located in the Boroughs of Jamesburg and Spotswood respectively, although portions of both lakes lie within Monroe Township. Manalapan Lake lies about four miles upstream (southwest) of DeVoe Lake and is partially bounded by Middlesex County's Thompson Park, as well as by residential and commercial development. DeVoe Lake is bounded by suburban residential development and a church and school complex. Upstream of Manalapan Lake, Manalapan Brook flows through forests, farmland, and an occasional rural residential development. Between Manalapan and DeVoe Lakes, the Brook flows through additional woodlands, but also through more developed residential, commercial and (abandoned) industrial land. An additional impoundment named Lake Marguerite once existed between the two lakes but the "old dam works" has long been abandoned. Both impoundments were originally created to provide water power for various types of mills close to two centuries ago, but earlier in the 20th century the lakes were used for recreation and flood control. However, due to pollution caused by agricultural runoff, street drainage, septic system leakage and runoff from animal holding areas in Thompson Park, swimming in the lakes has been discontinued (although the discharge of poorly treated municipal and industrial waste has been eliminated by the construction of a County Utilities Authority Interceptor). (Newman 1984) While Manalapan Brook has been stocked by the State, and some limited recreational fishing has been observed, drainage from acid soil upstream of Manalapan Lake that has been ditched for mosquito control, has limited fish population. Manalapan Lake has recently been dredged (Crafton 1997, New Jersey Department of

Environmental Protection 1997), while DeVoe Lake, which was recently emptied because of major reconstruction work on the dam, is in dire need of dredging, with wetlands rapidly replacing open water (Walsh 2000). As a result of this infilling and rapidly approaching extinction, DeVoe Lake has lost most of its flood control capability.

A sketch of Manalapan and DeVoe Lakes may be found in Figure 8.1.

Under the Degree of Urbanization Classification System, Manalapan Lake would score about 1.6 because of the suburban residential and commercial development along one portion of the shoreline and the parkland (which in this case is a source of contamination) on the remainder, while the major portion of the watershed remains rural, rural residential and agricultural. DeVoe Lake would, under this system, be classified as 2.3 since it has a somewhat more developed drainage area having sewers and sidewalks and is not buffered by parkland. Under the Degree of Artificiality System, both lakes are completely man-made through the impoundment of a tributary stream, with no hardening of the bottom nor of the shoreline, and so both are scored at 4.0. With regard to Water Input Mechanism scoring, both lakes are fed by a perennial tributary stream, supplemented by suburban and agricultural runoff, yielding a score of about 1.2 for each lake.

The New York City lakes most resembling Manalapan and DeVoe Lakes are the Richmondtown Millpond and Van Cortlandt Lakes, since all were created by impounding perennial streams, and all appear to be suffering the same types of sedimentation problems. A comparison of the classification scores of these lakes may be found in Table 8.1.

FIGURE 8.1

SKETCH OF MANALAPAN AND DeVOE LAKES, MIDDLESEX COUNTY,

NEW JERSEY

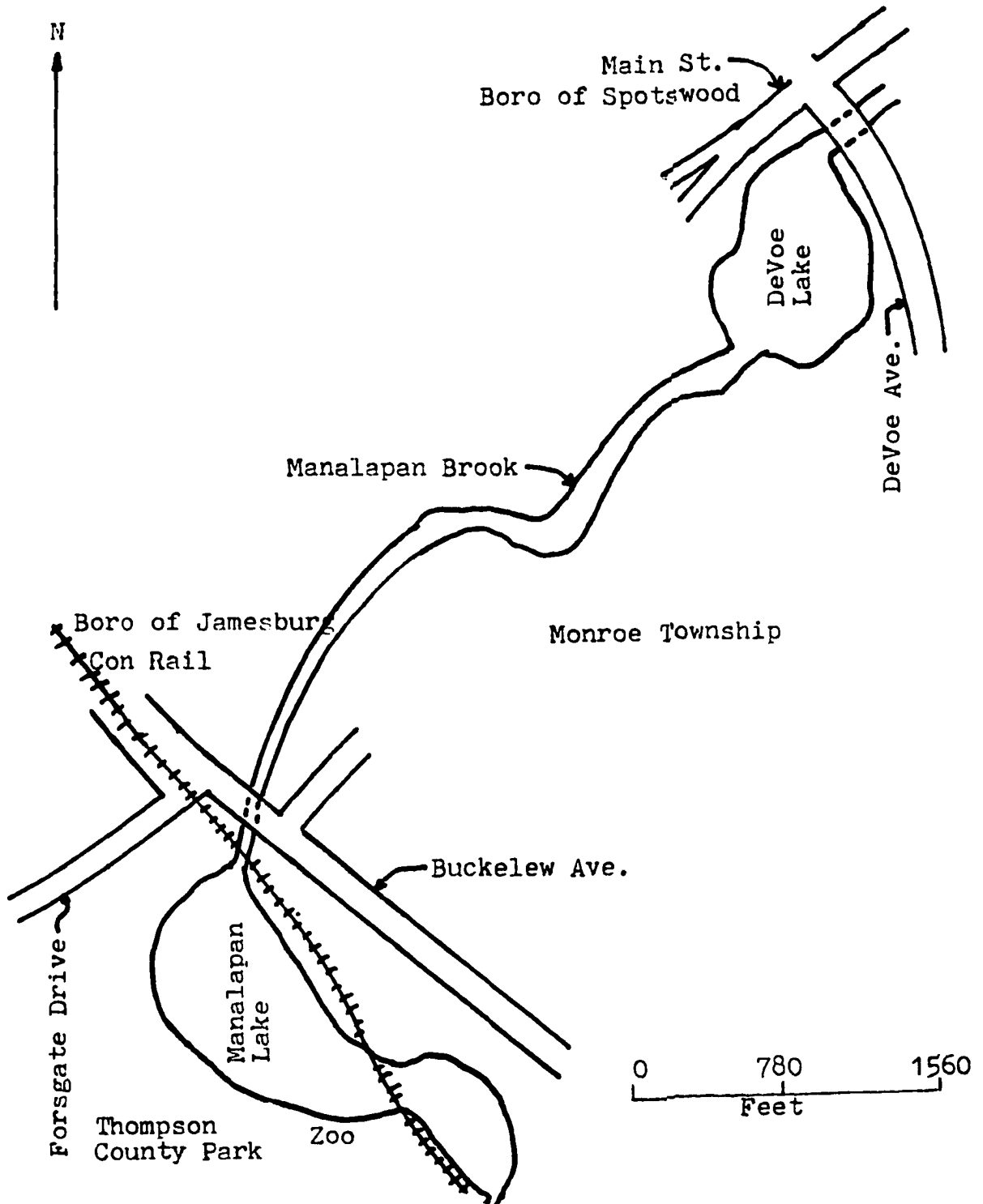


TABLE 8.1			
COMPARISON OF MIDDLESEX COUNTY AND NEW YORK CITY LAKES			
LAKE	DEGREE OF URBANIZATION SCORE	DEGREE OF ARTIFICIALITY SCORE	WATER INPUT MECHANISM SCORE
MANALAPAN LAKE	1.6	4.0	1.2
DEVOE LAKE	2.3	4.0	1.2
VAN CORTLANDT LAKE	2.7	4.0	1.0
RICHMONDTOWN MILLPOND	1.7	4.0	1.0

8.2 - San Diego County, California

In the residential community of Santee, located about 20 miles from downtown San Diego California, the Santee County Water District determined in 1959 that it would not abandon its one year old wastewater treatment plant and join the County system. Rather, it would provide the required upgrading of the facility and justify the increased cost by beneficially using the effluent to supply a series of proposed artificial recreational lakes. This action was approached in cooperation with the San Diego County Department of Health, the California Department of Public Health, and the United States Public Health Service. The District received approval to pass the effluent through an oxidation pond and then to recharge it into a sandy aquifer in the bottom of a canyon, which was underlain by a clay bed. The effluent would emerge about one mile down the canyon in a cutoff trench or collection gallery, receive chlorination and be conveyed to the first of a series of four lakes which were created by regrading spoil material in an area which had

long undergone aggregate mining. (U.S. Department of the Interior 1967) The lakes have subsequently been utilized for passive recreation, boating, fishing and swimming (in an isolated area which was provided with additional treatment). While the lakes have experienced algae blooms and fish kills, they have been met with overwhelming acceptance by the public.

The writer visited the recreational lakes of Santee in December of 1998, over thirty years after the concept of using renovated wastewater was widely approved by the citizens of San Diego County, and while the novelty has worn off, according to a park employee, the popularity of the concept has not (yet a tourist brochure makes no mention of the source of the lake water). However, at the time of the visit, admittedly during the off-season, the lakes were being used for recreation hardly at all. A sketch of the Santee lakes may be found in Figure 8.2.

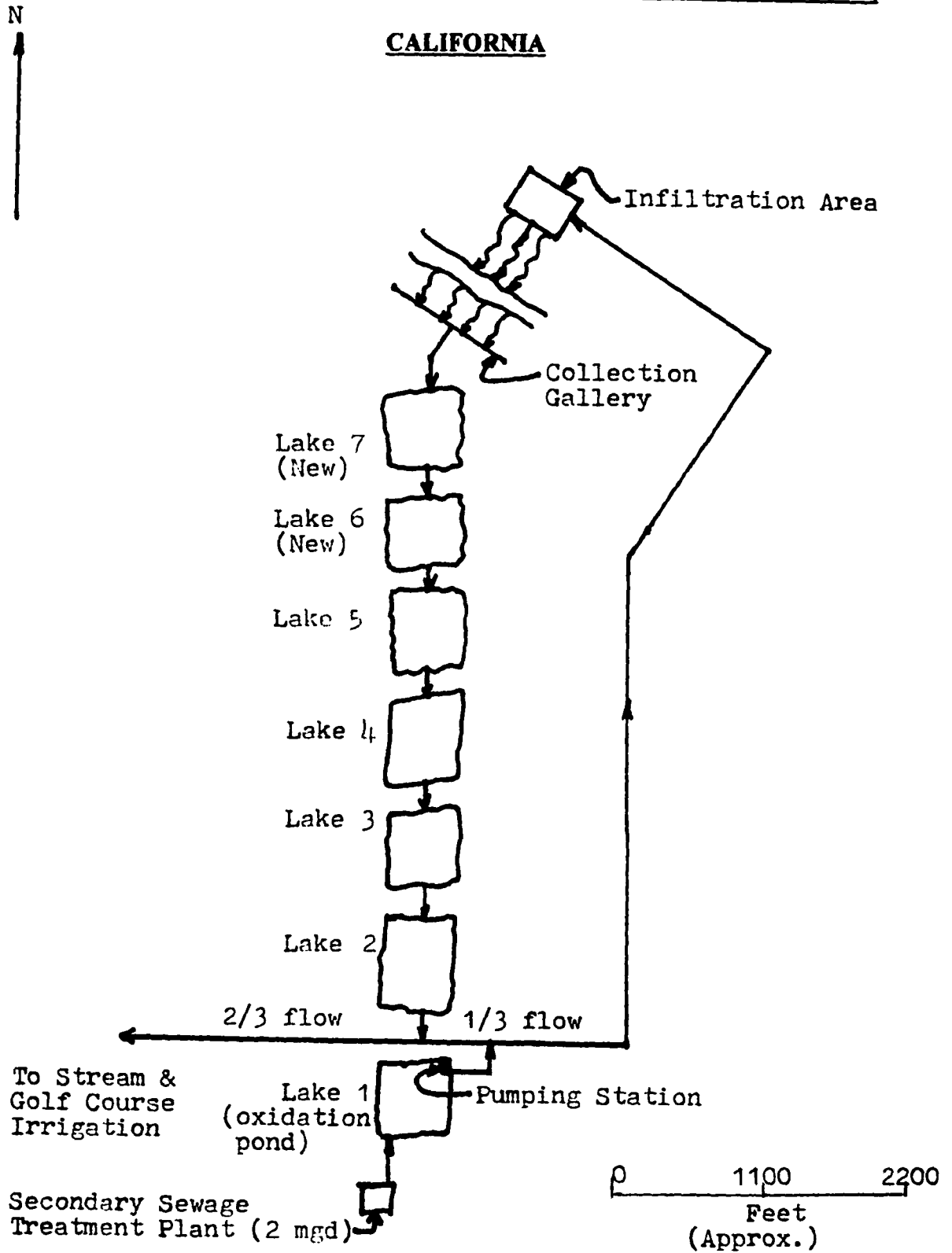
The score for the Santee recreational lakes under the Degree of Urbanization Classification System is 2.4, since the watershed consists of a residential area, without industry, connected to the municipal sewer system, which in the absence of much precipitation, provides most of the water for these lakes. Under the Degree of Artificiality System, not only are the lakes wholly artificial, but the water source is as well. They rate a score of 4.5. For use of renovated wastewater, the Santee lakes are assigned a score, under the Water Input Mechanism Classification System, of 4.

While the writer is not familiar with many lakes or ponds that directly utilize the Santee model, several lakes in lower Staten Island utilize groundwater which has to some degree been charged with partially treated sewage. This would include Wolfe's Pond, one

FIGURE 8.2

SKETCH OF SANTEE RECREATIONAL LAKES, SAN DIEGO COUNTY,

CALIFORNIA



of the study lakes, which is served by a watershed that is still far from being wholly sewerred. The origins of these lakes are different in that Santee is totally artificial while Wolfe's Pond is somewhat anthropogenically enhanced. However, the drainage areas are somewhat similar, although Santee is fully sewerred. A comparison of these two lakes may be seen in Table 8.2.

TABLE 8.2			
SANTEE RECREATIONAL LAKES VS WOLFE'S POND			
LAKE	DEGREE OF URBANIZATION SCORE	DEGREE OF ARTIFICIALITY SCORE	WATER INPUT MECHANISM SCORE
SANTEE RECREATIONAL LAKES	2.4	4.5	4.0
WOLFE'S POND	1.4	2.4	2.7

Obviously there is a much wider discrepancy between Santee and Wolfe's Pond than between the two New York City lakes formed by impounding perennial streams and the Middlesex County lakes formed in the same manner. This should be expected in view of the fairly unique water feedstock utilized at Santee.

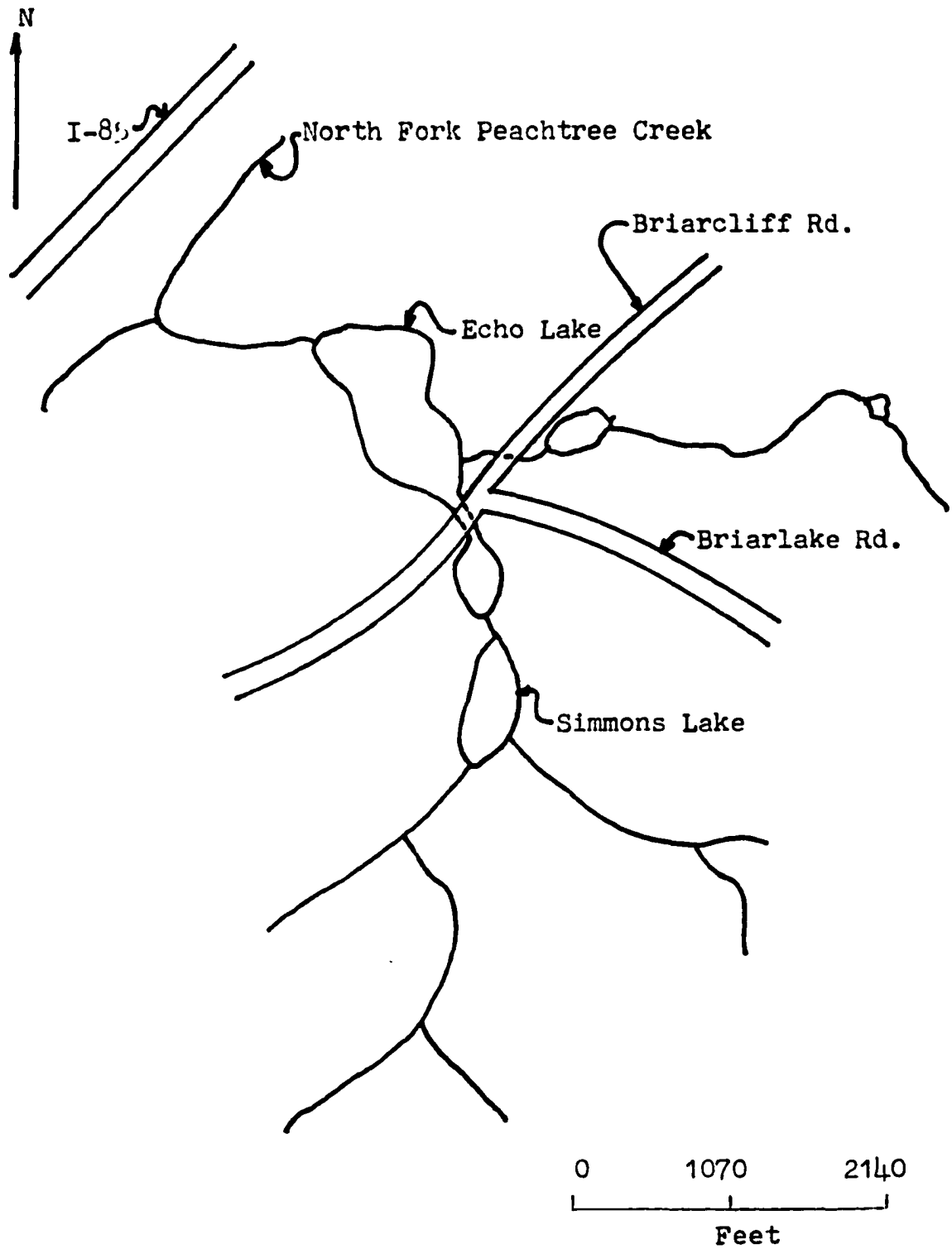
8.3 - DeKalb County, Georgia

In the Atlanta Metropolitan Area, man-made lakes are components of multiple use water resource projects. They serve as elements of flood control and drainage programs,

while at the same time they function as recreational hubs and as potential enhancements of real estate values. (Debo September 1977) In a flood control and drainage context, they serve to reduce peak flows down to pre-development levels downstream, through their storage function and/or they allow for the use of smaller and less expensive downstream hydraulic conveyance systems. The value of the artificial lakes (impoundments in this case) for recreation and aesthetic enhancement depends on proper planning (size, depth, upstream development and pollution sources) and maintenance (to control weed growth, algal growth, sedimentation, mosquitos, bank erosion, and dam leakage and failure). In a group of four multipurpose artificial lakes in DeKalb County, Georgia, the two largest and deepest (Kenilworth and Talmage Lakes), with public access, community facilities, open space, and minimal sedimentation problems met with general public approval, while the two smaller water bodies (Echo and Ivanhoe Lakes) with no public access, no public facilities and severe sedimentation problems have little public support and according to a survey, are considered little more than public nuisances. All four lakes are in middle class residential areas. A sketch of Echo Lake may be found in Figure 8.3.

It should be noted that the proposed classification systems take no cognizance of features such as multiple use versus single use; the availability versus the unavailability of public access; nor the issue of adequate versus inadequate maintenance, all of which were controversial issues in DeKalb County referenda on drainage improvement projects. The DeKalb County lakes receive a score of 2.2 in the Degree of Urbanization Classification System by virtue of being located in residential (suburban) areas outside of the City of

SKETCH OF ECHO LAKE, DeKALB COUNTY, GEORGIA



Atlanta. In the Degree of Artificiality System, they receive a score of 4, since they have all been created as man-made impoundments. Finally, a Water Input Mechanism System score of 0.8 is assigned to these lakes, since their primary water input mechanism is tributary flow (primarily during wet weather conditions).

Because the DeKalb County lakes were created to impound ephemeral flows, they most resemble Conselyea's Pond which also impounds ephemeral flows, although that does not appear to have been its original purpose. Additionally, Conselyea's Pond also currently serves a drainage and recreational function, but not a flood control function. A comparison of the DeKalb County lakes with Conselyea's Pond can be seen in Table 8.3.

TABLE 8.3			
DeKALB COUNTY LAKES VS CONSELYEA'S POND			
LAKE	DEGREE OF URBANIZATION SCORE	DEGREE OF ARTIFICIALITY SCORE	WATER INPUT MECHANISM SCORE
DeKalb County Lakes	2.2	4	0.8
Conselyea's Pond	3.8	4	0.5

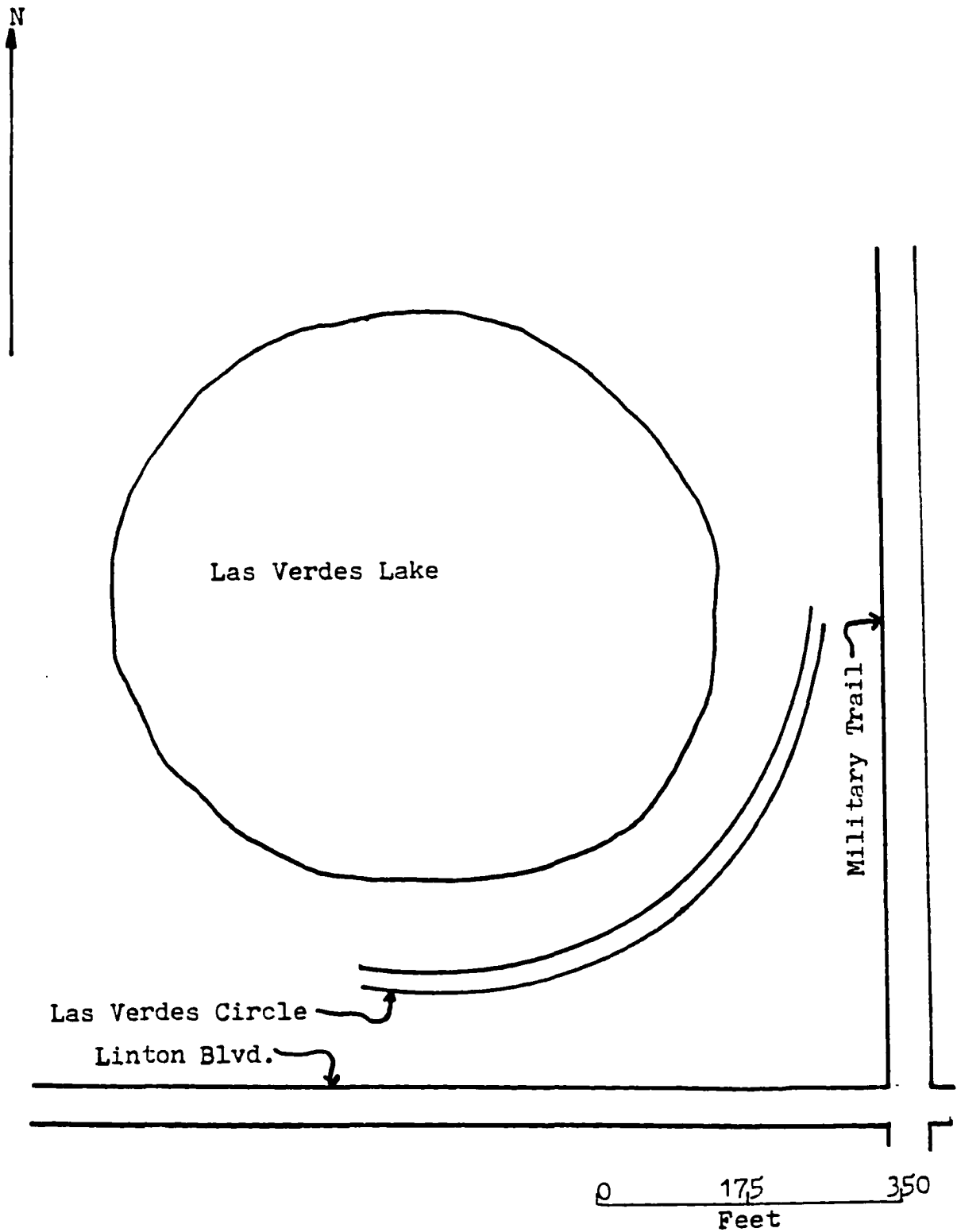
8.4 - Palm Beach County, Florida

Owing to the fact that much of Florida is underlain by limestone, most natural lakes on the peninsula are solution lakes. However, along the "Gold Coast", which includes the Atlantic shorelines of Dade, Broward and Palm Beach Counties, where development has been intense during the last five decades, there has also developed a far-flung system of multiple use man-made neighborhood lakes and ponds which function as

elements of a complex storm drainage system managed by the South Florida Water Management District. Unlike the multiple use lakes in DeKalb County, the artificial lakes of southern Florida are excavated or mined to below the water table, with strict site development regulations governing the excavation, reclamation and shoreline planting around the “mined” lakes. (Palm Beach, Florida, Department of Environmental Resources 1992). During times of intense precipitation, excess surface water drains to community lakes and on-site ponds by way of street and yard inlets, culverts, swails, ditches or canals. This constitutes the neighborhood or tertiary drainage system. Water then drains from the tertiary system to the secondary system via underground conduits. The secondary system consists of a network of canals, hydraulic structures, pumping stations and storage facilities maintained by a county, city or special district. Finally, the secondary system flows into the primary system of canals and natural waterways which drain to the sea by way of flood gates. In anticipation of heavy rain, the flood gates are opened to lower water levels, and during the rain event excess water is routed through the primary canals to regional storage facilities or to coastal discharge points. The primary system is operated by the South Florida Water Management District. (South Florida Water Management District 1997) The community lakes, which function much like retention basins (wet ponds), also serve to aesthetically enhance residential, institutional, commercial and industrial development, and function as anchors for passive recreation. A sketch of Las Verdes Lake (a typical community lake) may be found in Figure 8.4.

The coastal portion of Palm Beach County is moderately urbanized and so a

SKETCH OF LAS VERDES LAKE, PALM BEACH COUNTY, FLORIDA



Degree of Urbanization score of 3 is assigned to the mined lakes of this portion of the County. An appropriate Degree of Artificiality score for these lakes is 4.4 since storm drainage is introduced to an entirely artificial lake. Lastly, since urban runoff is being added to groundwater seepage, a water input mechanism score of 2.6 is assigned.

Like the Harlem Meer and Prospect Lake among the New York City lakes selected for detailed study, the lakes of Palm Beach County are designed to bring aesthetic enhancement to a harshly urbanized environment (heavily urbanized in the case of New York and moderately urbanized in the case of Palm Beach County). However, the mined lakes of Palm Beach County function mainly as real estate lakes on private property, while these artificial New York City lakes function as focal points of major urban parks. Both sets of lakes serve as components of drainage systems, storing urban or parkland runoff, and subsequently discharging these flows to the municipal sewer system in the case of New York, and to a secondary canal system in the case of Palm Beach County. Nevertheless, the primary water input mechanisms are different, with these New York City lakes being fed primarily by City water, while those of Palm Beach County are fed by groundwater, with major additions of runoff. A comparison of Palm Beach County lakes with the Harlem Meer and Prospect Lake can be seen in Table 8.4.

TABLE 8.4 THE LAKES OF PALM BEACH COUNTY VS HARLEM MEER AND PROSPECT LAKE			
LAKE	DEGREE OF URBANIZATION SCORE	DEGREE OF ARTIFICIALITY SCORE	WATER INPUT MECHANISM SCORE
Palm Beach County Lakes	3	4.4	2.6
Harlem Meer	4.2	4.8	4.4
Prospect Lake	3.5	4.4	4.7

CHAPTER 9

CONCLUSIONS

- 1- All the nine lakes selected for detailed study are eutrophic, hypereutrophic, or otherwise severely degraded.
- 2- All the lakes are shallow or very shallow (with only one lake having a maximum depth greater than 2.3 meters), a condition which directly leads to the aforementioned degraded conditions.
- 3- Only one of the nine lakes (Oakland Lake) undergoes thermal stratification. The other eight lakes appear to be holomictic and polymictic. Oakland Lake appears to be holomictic and dimictic (or monomictic if the surface does not freeze).
- 4- Severe erosion problems have been identified in the watersheds draining to most of the selected lakes, leading to severe sedimentation problems, enrichment (by nutrients sorbed onto the fine particulate matter), and likely near term extinction of all the lakes unless there is substantial intervention.
- 5- Two of the selected lakes are undergoing severe saltwater intrusion (Conselyea's Pond and Meadow Lake) because of defective outlet works.
- 6- The Microtox test (run only during the summer round of sampling) uncovered toxicity at the Richmondtown Millpond.
- 7- During the summer survey, vigorous photosynthetic activity resulted in supersaturated dissolved oxygen concentrations near the surface of the water column at all but

two of the selected lakes, while sediment oxygen demand resulted in low concentrations near the bottom. This type of gradient was established (to a greater or lesser degree) in spite of the absence of thermal stratification. During the spring and fall surveys, dissolved oxygen readings were far more vertically uniform.

- 8- All metals readings were below the 1983 "EPA Trace Metal Criteria for Urban Runoff Exposure." (Schueler 1987)
- 9- The impact of urban runoff is less than anticipated because the lakes are generally well buffered (isolated) physically by parkland, and by the orientation of the municipal sewer system away from the lakes. However, this buffering is far less extensive along lake tributaries, and some lakes are subjected to drainage from park circulation systems and from nearby high volume traffic arteries.
- 10- In running simple regression analyses among a series of seasonal water quality variable pairs, dissolved oxygen (DO) correlated well with Chlorophyll a, but secchi depth only correlated moderately well with turbidity. In two of the three seasons, chlorophyll a correlated well with turbidity. Eh correlated poorly with DO (this anomalous result is counter to expectation). Copper correlated poorly with turbidity suggesting that the copper may be associated with a fraction of the sediment input not represented by turbidity. However, it more likely means that the turbidity consists mainly of algae (not a significant source of copper), or it may mean that the turbidity is associated with eroded parkland runoff (not a potentially rich source of copper) rather than urban runoff.
- 11- Three new quantitative classification systems are proposed which could serve as useful

limnological tools. These systems are based on the source(s) of water feeding a lake, the extent to which a lake is anthropogenically enhanced or artificial, and the degree to which a lake's watershed has been urbanized. Using a bit of judgment, any lentic water body can be easily scored under each of these three classification systems. The nine selected New York City lakes were scored, as were four urban lake systems outside the City. Two outside lake systems (Middlesex County, New Jersey and DeKalb County, Georgia) received scores similar to two of the New York City impoundments, but the lakes in Palm Beach County, Florida and Santee, California displayed characteristics that differed from the selected New York City lakes, and their scores were appropriately different from the closest of the selected NYC lakes (See Tables 8.1, 8.2, 8.3 and 8.4).

- 12- An ideal outcome of this project would have been the development of a series of empirical models relating water quality parameters to classification system scores. However, given the limited project database resulting from inadequate sample replication, as well as the high degree of variability among the lakes (caused by such factors as the different mixes of water input to each lake and the variation in parkland buffering at each lake), such statistical models could not be established.
- 13- Independently of any classification system scoring, a goal of the project was to determine whether water input mechanism had any impact on lake water quality. Because of the aforementioned high degree of variability among the lakes, such impacts could not be statistically discerned, utilizing one-way analyses of variance at the 95% level of significance.

- 14- Utilizing a variety of new concepts such as best management practices (BMPs) to improve water quality and reduce erosion, the New York City Departments of Environmental Protection, and Parks and Recreation are attempting to remediate Wolfe's Pond, the Richmondtown Millpond, Van Cortlandt Lake, Prospect Lake and Oakland Lake. However, these municipal agencies are only suggesting minimal efforts to correct problems at Meadow Lake. This project is suggesting additional measures such as dredging, flow augmentation, diversion of runoff from roads and highways or the application of BMPs to this source, and watershed erosion control as possible supplements to the ongoing agency efforts, as well as the application of various combinations of these measures at the lakes not currently being considered for remediation.
- 15- In retrospect, laboratory analyses should have included alkalinity as a measure of acid neutralizing capacity.

CHAPTER 10

SUGGESTED FUTURE STUDIES AND RESEARCH

As discussed earlier, urban lakes have major potential value as focal points for passive and active recreation, for education, for aesthetic enhancement of residential, commercial, institutional, and industrial developments, as well as for parks. However, they realize this potential only when they are relatively free of the water quality degradation associated with severe eutrophication, high rates of sedimentation, high levels of toxics which pose a threat to aquatic life (on both the acute and chronic levels), the presence of pathogenic microorganisms, the presence of floatable and other debris (as represented by the currently accepted indicator of urban waterway degradation, viz; the abandoned shopping cart), severe infestation of waterfowl, and hypoxia or anoxia along with associated releases of H_2S . Historically, lakes in urban or urbanizing areas have been at risk relative to these insults because urban areas are sources of many of the agents that cause these degraded conditions. The impacts of these agents are compounded by measures such as “stream improvements,” which remove ameliorating features such as vegetative buffer strips and canopies.

Future studies should focus on reducing the quantity and improving the quality of urban runoff and other forms of diffuse pollution through ever improving watershed management and planning techniques, on lake remediation and maintenance, and on improving upon the classification systems suggested in this study along with the associated proposed scoring protocols.

High rates of urban runoff associated with impermeable surfaces are capable of scouring sediment, nutrients, toxics, oil, pathogens, heat and debris from the urban landscape into nearby receiving streams and eventually into standing water bodies, which, because of their low energy environments, function as sumps. In urbanizing and suburbanizing areas, evolving planning concepts (such as low impact development (Prince George's County, Maryland, Department of Environmental Resources 1997) and clustering) and ever improving best management practices (such as grassed swails, porous pavement and retention basins) can be designed into developments. However, in fully developed intensely urbanized areas, opportunities for applying such advanced concepts are only available at significant renewal projects. New approaches to retrofitting storage and recharge must be conceived, developed and optimized, hopefully in tandem with vegetative techniques. Such approaches might include subsurface recharge basins, roof leader disconnection, dry wells, bioretention, porous block sidewalks and plazas, and innovative landscape and building storage schemes. The development of retrofit recharge on the micro (building lot) level will probably be more effective than on the mezzo (block or neighborhood) or macro (city or regional) levels, since roof or yard drainage is more appropriate for recharge from a quality perspective than is street drainage or drainage from certain commercial or industrial areas. Any breakthroughs in retarding high flows of urban runoff would also be of great value in reducing another bane of urban water quality, namely, combined sewer overflows. In particular, such retardation should be imposed prior to the point where the runoff enters the combined sewer system. In general, ways must be found to convert urban runoff into a resource (for purposes such as recreation,

aesthetics (Environmental Protection Agency August 1979), and possibly as a water supply). More specifically, after treatment in facilities such as wet retention ponds, where physical, chemical and biological processes can be used to improve water quality, urban runoff can be used to irrigate parks, lawns and gardens, to wash vehicles, to augment stream flow, to supply artificial lakes and wetlands, to recharge aquifers for the purposes of preventing salt water intrusion and providing stream baseflow, for industrial cooling, and for firefighting. (Environment Australia 1997) It should be noted that some of these uses have been proposed for grey water, and in the case of either urban runoff or grey water, a dual water supply system would be necessary. There are, however, some old-line public health engineers like the writer who object to the use of dual water supply systems because of the real potential for both subtle and overt cross-connections.

To protect small sensitive urban waterways there is a need to develop high rate treatment techniques that can be applied to urban runoff near the points of discharge or at the entry points to the collection system. Such techniques should be capable of reducing levels of sediment, phosphorus, oil, and metals. Technologies such as constructed wetlands and subsurface filters are being installed along several "Bluebelt" streams in the lightly developed sections of Staten Island, but not yet in far more densely urbanized areas. By simply removing sediment, much of the oil, phosphorus and metals associated with particulate matter can also be removed.

Preventive and corrective maintenance (PM and CM) of the lakes, tributaries and associated appurtenances (weirs, shorelines, upstream sedimentation basins) appears to be highly variable across the City and across the Nation. Wastewater management authorities

have recently been engaging in “benchmarking” studies designed to optimize their PM and CM programs by assessing programs by others, both within and outside their industry. A similar study should be conducted among representative lake management entities across the United States to develop a nation-wide model for all to use.

Lakes fed by municipal water supplies using orthophosphate to form a protective coating on the interior surfaces of distribution system pipelines, service connections and plumbing systems to eliminate the leaching of heavy metals (mainly lead and copper) by aggressive water, are prone to additional enrichment and eutrophication. Alternative corrosion control techniques, such as the use of plastic coatings or chemicals such as silicates or calcium carbonate to form protective films (Clark et al. 1971), should be studied for possible application in such water supplies.

Additional techniques should be developed to discourage large flocks of waterfowl from occupying small urban lakes and their adjacent areas on a long term basis.

Long hydraulic residence times in shallow ponds and lakes may tend to enhance eutrophication, and so low flow augmentation utilizing a conjunctive use approach (multiple sources; surface water supplies during times of plenty and groundwater during times of drought) should be developed for tributary streams, especially for ephemeral streams. This approach should be studied in tandem with the aforementioned artificial recharge techniques in areas where urbanization has reduced recharge to the point where streams no longer have baseflow. Such techniques must also consider subsurface flooding at one extreme, and saltwater intrusion in coastal aquifers at the other.

A study should be performed to develop optimum design criteria for artificial

seepage and drainage lakes, including optimum depth, surface area, hydraulic residence time, buffering and siting. In tandem with good maintenance and good watershed management, implementation of such optimum designs should ensure long term high levels of water quality.

As the urban heat island effect intensifies with the continuing increase in urban sprawl, the potential for higher concentrations of undissociated toxic ammonia in shallow urban lakes should increase. The impact of this probability on urban aquatic ecosystems, urban fishing and future urban lake stocking programs should be assessed.

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THE URBAN LAKES OF NEW YORK CITY

by

RICHARD L. NEWMAN

VOLUME II

A dissertation submitted to the Graduate Faculty in Earth and Environmental Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

2001

APPENDIX A

FIELD OBSERVATIONS AND MEASUREMENTS, AND ANALYTICAL DATA IN ACCESS DATABASE; CLIMATOLOGICAL DATA

APPENDIX A1

FIELD OBSERVATIONS AND MEASUREMENTS, AND ANALYTICAL DATA IN ACCESS DATABASE

Lake Number	Name	Location
1A	Wolf's Pond	Southwestern Staten Island
1B		
1C		
2	Richmondtown Millpond	Central Staten Island
3A	Harlem Meer	North central Manhattan
3B		
3C		
4A	Van Cortlandt Lake	Northwestern Bronx
4B		
5A	Prospect Park Lake	Central Brooklyn
5B		
5C		
6A	Conselyea's Pond	Southeastern Queens
6B		
7A	Oakland Lake	Northeastern Queens
7B		
7C		
8A	Kissena Lake	Northeastern Queens
8B		
8C		
9A	Meadow Lake	North Central Queens
9B		

Fall 1997 Survey

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Main Water Input Mechanism	Date	Time	Appearance
Groundwater	11/10/97	11:30 AM	Murky, greenish - brown
Tributary Stream	11/10/97	3:00 PM	Murky, brown, turbid
Municipal Water Supply	11/12/97	1:30 PM	Murky, greenish gray
Tributary Stream	11/12/97	10:30 AM	Murky, greenish brownish gray
Municipal Water Supply	11/25/97	10:30 AM	Slightly murky, brownish green
Tributary Stream	11/25/97	1:30 PM	Murky, grayish brown, unattractive
Groundwater	12/4/97	10:30 AM	Murky, grayish green
Municipal water Supply	12/4/97	1:00 PM	Grayish green, murky
Groundwater	12/4/97	3:00 PM	Murky, dark greenish gray

Current Weather
Fair, moderate wind from the west, temperature - 55.5 degrees
Partly cloudy; light wind from southwest; 50.8 degrees F
Fair, Moderate northwest wind; 48.5 degrees F
Fair; light wind from the southeast; 45.9 degrees F
Fair; moderate wind from the southwest; 36.7 degrees F
Overcast; moderate wind from the south; 40.7 degrees F
Cloudy; calm; 49.8 degrees F
Fair; light westerly wind; 50 degrees F
Partly sunny; calm; 48.1 degrees F

Previous Weather
Heavy rain during previous 2 days
Heavy rain during previous 2 days
Fair on previous 2 days; heavy rain on 2 days prior to that
Fair last two days; heavy rain two days prior to that
Fair and windy on the previous day
Fair and windy on the previous day.
Light rain on previous day, preceded by three days of fair weather, cold and windy weat
Light rain during previous day; fair during preceding 3 days
Light rain during previous day; fair and windy during the prior 3 days

Lake Depth (meters)	Secchi Depth (meters)	Sampling Depths (feet)
1.5	0.55	1 ft below surface
		1 ft above bottom
		Mid-depth, 2 ft below surface
0.3	0.24	0.5 ft below surface
2.2	0.73	1 ft below surface
		1 ft above bottom
		Mid-depth, 3 ft below surface
1.2	0.50	1 ft below surface
		1 ft above bottom
2.3	1.16	1 ft below surface
		1 ft above bottom
		Mid-depth, 3 ft below surface
1.4	0.35	1 ft below surface
		1 ft above bottom
3.3	1.79	1 ft below surface
		1 ft above bottom
		Mid-depth, 4.5 ft below surface
2.0	1.38	1 ft below surface
		1 ft above bottom
		Mid-depth, 3 ft below surface
1.1	0.42	1 ft below surface
		1 ft above bottom

Fall 1997 Survey

Temperature (degrees F)	pH	Conductivity (microsiemens/cm)	Salinity (ppt)
50.7	7.12	181	0.1
50.5	7.21	182	0.1
50.6	7.18	182	0.1
51.2	7.87	452	0.2
48.8	7.29	242	0.1
48.6	7.11	242	0.1
48.6	7.22	244	0.1
47.0	7.73	373	0.2
46.8	7.29	378	0.2
39.5	7.70	93	0.0
39.5	7.36	93	0.0
39.5	7.41	93	0.0
48.4	8.99	16,720	7.5
51.1	7.42	23,360	13.6
40.2	7.66	564	0.3
40.1	7.44	567	0.3
40.1	7.49	566	0.3
41.5	7.55	7.6	0.0
41.2	7.23	7.6	0.0
41.3	7.34	7.6	0.0
39.1	8.66	1128	0.6
39.0	8.67	1129	0.6

Fall 1997 Survey

Dissolved Oxygen (mg/l)	Percent Saturation	Turbidity (NTU)	Hardness (mg/l)	265
9.07	80.8	7.5	58	
9.25	81.5			
9.21	82.3			
7.81	68.3	7.5	161	
7.19	62.3	6.1	71	
6.52	56.9			
6.78	58.9			
9.77	83.1	4.3	110	
8.80	74.4			
12.49	95.0	5.0	28	
11.65	91.0			
12.19	94.9			
20.22	196	8.0	1360	
17.75	181			
10.5	82	7.0	211	
10.3	79			
10.4	80			
11.09	88.0	9.0	26	
10.98	86.2			
10.87	86.0			
13.95	107.2	17.0	293	
13.87	106.2			

Chloride (mg/l)	Chlorophyll a (mg/cubic meter)	Chlorophyll b (mg/cubic meter)
22.1	13.0	14.6
66.3	3.60	6.24
90	3.9	5.4
69.2	6.64	10.3
8.68	12.8	14.2
3761	77.9	110.1
91.1	9.07	12.2
1.5	68.4	75.3
254.7	87.4	95.1

Fall 1997 Survey

Chlorophyll c (mg/cubic Meter)	Oxidation Reduction Potential (millivolts)	Lead (ug/l)
2.47	461	6.1
	458	
2.09	446	11.5
1.38	472	9.9
	467	
6.16	458	20.2
	454	
3.15	454	8.2
	450	
22.8	394	7.3
	383	
2.29	432	<1
	431	
11.3	447	1.6
	447	
11.7	404	8.8
	391	

Fall 1997 Survey

Copper (ug/l)	Zinc (ug/l)	Cadmium (ug/l)	Color (cu)	Nitrate Nitrogen (mg/l)
7.8	6	<1	80	0.144
			80	0.126
14.3	10.2	<1	80	0.288
9.5	3.6	<1	80	0.317
			80	0.359
13.1	5.8	<1	80	<0.05
			80	<0.05
2.0	12.0	<1	60	<0.05
			60	<0.05
1.7	9.6	<1	60	0.38
			60	0.27
<1	1.0	<1	30	1.52
			40	1.52
<1	1.3	<1	30	0.082
			30	0.082
1.8	2.2	<1	180	0.202
			120	0.202

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Nitrite Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Total Kjeldahl Nitrogen (mg/l)
<0.05	0.201	2.1
<0.05	0.207	1.54
<0.05	0.123	1.4
<0.05	0.141	2.52
<0.05	0.201	1.26
<0.05	<0.1	1.4
<0.05	<0.1	1.68
<0.05	<0.1	1.4
<0.05	<0.1	1.54
<0.05	0.14	2.8
0.15	<0.1	1.26
<0.05	<0.1	1.4
<0.05	<0.1	1.54
<0.05	<0.1	1.12
<0.05	<0.1	<1.0
<0.05	0.116	2.66
<0.05	0.13	2.8

Fall 1997 Survey

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Ortho-Phosphate (mg/l)	Total Phosphorous (mg/l)	Fecal Coliform (cfu/100ml)
<0.1	0.189	1800
<0.1	0.173	
0.247	0.274	2500
0.127	0.155	400
<0.1	0.182	
<0.1	0.139	800
0.128	0.145	
<0.1	<0.1	<1
<0.1	<0.1	
0.13	0.156	200
0.158	0.177	
<0.1	0.149	<1
<0.1	0.234	
<0.1	0.282	<1
<0.1	0.231	
<0.1	0.173	<1
<0.1	0.168	

Fecal Streptococci (cfu/100ml)	Total Organic Carbon (mg/l)
	<10
	<10
	<10
46	<10
	<10
31	<10
	<10
33	<10
	<10
49	<10
	<10
920	<10
	<10
5	<10
	<10
2	<10
	<10

Carlson's Trophic State Index (based on Secchi Readings)	
69	
79	
65	
70	
59	
75	
52	
56	
76	

Carlson's Trophic State Index (based on Chlorophyll a)	
42	
43	
44	
48	
56	
73	
52	
72	
75	

Lake Number	Name	Location
1A	Wolf's Pond	Southwestern Staten Island
1B		
1C		
2	Richmondtown Millpond	Central Staten Island
3A	Harlem Meer	North central Manhattan
3B		
3C		
4A	Vancortlandt Lake	Northwestern Bronx
4B		
5A	Prospect Park Lake	Central Brooklyn
5B		
5C		
6A	Conselyea's Pond	Southeastern Queens
6B		
7A	Oakland Lake	Northeastern Queens
7B		
7C		
8A	Kissena Lake	Northeastern Queens
8B		
8C		
9A	Meadow Lake	North Central Queens
9B		

Main Water Input Mechanism	Date	Time
Groundwater	5/26/98	11:00 AM
Tributary Stream	5/26/98	1:00 PM
Municipal Water Supply	6/4/98	10:15 AM
Tributary Stream	6/4/98	11:40 AM
Municipal Water Supply	6/8/98	9:35 AM
Tributary Stream	6/8/98	12:15 PM
Groundwater	6/9/98	9:30 AM
Municipal Water Supply	6/9/98	11:15 AM
Groundwater	6/9/98	1:15 PM

Appearance
Turbid; brownish green; moderately appealing
Turbid; murky
Brownish green; moderately clear; pleasant aesthetic appearance; fishing taking place;
Brownish green; murky; abundant waterfowl; black organic bottom; no floating algae no
Green; murky; algal particles in water column; no floating macrophytes; rooted macrop
Brownish green; unpleasant; murky; floating algal colonies; black organic bottom; fewer
Clear; some pond scum along shore; aesthetically pleasing; rooted emergent macrophy
Grayish green; murky; visible suspended algae in the water column; some black organi
Green; murky; not aesthetically appealing; suspended algae; black organic sediment on

Current Weather
Fair; light westerly wind; 78.2 degrees F
Partly cloudy; calm; 75 degrees F
Fair; moderate west northwest winds; 65.5 degrees F
Fair; moderate wind from the southwest; 67.7 degrees F
Fair; moderate wind from the west; 65.3 degrees F
Partly cloudy; light westerly wind; 68.6 degrees F
Fair; light to moderate winds from the southeast; 68.3 degrees
Partly cloudy; light wind from the southwest; 73.5 degrees F
Partly cloudy; calm; 71.0 degrees F

Previous Weather
Thunder showers yesterday; fair previous 1 1/2 weeks; heavy rains during first half of M
Thundershowers on previous day; fair during prior 1 1/2 weeks; heavy rains during first
Fair and cool on previous 3 days; heavy thunderstorm during night of 5/31; heavy rains
Fair and cool previous 3 days; heavy thunderstorm on the night of 5/31; Heavy rains du
Showers during previous day; fair and cool during previous week; heavy rains in late Ap
Showers during previous day; fair and cool during previous week; heavy thunderstorm
Fair and cool on previous day; showers on 6/7; fair and cool during previous week; hea
Fair and cool on previous day; showers on 6/7; fair and cool during previous week; hea
Fair and cool during previous day; showers on 6/7; fair and cool during previous week;

Lake depth (m)	Secchi depth (meters)	Sampling depth (feet)
1.5	0.55	1 ft below surface
		1 ft above bottom
		Mid-depth, 2ft below surface
0.3	visible to 1ft bottom	0.5 ft below surface
2.2	1.52	1 ft below surface
		1 ft above bottom
		Mid-depth, 3ft below surface
1.2	0.88	1ft below surface
		1 ft above bottom
2.3	0.40	1ft below surface
		1ft above bottom
		Mid-depth, 3 ft below surface
1.4	0.60	1ft below surface
		1 ft above bottom
3.3	2.34	1 ft below surface
		1 ft above bottom
		Mid-depth, 4.5 ft below surface
2.0	1.03	1ft below surface
		1ft above bottom
		Mid-depth, 3ft below surface
1.1	0.16	1ft below surface
		1ft above bottom

Temperature (degrees F)	pH	Conductivity (microsiemens/cm)	Salinity (ppt)
71.4	7.50	177	0.1
70.2	7.28	178	0.1
70.6	7.33	179	0.1
62.2	7.25	606	0.3
71.0	9.08	305	0.1
70.7	9.07	308	0.1
70.9	9.09	306	0.1
68.7	7.83	621	0.3
66.1	7.98	647	0.3
65.9	9.48	109	0.0
65.7	9.48	107	0.0
65.9	9.53	107	0.0
77.7	8.37	16500	9.0
74.8	7.81	19300	11.4
66.3	7.49	580	0.3
64.6	7.11	582	0.3
65.7	7.42	574	0.3
68.2	9.88	128	0.1
66.1	9.81	126	0.1
66.2	9.87	128	0.1
64.8	9.31	6480	3.6
64.1	9.31	6570	3.6

Dissolved Oxygen (mg/l)	Percent Saturation	Turbidity (NTU)	Hardness (mg/l)
7.10	82.0	6.0	58
6.42	73.3		
6.66	74.5		
8.10	84.0	4.0	183
9.90	112.9	3.4	95
10.20	116.1		
9.83	112.4		
9.62	107.0	5.6	155
10.88	120.1		
10.12	109.5	15.0	35
9.46	101.8		
9.74	106.3		
13.9	183.0	14.0	1060
13.6	174.0		
9.41	102.1	2.4	189
8.18	86.4		
10.35	111.5		
11.56	128.5	5.1	34
10.67	115.4		
10.60	115.0		
11.53	125.3	30.0	742
11.34	124.0		

Chloride (mg/l)	Chlorophyll a (mg/cubic meter)	Chlorophyll b (mg/cubic meter)
10.6	14.30	22.00
82.5	<1.00	3.05
33.6	3.83	6.90
107.1	1.81	1.46
8.4	59.9	71.80
5691.0	68.8	85.90
83.9	7.56	9.83
12.8	22.2	26.3
186.5	70.4	70.2

Chlorophyll c (mg/cubic meter)	ORP (millivolts)	Lead (ug/l)	Copper (ug/l)	Zinc (ug/l)	283
4.21	403	7.6	4.2	3.3	
	403				
<1.00	412	6.3	9.8	4.4	
1.49	388	16.6	<1.0	5.7	
	421				
<1.00	431	20.2	1.3	3.9	
	452				
<1.00	375	17.1	<1.0	<1.0	
	398				
7.66	429	<1.0	11.9	23.9	
	442				
6.81	398	6.7	5.0	2.1	
	307				
1.60	309	3.0	13.9	1.9	
	297				
<1.00	336	22.1	6.6	3.0	
	328				

Cadmium (ug/l)	Color (pcu)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)
<1	70	0.116	<0.050
	80	0.129	<0.050
<1	25	0.850	<0.050
<1	25	<0.050	<0.050
	25	<0.050	<0.050
<1	40	0.295	<0.050
	40	0.301	<0.050
<1	40	<0.050	<0.050
	30	<0.050	<0.050
<1	40	<0.050	<0.050
	25	<0.050	<0.050
<1	<5	0.496	<0.050
	<5	<0.050	0.052
<1	10	<0.050	<0.050
	20	0.069	<0.050
<1	30	<0.050	<0.050
	25	<0.050	<0.050

Ammonia Nitrogen (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Ortho-Phosphate (mg/l)
0.137	6.86	<0.100
0.126	3.50	<0.100
0.176	7.98	<0.100
0.111	3.22	<0.100
0.100	3.08	<0.100
<0.100	4.20	<0.100
0.166	3.50	<0.100
0.139	5.46	<0.100
0.106	10.80	<0.100
0.155	8.26	<0.100
0.441	9.66	0.543
0.229	3.22	<0.100
0.649	3.36	<0.100
<0.100	3.50	0.228
<0.100	3.64	0.257
0.223	3.36	<0.100
0.205	3.50	<0.100

Total Phosphorous (mg/l)	Fecal Colliform (cfu/100ml)	Fecal Streptococci (cfu/100ml)
<0.100	32	<1
<0.100		
0.110	TNTC	<1
<0.100	12	<1
<0.100		
<0.100	16	<1
<0.100		
<0.100	8	<1
<0.100		
0.131	100	<1
0.571		
<0.100	3	<1
<0.100		
0.258	1	<1
0.301		
<0.100	18	<1
<0.100		

Copy Spring 1998 Survey

Total Organic Carbon (mg/l)	Carlson's Trophic State Index (based on Secchi Reading)	287
<10	68	
<10		
<10	-	
<10	54	
<10		
<10	61	
<10		
<10	74	
<10		
<10	68	
<10		
<10	48	
<10		
<10	60	
<10		
<10	>80	
<10		

Carlson's Trophic State Index (based on Chlorophyll a)	
57	
31	
44	
37	
70	
72	
51	
62	
73	

Summer 1998 Survey

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Lake Number	Name	Location
1A	Wolf's Pond	Southwestern Staten Island
1B		
1C		
2	Richmondtown Millpond	Central Staten Island
3A	Harlem Meer	North Central Manhattan
3B		
3C		
4A	Van Cortlandt Lake	Northwestern Bronx
4B		
5A	Prospect Park Lake	Central Brooklyn
5B		
5C		
6A	Conselyea's Pond	Southeastern Queens
6B		
7A	Oakland Lake	Northeastern Queens
7B		
7C		
8A	Kissena Lake	Northeastern Queens
8B		
8C		
9A	Meadow Lake	North Central Queens
9B		

Main Water Input Mechanism	Date	Time
Groundwater	7/29/98	10:20 AM
Tributary Stream	7/29/98	12:30 PM
Municipal Water Supply	8/3/98	10:00 AM
Tributary Stream	8/3/98	12:45 PM
Municipal Water Supply	8/5/98	9:45 AM
Tributary Stream	8/5/98	12:30 PM
Groundwater	8/10/98	10:00 AM
Municipal Water Supply	8/10/98	11:30 AM
Groundwater	8/10/98	12:45 PM

Appearance
Greenish-brown; cloudy; some floating algae
Grayish-brown; floating material; murkey; turbid; unappealing; numerous waterfowl
Rooted submergent macrophytes; some waterfowl; fish; emergent macrophytes and filii
Floating algae (heavy in places); brownish-green water color; murkey; very turbid; floati
Pea-green water color; floating algae; turbid; pin sized algae in the water column; recre
Many waterfowl; murkey; turbid; floating algal clumps; dull grayish-green appearance; fl
Floating algae and rooted macrophytes at the margins; dense algal mata throughout; so
Pea-green color; algal slicks; aesthetically unappealing; few waterfowl; passive recreati
Grayish-green; dense suspended algal colonies; passive recreation

Current Weather
Hazy, hot, humid; light breeze from the south; 85.3 degrees F
Hazy, hot, humid; calm; 87.3 degrees F
Fair; light wind from the west; 79.1 degrees F
Partly cloudy; warm; light breeze from the northwest; 88.8 degrees F
Partly cloudy; warm, humid; calm; 86.4 degrees F
Fair; warm; light breeze from the southeast; 88.5 degrees F
Partly cloudy; light breeze from the west; 79.5 degrees F
Partly cloudy; humid; very light breeze from the west; 83.6 degrees
Partly cloudy; moderate wind from the south; 83.6 degrees F

Summer 1998 Survey

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Previous Weather	Lake depth (meters)
Hot; very little thunderstorm activity	1.5
Prior month was hot, with very little thunderstorm activity	0.3
July was dry (precipitation below average); rain during AM of 7/31	2.2
July had under average precipitation; rain during AM of 7/31	1.2
July was quite dry; rain on 7/31 in the AM	2.3
Very dry during past month; rain during PM of 7/31	1.4
July and early August have been very dry	3.3
July and early August have been very dry	2.0
July and early August have been very dry	1.1

Summer 1998 Survey

Secchi depth (meters)	Sampling depth (feet)	Temperature (degrees F)	pH
0.60	1ft below the surface	80.4	7.72
	1ft above the bottom	78.8	7.93
	Mid-depth, 2 ft below the surface	78.8	7.47
Visible on bottom	0.5 ft below surface	69.6	7.18
1.28	1ft below the surface	78.5	9.77
	1ft above the bottom	77.8	9.35
	Mid-depth, 3ft below the surface	78.1	9.77
0.46	1 ft below the surface	80.5	9.47
	1 ft above the bottom	75.9	9.25
0.33	1 ft below the surface	79.0	10.22
	1 ft above the bottom	77.5	7.06
	Mid-depth, 3 ft below the surface	78.4	10.05
0.70	1 ft below the surface	90.6	7.69
	1 ft above the bottom	83.6	7.20
1.77	1 ft below the surface	78.3	7.64
	1 ft above the bottom	65.4	7.62
	Mid-depth, 4.5 ft below the surface	71.7	6.87
0.24	1 ft below the surface	81.3	10.44
	1 ft above the bottom	77.9	7.57
	Mid depth-3 ft below the surface	78.5	10.41
0.32	1 ft below the surface	83.1	10.07
	1 ft above the bottom	81.9	10.13

Summer 1998 Survey

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Conductivity (microsiemens/cm)	Salinity (ppt)	Dissolved Oxygen (mg/l)
195	0.1	7.21
193	0.1	4.60
194	0.1	4.99
741	0.4	6.69
317	0.2	15.52
315	0.2	9.80
317	0.2	11.42
608	0.3	13.65
609	0.3	14.92
125	0.1	14.80
102	0.0	4.73
118	0.0	12.85
24000	14.5	12.49
29730	18.4	0.30
610	0.3	15.15
811	0.4	0.41
641	0.3	0.58
126	0.1	14.30
97	0.0	0.69
94	0.0	5.62
9470	5.3	12.26
9500	5.4	12.50

Summer 1998 Survey

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Percent Saturation	Turbidity (NTU)	Hardness (mg/l)	Chloride (mg/l)
89.2	16.0	63	19.3
57.1			
60.2			
75.6	15.0	242	109.8
192.0	4.3	76	57.4
120.3			
140.0			
172.3	8.0	135	137.5
179.6			
185.8	25.0	32	11.9
63.6			
156.5			
189.6	10.0	3100	9099.0
5.6			
187.7	3.5	226	100.40
4.2			
6.5			
182.0	17.0	23	10.4
10.5			
68.7			
165.4	17.0	1140	3373
167.6			

Chlorophyll a (mg/cubic meter)	Chlorophyll b (mg/cubic meter)
32.30	30.20
1.36	129.00
11.20	11.00
69.60	64.50
46.10	39.00
19.60	19.50
10.70	7.64
152.8	126.60
240.5	209.70

Summer 1998 Survey

Chlorophyll c (mg/cubic meter)	ORP (millivolts)	Lead (ug/l)	Copper (ug/l)	Zinc (ug/l)
10.40	404	11.4	1.8	3.4
	397			
<1.00	405	8.5	5.4	9.1
6.57	391	5.8	6.4	6.8
	371			
16.50	373	6.4	2.6	5.2
	393			
7.35	351	1.5	1.1	2.6
	439			
<1.00	431	<1.0	2.7	7.1
	-146			
3.23	439	3.4	1.8	3.6
	236			
<1.00	306	3.1	<1.0	<1.0
	308			
43.30	325	<1.0	3.0	<1.0
	307			

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Cadmium (ug/l)	Color (pcu)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)
<1	160	<0.050	<0.050
	180	<0.050	<0.050
<1	80	2.140	0.112
<1	40	<0.050	<0.050
		<0.050	<0.050
<1	120	<0.050	<0.050
		<0.050	<0.050
<1	240	<0.050	<0.050
		<0.050	<0.050
<1	90	<0.050	<0.050
		<0.050	<0.050
<1	40	0.242	<0.050
		<0.050	<0.050
<1	280	<0.050	<0.050
		<0.050	0.091
<1	250	0.310	0.085
		0.280	<0.050

Ammonia Nitrogen (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Ortho-Phosphate (mg/l)
0.140	0.280	0.123
0.120	0.280	0.109
0.200	0.420	0.110
0.280	0.420	<0.100
0.280	0.420	0.114
0.420	0.588	<0.100
0.420	0.588	0.109
0.140	1.540	<0.100
0.280	1.680	<0.100
<0.100	2.940	0.118
1.050	1.400	1.510
<0.100	0.140	<0.100
3.22	3.920	<0.100
<0.100	0.420	0.245
0.560	0.840	0.411
0.420	0.280	<0.050
0.280	0.560	<0.050

Summer 1998 Survey

Total Phosphorous (mg/l)	Fecal Coliform (cfu/100ml)	Fecal Streptococci (cfu/100ml)
0.504	<1	<1
0.130		
0.127	<1	<1
<0.100	1	<1
0.163		
0.123	30	3
0.194		
<0.100	<1	3
<0.100		
0.138	TNTC	68
1.670		
0.208	68	4
<0.100		
0.294	41	<1
0.429		
<0.050	12	<1
<0.050		

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Summer 1998 Survey

Total Organic Carbon (mg/l)	Carlson's Trophic State Index (based on Secchi Reading)	302
<10	69	
14.2		
13.2	-	
<10	57	
<10	72	
<10	76	
26.6	66	
<10	52	
<10	79	
<10	76	

Carlson's Trophic State Index (based on Chlorophyll a)	
65	
34	
54	
72	
68	
60	
54	
>80	
>>80	

APPENDIX A2

CLIMATOLOGICAL DATA



NOVEMBER 1997

LOCAL CLIMATOLOGICAL DATA

NOAA, National Climatic Data Center

NEW YORK C.PARK, NY

CENTRAL PARK OBSERVATORY (NYC)

Lat: 40°47' N Long: 73°58' W Elev (Ground): 132 Feet

Time Zone: EASTERN WBAN: 94728 ISSN #:0198-3601

DATE	TEMPERATURE °F						DEG DAYS BASE 65°		WEATHER	SNOW/ICE ON GND (IN)		PRECIPITATION (INCHES)		PRESSURE (INCHES OF HG)		WIND SPEED - MPH DIR = TENS OF DEGREES								
	MAXIMUM	MINIMUM	AVERAGE	DEP FROM NORMAL	AVERAGE DEW PT	AVERAGE WET BULB	HEATING	COOLING		0700 LST	1300 LST	2400 LST	2400 LST	AVERAGE STATION	AVERAGE SEA LEVEL	RESULTANT SPEED	RES DIR	AVERAGE SPEED	MAXIMUM 5-SEC 2-MIN					
																			SPEED	DIR	SPEED	DIR		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
01	62	59	61*	9	59	60	4	0	RA BR			0.0	0.93	29.60	29.67	5.6	12	8.1	29	10	20	10	01	
02	61	47	54	2	52	55	11	0	RA FG+ BR			0.0	0.59	29.43	29.49	3.4	23	7.4	29	26	16	28	02	
03	65*	46	56	4			9	0				0.0	0.00	29.80		2.9	21	6.4	21	21	14	19	03	
04	63	43	53	1	44	49	12	0	BR			0.0	0.00	29.92	29.99	2.2	27	6.8	24	29	15	29	04	
05	56	40	48	-3	34	42	17	0				0.0	0.00	30.31	30.38	1.9	34	4.7	16	31	13	31	05	
06	55	44	50	-1	36	44	15	0	RA			0.0	T	30.28	30.35	8.5	08	9.2	30	07	23	08	06	
07	55	47	51	0	41	46	14	0	RA			0.0	0.01	29.94	30.01	16.2	08	16.4	41	07	30	08	07	
08	49	46	48	-2	45	46	17	0	RA BR			0.0	0.82	29.64	29.71	14.0	07	14.5	36	08	26	07	08	
09	49	45	47	-3	45	46	18	0	RA BR			0.0	0.77	29.45	29.52	4.4	05	7.5	26	07	17	07	09	
10	53	43	48	-2	34	41	17	0				0.0	0.00	29.67	29.74	7.3	31	8.8	21	34	15	33	10	
11	53	39	46	-3	27	38	19	0				0.0	0.00	29.83	29.90	5.0	32	7.2	21	34	16	33	11	
12	49	37	43	-6	21	34	22	0				0.0	0.00	29.88	29.96	6.4	31	7.7	31	31	21	31	12	
13	42	32	37	-12	19	31	28	0	RA			0.0	0.05	30.02	30.09	4.1	08	7.7	26	07	17	09	13	
14	38	32	35	-13	31	33	30	0	RA FZRA SN BR UP			T	0.66	29.55	29.62	12.1	07	13.2	38	07	26	07	14	
15	37	32	35	-13	28	32	30	0	SN BR			T	0.01	29.70	29.77	3.6	31	6.6	21	32	16	32	15	
16	39	31	35	-13	23	31	30	0	SN BR UP			T	0.01	29.79	29.86	8.2	31	10.2	30	34	21	30	16	
17	41	30	36	-11	22	30	29	0				0.0	0.00	30.08	30.16	6.1	29	7.6	23	30	15	31	17	
18	43	31	37	-10	21	31	28	0				0.0	0.00	30.18	30.25	2.7	29	5.2	17	28	11	30	18	
19	48	34	41	-5	24	35	24	0				0.0	0.00	30.00	30.07	2.5	25	4.2	17	24	13	25	19	
20	51	39	45	-1	27	37	20	0				0.0	0.00	29.96	30.03	1.3	31	3.5	18	29	14	33	20	
21	59	41	50	4	29	41	15	0	RA HZ			0.0	0.17	29.99	30.06	0.9	24	3.5	24	26	16	26	21	
22	47	39	43	-2	39	41	22	0	RA BR			0.0	0.53	29.78	29.85	7.4	07	8.7	23	06	18	09	22	
23	43	38	41	-4	37	39	24	0	RA BR HZ			0.0	T	29.91	29.98	2.0	06	4.2	15	07	14	07	23	
24	42	30	36	-9	21	31	29	0	BR HZ			0.0	0.00	29.93	30.00	11.0	32	11.7	36	33	23	33	24	
25	41	27*	34*	-10	17	29	31	0				0.0	0.00	30.07	30.14	5.6	29	8.2	30	26	20	25	25	
26	54	40	47	3	30	40	18	0	RA			0.0	0.02	29.64	29.70	8.0	26	9.1	25	23	17	25	26	
27	49	39	44	1	22	36	21	0				0.0	0.00	29.79	29.85	12.3	32	12.9	41*	31	30*	32	27	
28	48	39	44	1	32	39	21	0	RA			0.0	0.03	29.91	29.98	3.5	25	5.8	22	25	15	26	28	
29	52	43	48	5	30	40	17	0				0.0	0.00	29.92	29.99	1.5	36	3.8	20	02	15	02	29	
30	49	43	46	4	36	41	19	0	RA BR HZ			0.0	0.08	29.59	29.66	1.5	07	4.4	14	06	11	07	30	
49.8 39.2 44.5 20.4 0.0 < MONTHLY AVERAGES TOTALS-->													T	4.68	29.85		1.9	36	7.8	<-- MONTHLY AVERAGES				
-4.2 -1.9 -3.1 <----- DEPARTURE FROM NORMAL ----->													0.21	SUNSHINE, CLOUD, & VISIBILITY TABLES ON PAGE 3										
DEGREE DAYS									GREATEST 24-HR PRECIPITATION: 0.93 DATE: 1				SEA LEVEL PRESSURE DATE TIME											
MONTHLY TOTAL DEPARTURE									GREATEST 24-HR SNOWFALL: T DATE: 16				MAXIMUM MINIMUM											
SEASON TO DATE TOTAL DEPARTURE									GREATEST SNOW DEPTH: DATE:				MAXIMUM MINIMUM											
HEATING: 611 89 945 139									NUMBER OF DAYS WITH →				MAXIMUM TEMP ≥ 80: 0				MINIMUM TEMP ≤ 32: 8				PRECIPITATION ≥ 0.01 INCH: 14			
COOLING: 0 0 982 -114													MAXIMUM TEMP ≤ 32: 0				MINIMUM TEMP ≤ 0: 0				PRECIPITATION ≥ 0.10 INCH: 7			
													THUNDERSTORMS: 0				HEAVY FOG: 1				SNOWFALL ≥ 1.0 INCH: 0			

NOVEMBER 1997
NEW YORK C.PARK, NY

HOURLY PRECIPITATION

(WATER EQUIVALENT IN INCHES)

NEW YORK C.PARK, NY
NOVEMBER 1997 NYC WBAN # 94728

DATE	FOR HOUR (LST) ENDING AT												DATE	FOR HOUR (LST) ENDING AT												DATE	Sum of Differents (See Note 2)	2400 LST	
	1	2	3	4	5	6	7	8	9	10	11	12		13	14	15	16	17	18	19	20	21	22	23	24			Water	Equiv.
01									0.03	0.12	0.14	0.04	01	0.08		0.19	0.10	0.10	0.04	0.02	T	0.01	T	T		01	0.85	0.83	
02										T	0.01	T	02	T	0.08	0.49	0.01									02		0.59	
03													03													03		0.00	
04													04													04		0.00	
05													05													05		0.00	
06													06													06		T	
07	T			0.01									07											T		07		0.01	
08		T		0.04	0.24	0.03	0.03	0.08	T	T	0.12	0.20	08	0.02	0.01	0.01	0.06	0.03	0.01	0.02	0.01	0.01			08		0.82		
09	T	0.08	0.01	T	0.02	0.10	0.01	0.01	T			T	09	0.03	0.26	0.11	0.06	0.03	0.01	0.02	0.01	0.01			09		0.77		
10													10													10		0.00	
11													11													11		0.00	
12													12													12		0.00	
13													13													13	0.04	0.05	
14	0.04	0.07	0.10	0.08	0.03	T	0.02	0.06	0.04	T		0.02	14	T	0.03		T	0.01	0.03	0.02	T	T	T	0.02	0.02	14	0.67	0.68	
15	0.01	T		T	T								15								0.07	0.04	0.01	T	T	15		0.01	
16	T	0.01	T										16													16		0.01	
17													17													17		0.00	
18													18													18		0.00	
19													19													19		0.00	
20													20													20		0.00	
21													21								T	T	T			21	T	0.17	
22													22													22	0.00	0.53	
23													23													23	0.00	T	
24													24													24		0.00	
25													25													25		0.00	
26													26				T	T								26		0.02	
27													27								T	0.02	T			27		0.00	
28											T		28	T	0.03	T										28		0.03	
29													29			0.02	0.01	0.01	T				0.01	0.03	T	29		0.00	
30										T			30	T	T											30		0.08	

MAXIMUM SHORT DURATION PRECIPITATION (See Note 1)

Time Period (Minutes)	5	10	15	20	30	45	60	80	100	120	150	180
Precipitation (Inches)	.15	.21	.27	.31	.46	.48	.52	.55	.57	.57	.58	.58
Ending Date	02	02	02	02	02	02	02	02	02	02	02	02
Ending Time (Hour/Min)	1408	1412	1417	1423	1431	1442	1431	1442	1455	1455	1455	1455

Date and time are not entered for TRACE amounts.

Note 1: NCDC derives these data from one-minute ASOS values. The table is not printed when inconsistent with ASOS hourly totals.

Note 2: The sum of the hourly totals is given when it differs from the daily total. NWS does not edit ASOS hourly values but may edit daily and monthly totals. Hourly, daily, and monthly totals are printed as reported by the ASOS site.



DECEMBER 1997

LOCAL CLIMATOLOGICAL DATA

NOAA, National Climatic Data Center

NEW YORK C.PARK, NY

CENTRAL PARK OBSERVATORY (NYC)

Lat: 40°47' N Long: 73°58' W Elev (Ground): 132 Feet

Time Zone: EASTERN WBAN: 94728 ISSN #:0198-3601

DATE	TEMPERATURE °F						DEG DAYS BASE 65°		WEATHER	SNOW/ICE ON GND(IN)		PRECIPITATION (INCHES)		PRESSURE (INCHES OF HG)		WIND SPEED - MPH DIR - TENS OF DEGREES								DATE													
	MAXIMUM	MINIMUM	AVERAGE	DEP FROM NORMAL	AVERAGE DEW PT	AVERAGE WET BULB	HEATING	COOLING		0700 LST	1300 LST	2400 LST	2400 LST	AVERAGE STATION	AVERAGE SEA LEVEL	RESULTANT SPEED	RES DIR	AVERAGE SPEED	MAXIMUM 5-SEC 2-MIN																		
																			SPEED	DIR	SPEED	DIR															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24														
01	45	34	40	-2	24	34	25	0	RA BR HZ			0.0	0.02	29.41	29.48	13.7	32	14.2	34	32	26	32	01														
02	43	33	38	-3	19	31	27	0				0.0	0.00	29.79	29.86	11.3	31	11.6	36	34	24	29	02														
03	51	33	42	1	24	35	23	0	RA			0.0	T	29.92	29.99	3.2	29	5.3	20	24	15	26	03														
04	53	40	47*	7	41	44	18	0	RA BR HZ			0.0	0.14	29.56	29.63	2.6	27	4.0	23	25	15	25	04														
05	49	35	42	2	35	38	23	0	RA BR			0.0	0.09	29.42	29.49	1.7	33	7.3	23	30	16	30	05														
06	39	30	35	-5	21	29	30	0				0.0	0.00	29.49	29.56	5.1	28	7.6	25	24	17	30	06														
07	41	30	36	-3	23	31	29	0				0.0	0.00	29.63	29.70	7.6	30	9.6	25	33	18	33	07														
08	44	34	39	0	26	35	26	0				0.0	0.00	29.89	29.96	6.4	31	8.2	25	31	17	32	08														
09	41	31	36	-3	26	33	29	0				0.0	0.00	29.92	29.99	1.1	05	1.8	11	05	9	05	09														
10	42	33	38	0	29	34	27	0	RA PZRA SN BR UP			T	0.65	29.73	29.79	5.5	08	6.1	24	09	16	08	10														
11	35	33	34	-4	29	32	31	0	SN BR UP			T	0.05	29.90	29.98	6.6	07	7.6	24	06	17	07	11														
12	39	33	36	-1	33	35	29	0	RA SN BR UP			T	0.13	29.91	29.98	1.2	35	4.4	14	31	11	07	12														
13	38	33	36	-1	24	32	29	0				0.0	0.00	29.79	29.86	6.6	30	7.2	20	31	15	31	13														
14	43	28	36	-1	16	29	29	0				0.0	0.00	29.80	29.87	7.4	31	9.3	36	01	23	32	14														
15	42	26	34	-3	18	29	31	0				0.0	0.00	29.99	30.06	3.0	26	5.3	23	27	15	26	15														
16	54*	36	45	9	21	36	20	0				0.0	0.00	29.91	29.98	2.1	27	3.0	23	26	17	25	16														
17	53	38	46	10	24	37	19	0				0.0	0.00	29.78	29.85	0.5	33	1.4	18	30	13	32	17														
18	45	34	40	4	25	34	25	0				0.0	0.00	29.94	30.01	0.4	34	1.1	15	26	9	26	18														
19	50	39	45	10	27	38	20	0				0.0	0.00	29.88	29.95	3.6	29	5.3	22	27	15	28	19														
20	50	39	45	10	30	38	20	0	RA			0.0	T	29.87	29.94	1.9	32	2.8	22	33	15	32	20														
21	39	29	34	-1	15	28	31	0				0.0	0.00	30.17	30.24	0.9	36	1.2	21	01	15	01	21														
22	36	25	31	-4	17	27	34	0	RA SN BR			T	0.14	30.22	30.29	0.5	08	7	20	09	13	07	22														
23	41	35	38	4	32	35	27	0	RA BR			0.0	0.63	29.83	29.90	1.0	01	4.0	25	06	17	07	23														
24	41	38	40	6	29	35	25	0	RA BR			0.0	0.08	30.03	30.10	1.3	16	6.0	17	18	13	16	24														
25	50	37	44	10	41	43	21	0	RA BR			0.0	0.83	29.64	29.71	1.6	29	6.9	22	32	14	30	25														
26	49	40	45	11	32	40	20	0				0.0	0.00	29.76	29.82	5.7	30	7.7	24	31	18	30	26														
27	41	33	37	3	29	34	28	0	RA SN BR UP HZ			T	0.22	29.68	29.74	3.7	03	6.2	24	02	17	03	27														
28	38	32	35	2	21	30	30	0	BR			0.0	0.00	29.75	29.83	3.7	34	6.3	20	01	15	01	28														
29	41	31	36	3	30	34	29	0	RA BR			0.0	1.25	29.64	29.71	8.5	08	10.6	51*	06	34*	07	29														
30	39	34	37	4	29	33	28	0	RA SN BR			T	0.04	29.03	29.10	9.5	28	10.7	34	28	24	30	30														
31	35	17*	26*	-7	9	21	39	0				0.0	0.00	29.77	29.84	12.0	31	12.4	31	31	22	30	31														
< MONTHLY AVERAGES										TOTALS-->				T	4.27	29.78	29.85	3.0	32	6.3	<-- MONTHLY AVERAGES																
1.0										2.3				1.7				0.36				SUNSHINE, CLOUD, & VISIBILITY TABLES ON PAGE 3															
DEGREE DAYS										GREATEST 24-HR PRECIPITATION: 1.29 DATE: 29-30										GREATEST 24-HR SNOWFALL: T DATE: 30+																	
MONTHLY TOTAL DEPARTURE										GREATEST SNOW DEPTH: DATE:										SEA LEVEL PRESSURE DATE TIME																	
HEATING: 822 -58										MAXIMUM TEMP ≥ 80: 0										MAXIMUM TEMP ≤ 32: 10																	
COOLING: 0 0										NUMBER OF DAYS WITH →										PRECIPITATION ≥ 0.01 INCH : 13																	
SEASON TO DATE TOTAL DEPARTURE 1767 81										MAXIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH : 8																	
982 -114										THUNDERSTORMS: 0										HEAVY FOG: 0																	

DECEMBER 1997
NEW YORK C.PARK, NY

HOURLY PRECIPITATION

(WATER EQUIVALENT IN INCHES)

NEW YORK C.PARK, NY

DECEMBER 1997 NYC WBAN # 94728

DATE	FOR HOUR (LST) ENDING AT												DATE	FOR HOUR (LST) ENDING AT												DATE	Sum if Different (See Note 2)	2400 LST
	1	2	3	4	5	6	7	8	9	10	11	12		13	14	15	16	17	18	19	20	21	22	23	24			
01	0.01	T	0.01										01												01		0.02	
02													02												02		0.00	
03													03												03		T	
04													04												04		0.14	
05	T	0.01	0.09	0.02	T	0.01	T	T	T	T	0.02	T	05	0.02	0.02	0.01	T	T	0.01	T	T	0.01	T	T	05		0.09	
06													06												06		0.00	
07													07												07		0.00	
08													08												08		0.00	
09													09												09		0.00	
10													10	0.04	0.07	0.10	0.05	0.07	0.11	0.09	0.06	0.02	T	T	0.04	10		0.65
11	0.01	0.01	0.01	0.01	T	T	T	0.01	T	T			11												11		0.05	
12	T	T	0.02	0.02	T	0.01	0.02	0.01	0.01	T	0.01	0.02	12	T	0.01										12		0.13	
13													13												13		0.00	
14													14												14		0.00	
15													15												15		0.00	
16													16												16		0.00	
17													17												17		0.00	
18													18												18		0.00	
19													19												19		0.00	
20													20												20		T	
21													21												21		0.00	
22													22												22		0.14	
23	0.04	0.01	0.07	0.10	0.17	0.12	0.09	0.03					23												23		0.63	
24													24												24	0.07	0.08	
25	0.02	0.05	0.06	0.07	0.13	0.20	0.18	0.07	0.05	0.01			25												25	0.84	0.83	
26													26												26		0.00	
27									0.01	0.02	0.01	0.02	27	T	T	0.02	0.02	0.02	T	T	0.01	0.04	0.04	0.01	T	27		0.22
28													28												28		0.00	
29													29			T	0.01	0.05	0.11	0.17	0.26	0.31	0.15	0.07	0.12	29		1.25
30	T				0.01	T	0.01	T	0.01	T	0.01	T	30	T	T	T	T	T							30		0.04	
31													31												31		0.00	

MAXIMUM SHORT DURATION PRECIPITATION (See Note 1)

Time Period (Minutes)	5	10	15	20	30	45	60	80	100	120	150	180
Precipitation (Inches)	.06	.07	.11	.14	.19	.29	.37	.46	.53	.58	.68	.74
Ending Date	25	25	29	29	29	29	29	29	29	29	29	29
Ending Time (Hour/Min)	0501	0501	1959	1959	2001	2019	2034	2032	2039	2054	2125	2045

Date and time are not entered for TRACE amounts.

Note 1: NCDC derives these data from one-minute ASOS values. The table is not printed when inconsistent with ASOS hourly totals.

Note 2: The sum of the hourly totals is given when it differs from the daily total. NWS does not edit ASOS hourly values but may edit daily and monthly totals. Hourly, daily, and monthly totals are printed as reported by the ASOS site.

TEMPERATURE °F										DEG DAYS BASE 65		WEATHER		SNOWICE ON GROUND				PRECIPITATION (INCHES)				PRESSURE (INCHES OF HG)		WIND SPEED - MPH DIR - TENS OF DEGREES																									
DATE		MAXIMUM	MINIMUM	AVERAGE	DEP FROM NORMAL	AVERAGE DWB PT	AVERAGE WET BULB	HEATING	COOLING	0700 LST	1300 LST			2400 LST	2400 LST	2400 LST	AVERAGE STATION	AVERAGE SEA LEVEL	RESULTANT SPEED	RES DIR	AVERAGE SPEED	5-SEC 2-MIN MAXIMUM																											
																						SPEED	DIR																										
1	1	2	3	4	5	6	7	8	10	RA BR HZ	11	12	13	14	15	16	17	18	19	20	21	22	23	24																									
01	66	55	61	3	57	58	4	0	RA BR HZ	0	0	0	0.58	29.71	29.78	3.6	11	6.3	25	08	18	09	01																										
02	71	54	63	5	56	57	2	0	RA BR	0	0	0	0.25	29.47	29.53	0.3	19	6.0	20	18	15	17	02																										
03	67	53	60	2	55	56	5	0	RA FG BR HZ	0	0	0	0.10	29.62	29.68	1.9	12	4.7	16	18	11	19	03																										
04	62	50	56	0	55	56	6	0	RA BR HZ	0	0	0	0	29.77	29.83	3.1	12	6.4	17	13	13	08	04																										
05	62	55	59	0	57	57	6	0	RA BR	0	0	0	0.57	29.89	29.95	3.5	11	6.3	16	08	15	07	05																										
06	66	55	61	2	58	59	4	0	RA BR	0	0	0	0	29.88	29.95	3.3	09	5.4	16	07	13	07	06																										
07	67	56	62	2	57	58	3	0	RA BR HZ	0	0	0	0	29.82	29.89	1.0	08	2.3	13	08	10	08	07																										
08	57	54	56	-4	54	55	9	0	RA BR	0	0	0	0.28	29.64	29.71	9.9	09	11.1	31	07	22	07	08																										
09	59	55	57	-4	57	57	8	0	RA BR	0	0	0	1.42	29.60	29.66	11.2	06	11.7	32	07	21	08	09																										
10	58	53	56	-5	55	55	9	0	RA BR	0	0	0	1.94	29.65	29.71	12.0	08	12.1	29	07	23	08	10																										
11	57	50	54	-7	51	52	11	0	RA BR	0	0	0	0.68	29.66	29.73	13.0	08	13.2	37	07	24	10	11																										
12	63	50	57	-4	45	50	8	0	RA	0	0	0	0	29.88	29.95	14.7	09	15.0	37	07	28	09	12																										
13	64	44	54	-8	43	47	11	0	BR	0	0	0	0.00	30.06	30.13	4.8	09	7.5	25	08	20	07	13																										
14	72	45	59	-3	44	51	6	0	BR HZ	0	0	0	0.00	30.04	30.11	2.1	09	3.7	15	10	11	11	14																										
15	85	53	69	7	52	59	0	4	HZ	0	0	0	0.00	29.93	30.00	1.0	06	3.2	21	07	15	08	15																										
16	85	62	74	11	57	63	0	9	HZ	0	0	0	0.00	29.89	29.96	1.6	13	5.9	17	16	14	17	16																										
17	67	58	63	0	52	56	2	0	HZ	0	0	0	0.00	29.94	30.01	3.3	10	5.9	16	07	11	09	17																										
18	84	55	70	7	54	61	0	5	RA BR HZ	0	0	0	0	29.87	29.94	2.6	33	4.8	25	32	15	32	23																										
19	87	60	74	10	58	65	0	9	RA FG BR HZ	0	0	0	0	29.74	29.80	0.8	30	6.3	23	16	16	10	19																										
20	78	59	69	5	58	61	0	4	RA FG BR HZ	0	0	0	0.07	29.69	29.76	2.1	18	4.9	15	16	11	17	20																										
21	81	58	70	6	53	60	0	5	RA BR	0	0	0	0	29.61	29.67	5.1	32	7.8	30	33	18	32	21																										
22	70	53	62	-3	43	51	3	0	RA BR	0	0	0	0.00	29.75	29.82	6.7	33	8.9	25	33	17	32	22																										
23	75	52	64	-1	44	54	1	0	RA BR	0	0	0	0.00	29.80	29.87	3.7	32	6.4	18	33	14	29	23																										
24	80	58	69	4	46	57	0	4	RA BR	0	0	0	0.00	29.83	29.90	1.7	33	5.0	17	27	11	26	24																										
25	69	59	64	-2	58	60	1	0	RA FG+ BR	0	0	0	0.42	29.74	29.81	0.4	02	4.0	17	03	13	04	25																										
26	79	59	69	3	57	62	0	4	RA BR HZ	0	0	0	0.00	29.76	29.82	0.8	31	3.9	16	36	11	34	26																										
27	76	63	70	4	56	61	0	5	RA BR HZ	0	0	0	0.00	29.94	30.01	1.0	12	3.9	15	19	11	19	27																										
28	85	65	75	8	59	65	0	10	RA BR HZ	0	0	0	0.00	29.93	30.00	2.0	23	5.3	22	24	15	25	28																										
29	84	65	75	8	66	68	0	10	RA BR HZ	0	0	0	0.17	29.84	29.91	4.4	26	7.1	30	30	18	32	29																										
30	85	66	76	9	62	67	0	11	RA BR HZ	0	0	0	0.00	29.84	29.91	1.1	26	4.4	16	27	11	27	30																										
31	84	64	74	6	68	70	0	9	RA BR HZ	0	0	0	0.46	29.66	29.72	4.0	18	6.7	31	07	12	22	31																										
TOTALS		72.4	56.2	64.3	1.6	54.4	58.3	3.2	3.9	< MONTHLY AVERAGES										22.79		29.85	1.3	08	6.7	< MONTHLY AVERAGES																							
DEGREE DAYS										DEPARTURE FROM NORMAL										SUNSHINE, CLOUD, & VISIBILITY TABLES ON PAGE 3																													
MONTHLY										GREATEST 24-HR PRECIPITATION:										SEA LEVEL PRESSURE										DATE TIME																			
TOTAL DEPARTURE										GREATEST 24-HR SNOWFALL:										MAXIMUM										30.30										28 1043									
TOTAL DEPARTURE										GREATEST SNOW DEPTH:										MINIMUM										29.28										09 2039									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.01 INCH: 12									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									
TOTAL DEPARTURE										NUMBER OF DAYS WITH										MAXIMUM TEMP ≥ 60:										MINIMUM TEMP ≤ 32: 0										PRECIPITATION ≥ 0.10 INCH: 11									

HOURLY PRECIPITATION

(WATER EQUIVALENT IN INCHES)

NEW YORK C.PARK, NY

MAY 1998

NYC

WBAN # 94728

DATE	FOR HOUR (LST) ENDING AT												DATE	FOR HOUR (LST) ENDING AT												DATE	Sum if Different (See Note 2)	2400 LST Water Equiv.
	1	2	3	4	5	6	7	8	9	10	11	12		13	14	15	16	17	18	19	20	21	22	23	24			
01													01												01		0.58	
02	0.02	0.12	0.09	0.02									02													02		0.25
03		T	T					T	0.10	T			03													03		0.10
04												T	04													04		T
05											0.01	0.07	05	0.04	0.10	0.14	0.09	0.06	T	0.04	T					05		0.57
06													06													06		
07	0.01				0.01								07						T		T					07	0.01	T
08			T							T	0.03	0.03	08				T	0.01	T	T					08	0.24	0.28	
09	0.06	0.05	0.05	0.03	0.02	0.06	0.11	0.06	0.13	0.14	0.03	0.04	09	0.06	0.04	0.10	0.06	0.02	0.03	0.05	0.03	T	0.01	0.01	0.14	09	1.43	1.42
10	0.21	0.13	0.10	0.06	0.02	T		0.04	0.23	0.34	0.23	0.12	10	0.03	0.03	0.06	0.05	0.03	T	T	0.01	0.03	0.10	0.06	0.06	10	1.96	1.94
11	0.01	0.02	0.01	T		T	0.02	0.01	T	T	T		11			T	T	0.11	0.24	0.14	0.10	0.03			T	11	0.69	0.66
12	T		T	T									12													12		T
13													13													13		0.00
14													14													14		0.00
15													15													15		0.00
16													16													16		0.00
17													17													17		0.00
18													18			T										18		T
19													19													19		T
20													20					T	0.07	0.05					T	20	0.12	0.07
21													21		T											21		T
22													22													22		0.00
23													23													23		0.00
24													24													24		0.00
25									0.06	0.20	0.12	0.03	25	0.01												25		0.42
26													26													26		0.00
27													27		T											27	T	0.00
28													28													28		0.00
29													29							0.09	0.01	0.03	T			29	0.13	0.17
30													30													30		0.00
31													31									0.01				31	0.01	0.46

MAXIMUM SHORT DURATION PRECIPITATION (See Note 1)

Time Period (Minutes)	5	10	15	20	30	45	60	80	100	120	150	180
Precipitation (inches)												
Ending Date												
Ending Time (Hour/Min)												

Date and time are not entered for TRACE amounts.

Note 1: NCDC derives these data from one-minute ASOS values. The table is not printed when inconsistent with ASOS hourly totals.

Note 2: The sum of the hourly totals is given when it differs from the daily total. NWS does not edit ASOS hourly values but may edit daily and monthly totals. Hourly, daily, and monthly totals are printed as reported by the ASOS site.



JUNE 1998

LOCAL CLIMATOLOGICAL DATA

NOAA, National Climatic Data Center

NEW YORK C.PARK, NY

CENTRAL PARK OBSERVATORY (NYC)

Lat: 40°47' N Long: 73°58' W Elev (Ground): 132 Feet

Time Zone: EASTERN WBAN: 94728 ISSN #:0198-3601

DATE	TEMPERATURE °F						DEG DAYS BASE 65°		WEATHER	SNOW/ICE ON GND (IN)		PRECIPITATION (INCHES)		PRESSURE (INCHES OF HG)		WIND SPEED = MPH DIR = TENS OF DEGREES						DATE									
	MAXIMUM	MINIMUM	AVERAGE	DEP FROM NORMAL	AVERAGE DEW PT	AVERAGE WET BULB	HEATING	COOLING		0700 LST	1300 LST	2400 LST	2400 LST	AVERAGE STATION	AVERAGE SEA LEVEL	RESULTANT SPEED	RES DIR	AVERAGE SPEED	MAXIMUM												
																			5-SEC	2-MIN	SPEED		DIR	SPEED	DIR						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24								
01	73	59	66	-2			0	1	RA			0.0	0.69					6.3					01								
02	71	55	63	-5	54	58	2	0	RA			0.0	T	29.59	29.66	3.4	18	6.9	25	20	16	19	02								
03	67	57	62	-6	46	54	3	0				0.0	0.00	29.54	29.61	9.4	32	10.7	32	30	20	33	03								
04	69	53	61	-8	40	50	4	0				0.0	0.00	29.65	29.72	5.8	31	8.7	29	27	20	32	04								
05	69	54	62	-7	39	50	3	0	RA			0.0	T	29.63	29.70	7.9	31	9.2	24	34	18	29	05								
06	71	54	63	-6	42	52	2	0				0.0	0.00	29.72	29.79	4.9	32	7.3	24	34	16	30	06								
07	67	54	61	-8	43	51	4	0				0.0	0.00	29.84	29.90	4.5	31	7.3	21	29	14	30	07								
08	66	52*	59*	-11	48	54	6	0				0.0	0.00	29.93	30.00	4.8	31	8.1	24	31	16	33	08								
09	71	54	63	-7	53	57	2	0				0.0	0.00	30.07	30.14	1.2	16	5.1	16	19	13	16	09								
10	72	56	64	-6	54	58	1	0	BR HZ			0.0	0.00	30.05	30.12	2.0	19	5.0	17	19	13	17	10								
11	70	61	66	-5	58	61	0	1	RA BR			0.0	T	30.05	30.11	4.9	16	6.7	17	16	13	18	11								
12	65	61	63	-8	63	63	2	0	RA BR			0.0	1.29	29.87	29.93	3.9	17	6.9	22	17	15	17	12								
13	70	63	67	-4	66	66	0	2	RA FG+ BR			0.0	1.57	29.52	29.59	1.6	08	4.1	17	08	13	07	13								
14	70	62	66	-5	65	65	0	1	RA FG BR			0.0	0.34	29.38	29.45	1.0	04	5.1	18	06	15	07	14								
15	71	64	68	-4	66	66	0	3	RA FG BR HZ			0.0	0.09	29.49	29.55	1.4	12	4.6	17	19	11	16	15								
16	83	66	75	3	68	70	0	10	RA FG BR HZ			0.0	0.04	29.55	29.62	2.0	27	4.7	22	30	15	30	16								
17	80	66	73	1	66	68	0	8	RA BR HZ			0.0	0.30	29.71	29.78	3.1	28	6.3	20	30	13	02	17								
18	82	66	74	2	65	68	0	9	RA FG+ BR HZ			0.0	0.35	29.77	29.83	2.8	31	5.5	32	08	28*	08	18								
19	84	67	76	3	65	69	0	11				0.0	0.00	29.72	29.78	1.4	28	4.3	15	24	11	27	19								
20	87	70	79	6	69	71	0	14	RA BR HZ			0.0	0.10	29.72	29.78	1.4	31	4.0	23	29	18	28	20								
21	83	68	76	3	69	71	0	11	BR HZ			0.0	0.00	29.92	29.99	2.5	10	5.9	17	21	13	17	21								
22	73	67	70	-3	65	67	0	5	BR HZ			0.0	0.00	30.05	30.11	1.1	15	4.2	13	16	10	16	22								
23	73	68	71	-2	68	69	0	6	RA BR			0.0	T			1.9	18	4.2	14	19	9	19	23								
24	84	70	77	3	72	73	0	12	RA FG+ BR HZ			0.0	0.33			1.8	26	3.7	17	30	15	29	24								
25	90	72	81	7	71	75	0	16	BR HZ			0.0	0.00			2.3	29	4.8	18	27	13	27	25								
26	92*	75	84*	10	73	76	0	19	RA BR HZ			0.0	0.02			3.3	27	7.2	25	27	17	26	26								
27	84	69	77	3	68	71	0	12	RA BR HZ			0.0	0.03			2.1	36	8.5	31	29	20	30	27								
28	78	63	71	-4	62	65	0	6				0.0	0.00			2.5	22	5.8	20	25	14	24	28								
29	76	65	71	-4	67	68	0	6	RA BR HZ			0.0	T			6.5	25	8.2	24	26	15	26	29								
30	82	65	74	-1	70	71	0	9	RA FG BR HZ			0.0	0.79			3.2	27	6.4	33*	31	20	32	30								
75.8 62.5 69.2										1.0 5.4		< MONTHLY AVERAGES		TOTALS-->		0.0 5.94		6.2		<-- MONTHLY AVERAGES											
-4.3 -5 -2.4												<----- DEPARTURE FROM NORMAL ----->		2.27		SUNSHINE, CLOUD, & VISIBILITY TABLES ON PAGE 3															
DEGREE DAYS										GREATEST 24-HR PRECIPITATION: 1.57 DATE: 13										SEA LEVEL PRESSURE DATE TIME											
MONTHLY TOTAL DEPARTURE 29 29										GREATEST 24-HR SNOWFALL: 0.0 DATE:										MAXIMUM MINIMUM											
SEASON TO DATE TOTAL DEPARTURE 4296 -509										GREATEST SNOW DEPTH:										PRECIPITATION ≥ 0.01 INCH : 13											
HEATING: 29 29										NUMBER OF DAYS WITH → MAXIMUM TEMP ≥ 90: 2										PRECIPITATION ≥ 0.10 INCH : 9											
COOLING: 162 -41										MINIMUM TEMP ≤ 32: 0										SNOWFALL ≥ 1.0 INCH : 0											
287 30										THUNDERSTORMS : 0										HEAVY FOG : 3											

JUNE 1998
NEW YORK C.PARK, NY

HOURLY PRECIPITATION

(WATER EQUIVALENT IN INCHES)

NEW YORK C.PARK, NY
JUNE 1998 NYC WBAN # 94728

DATE	FOR HOUR (LST) ENDING AT												DATE	FOR HOUR (LST) ENDING AT												DATE	Sum of Differents (See Note 2)	2400 LST
	1	2	3	4	5	6	7	8	9	10	11	12		13	14	15	16	17	18	19	20	21	22	23	24			Equiv.
01													01												01	0.00	0.69	
02													02										T	T	02		T	
03													03												03		0.00	
04													04												04		0.00	
05													05							T					05		T	
06													06												06		0.00	
07													07												07		0.00	
08													08												08		0.00	
09													09												09		0.00	
10													10												10		0.00	
11	T	T											11					T	T						11		T	
12	0.02	0.03	0.02	0.05	0.06	0.05	0.06	0.06	0.04	0.01	0.03	0.07	12	0.16	0.17	0.04	0.02	0.01	0.15	0.09	0.09	0.05	0.01	T	0.11	1.45	1.29	
13		0.01		T	T					0.01	0.46	0.85	13	T	T		T						0.01		13	0.47	1.57	
14	0.16	0.01	0.01	0.12	0.01							0.07	14	0.03	0.04	0.01	T	0.01							14		0.34	
15											T	0.05	15	0.04	T	T	T								15		0.09	
16	0.01												16												16		0.04	
17													17							0.27	0.03		0.02	0.01	17		0.30	
18								T	T			0.01	18					0.35							18	0.36	0.35	
19													19												19		0.00	
20												0.09	20	T				0.01	T						20		0.10	
21													21												21		0.00	
22													22												22		0.00	
23													23			T									23		T	
24													24												24	0.00	0.33	
25													25												25		0.00	
26													26												26	0.00	0.02	
27													27												27	0.00	0.03	
28													28												28		0.00	
29													29												29	0.00	T	
30													30												30	0.00	0.79	

MAXIMUM SHORT DURATION PRECIPITATION (See Note 1)

Time Period (Minutes)	5	10	15	20	30	45	60	80	100	120	150	180
Precipitation (Inches)												
Ending Date												
Ending Time (Hour/Min)												

Date and time are not entered for TRACE amounts.

Note 1: NCDC derives these data from one-minute ASOS values. The table is not printed when inconsistent with ASOS hourly totals.

Note 2: The sum of the hourly totals is given when it differs from the daily total. NWS does not edit ASOS hourly values but may edit daily and monthly totals. Hourly, daily, and monthly totals are printed as reported by the ASOS site.

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Time Zone: EASTERN **WBAN:** 94728 **ISSN #:** 0198-3601

TEMPERATURE °F										DEG DAYS BASE 65		WEATHER	SNOWICE ON GROUND				PRECIPITATION (INCHES)				PRESSURE (INCHES OF Hg)		WIND				SPEED - MPH																																																																																																																																																																																																																																																																																																																																																																												
MAXIMUM		MINIMUM		AVERAGE		DEP FROM NORMAL		AVERAGE WET BULB		HEATING			COOLING		DEPTH	0700 LST	1300 LST	EQUIN	2400 LST	FALL	WATER	2400 LST	AVERAGE STATION	AVERAGE SEA LEVEL	RESULTANT	SPEED	RES DIR	AVERAGE SPEED	5-SEC 2-MIN		MAXIMUM																																																																																																																																																																																																																																																																																																																																																																								
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DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100																																																																																																																																																																																																																																																																																																			
01	76	64	70	73	77	79	81	84	86	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200																																																																																																																																																																																																																																																																													
02	81	64	73	77	79	81	84	86	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200																																																																																																																																																																																																																																																																														
03	85	68	77	79	81	84	86	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200																																																																																																																																																																																																																																																																															
04	84	68	76	77	79	81	84	86	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200																																																																																																																																																																																																																																																																														
05	81	66	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	

HOURLY PRECIPITATION

(WATER EQUIVALENT IN INCHES)

NEW YORK C.PARK, NY

JULY 1998

NYC

WBAN # 94728

DATE	FOR HOUR (LST) ENDING AT												DATE	FOR HOUR (LST) ENDING AT												DATE	Sum if Different (See Note 2)	2400 LST Water Equiv.
	1	2	3	4	5	6	7	8	9	10	11	12		13	14	15	16	17	18	19	20	21	22	23	24			
01													01												01	0.00	T	
02													02												02		0.00	
03													03												03		0.00	
04													04												04	0.00	0.05	
05													05												05	0.00	0.32	
06													06												06		0.00	
07													07												07		T	
08		T					T	T	T	T	0.02	0.02	08	T	0.01										08		0.05	
09													09												09		0.00	
10													10												10		0.00	
11													11												11		0.00	
12													12												12		0.00	
13													13												13		0.00	
14													14												14		0.00	
15													15												15		0.00	
16			T							T			16				0.02	0.01				T			16		T	
17													17												17		0.03	
18													18												18		0.00	
19									T				19												19		T	
20													20												20		0.00	
21													21				0.05	T							21		0.05	
22													22												22		0.00	
23													23	0.26	T				T						23		0.26	
24													24												24		0.00	
25													25												25		0.00	
26													26												26		0.00	
27													27												27		0.00	
28													28												28		0.00	
29													29												29		0.00	
30	0.01	0.02	0.02	0.06	0.05	0.13	0.01	T	0.01	T	0.02		30										T	T	30		T	
31													31												31		0.33	

MAXIMUM SHORT DURATION PRECIPITATION (See Note 1)

Time Period (Minutes)	5	10	15	20	30	45	60	80	100	120	150	180
Precipitation (Inches)												
Ending Date												
Ending Time (Hour/Min)												

Date and time are not entered for TRACE amounts.

Note 1: NCDC derives these data from one-minute ASOS values. The table is not printed when inconsistent with ASOS hourly totals.

Note 2: The sum of the hourly totals is given when it differs from the daily total. NWS does not edit ASOS hourly values but may edit daily and monthly totals. Hourly, daily, and monthly totals are printed as reported by the ASOS site.

AUGUST 1998 NEW YORK C.PARK, NY

NEW YORK C.PARK, NY

CENTRAL PARK OBSERVATORY (NYC)

Lat: 40°47' N Long: 73°58' W Elev (Ground): 132 Feet
Time Zone: EASTERN WBAN: 94728 ISSN #0198-3601

AUGUST 1998

LOCAL CLIMATOLOGICAL DATA

NOAA, National Climatic Data Center



DATE	TEMPERATURE °F					DEG DAYS BASE 65°		WEATHER	SNOW/ICE ON GROUND				PRECIPITATION (INCHES)		PRESSURE (INCHES OF HG)		WIND SPEED - MPH DIR - TENS OF DEGREES															
	MAXIMUM	MINIMUM	AVERAGE	DEP FROM NORMAL	AVERAGE DWB PT	AVERAGE WET BULB	HEATING		COOLING		0700 LST	1300 LST	2400 LST	2400 LST	AVERAGE STATION	AVERAGE SEA LEVEL	RESULTANT SPEED	RES DIR	AVERAGE SPEED	5-SEC 2-MIN		MAXIMUM SPEED	DIR	DATE								
01	2	3	4	5	6	7	8	9	0	0	0	11	12	13	14	15	16	17	18	19	20	21	22	23	24							
01	81	64	73	-4	53	62	0	9	0	0	0	0	0	0	0	30.17	30.24	1.8	24	4.7	18	06	15	08	01							
02	83	64	74	-3	58	65	0	12	0	0	0	0	0	0	0	30.09	30.15	0.5	15	4.5	18	20	13	20	02							
03	87	67	77	0	61	67	0	14	0	0	0	0	0	0	0	30.09	30.16	1.7	09	4.4	20	07	15	07	04							
04	87	70	79	2	61	67	0	13	0	0	0	0	0	0	0	30.12	30.18	0.1	07	3.2	16	11	20	05								
05	86	70	78	1	59	66	0	13	0	0	0	0	0	0	0	30.12	30.18	0.1	07	3.2	16	11	20	05								
06	87	70	79	2	58	65	0	14	0	0	0	0	0	0	0	30.12	30.18	1.2	21	3.8	16	19	10	17	06							
07	84	68	76	-1	61	67	0	11	0	0	0	0	0	0	0	30.18	30.24	2.7	12	5.8	22	07	14	07	07							
08	85	67	76	-1	65	69	0	11	0	0	0	0	0	0	0	30.25	30.32	2.0	13	6.0	18	18	14	20	08							
09	86	72	79	2	68	71	0	14	0	0	0	0	0	0	0	30.15	30.21	1.1	19	5.4	17	16	13	19	09							
10	85	73	79	2	70	73	0	14	0	0	0	0	0	0	0	29.88	29.94	3.6	21	6.9	22	19	15	20	10							
11	88	71	80	3	69	72	0	15	0	0	0	0	0	0	0	29.72	29.79	1.7	30	4.6	16	27	11	30	11							
12	86	68	77	1	62	67	0	12	0	0	0	0	0	0	0	29.93	29.99	4.2	08	7.2	21	07	16	07	12							
13	77	68	73	-3	63	66	0	8	0	0	0	0	0	0	0	30.08	30.14	3.0	11	6.9	21	07	15	07	13							
14	76	69	73	-3	62	66	0	8	0	0	0	0	0	0	0	29.98	30.05	3.1	22	6.6	22	21	14	21	14							
15	84	70	77	1	63	68	0	12	0	0	0	0	0	0	0	29.91	29.97	1.0	20	4.9	20	18	13	19	15							
16	87	71	79	3	67	71	0	14	0	0	0	0	0	0	0	29.97	30.03	1.1	19	2.9	13	18	10	17	16							
17	79	73	76	0	73	74	0	11	0	0	0	0	0	0	0	29.91	29.97	3.2	09	5.0	15	07	11	07	17							
18	87	65	76	1	68	71	0	11	0	0	0	0	0	0	0	29.80	29.87	1.8	35	6.0	24	03	18	07	18							
19	73	59	66	-9	48	56	0	1	0	0	0	0	0	0	0	30.03	30.09	6.8	04	8.5	24	07	17	07	19							
20	79	58	69	-6	50	58	0	4	0	0	0	0	0	0	0	30.14	30.21	0.3	29	4.2	16	24	11	25	20							
21	84	64	74	-1	59	65	0	9	0	0	0	0	0	0	0	30.05	30.12	1.0	31	3.5	13	07	10	29	21							
22	84	67	76	1	64	68	0	11	0	0	0	0	0	0	0	29.98	30.05	1.7	10	5.6	15	10	11	07	22							
23	85	71	78	4	69	72	0	13	0	0	0	0	0	0	0	29.84	29.90	1.6	24	5.4	21	24	13	25	23							
24	90	75	83	9	69	73	0	18	0	0	0	0	0	0	0	29.71	29.77	6.4	27	8.3	24	26	16	26	24							
25	91	76	84	10	65	71	0	19	0	0	0	0	0	0	0	29.74	29.80	3.7	28	5.7	26	30	18	29	25							
26	88	70	79	5	72	74	0	14	0	0	0	0	0	0	0	29.82	29.89	1.0	25	4.3	18	25	14	27	26							
27	85	72	79	5	65	69	0	13	0	0	0	0	0	0	0	29.94	30.00	5.2	08	6.9	18	07	15	07	27							
28	82	73	78	5	66	69	0	14	0	0	0	0	0	0	0	29.86	29.92	10.6	09	11.5	36	07	25	08	28							
29	87	71	79	6	64	69	0	15	0	0	0	0	0	0	0	29.75	29.81	3.7	30	5.6	16	31	13	31	29							
30	88	71	80	7	64	69	0	14	0	0	0	0	0	0	0	29.81	29.88	2.3	28	4.0	13	30	9	27	30							
31	84	70	77	4	62	67	0	12	0	0	0	0	0	0	0	29.82	29.88	1.5	09	5.1	16	07	11	08	31							
TOTALS ->																		<- MONTHLY AVERAGES					5.6					<- MONTHLY AVERAGES				
84.4 68.9 76.7																		0.7 1.6 1.2					SUNSHINE, CLOUD, & VISIBILITY TABLES ON PAGE 3									
0.7																		1.6 1.2					SEA LEVEL PRESSURE					DATE TIME				
GREATEST 24-HR PRECIPITATION: 2.39																		GREATEST 24-HR SNOWFALL: 0.0					MAXIMUM MINIMUM					30.35 08 1037				
GREATEST SNOW DEPTH: 0.0																		NUMBER OF DAYS WITH					PRECIPITATION ≥ 0.01 INCH					5				
HEATING: 1021																		COOLING: 368					PRECIPITATION ≥ 0.10 INCH					2				
TOTAL DEPARTURE																		MONTHLY					SNOWFALL ≥ 1.0 INCH					0				

HOURLY PRECIPITATION

(WATER EQUIVALENT IN INCHES)

NEW YORK C.PARK, NY

AUGUST 1998

NYC

WBAN # 94728

DATE	FOR HOUR (LST) ENDING AT												DATE	FOR HOUR (LST) ENDING AT												DATE	Sum if Different (See Note 2)	2400 LST	
	1	2	3	4	5	6	7	8	9	10	11	12		13	14	15	16	17	18	19	20	21	22	23	24			Water	Equip.
01													01												01			0.00	
02													02												02			0.00	
03													03												03			0.00	
04													04												04			0.00	
05													05												05			0.00	
06													06												06			0.00	
07													07												07			0.00	
08													08												08			0.00	
09													09												09			0.00	
10													10							T		T	0.05	0.01	10			0.08	
11	T	0.01	0.04	0.03	0.01	T							11												11			0.09	
12													12												12			0.00	
13													13												13			0.00	
14													14												14			0.00	
15													15												15			0.00	
16													16												16			0.00	
17											0.05	0.10	17	0.34	0.70	0.79	0.16	0.22	T						17			2.38	
18	0.01												18					T							18			0.05	
19													19						T						19			0.00	
20													20							0.01	0.03	T	0.01	T	20			0.00	
21													21												21			0.00	
22													22												22			0.00	
23													23												23			0.00	
24													24												24			0.00	
25													25		T	T		T							25			T	
26	0.04	0.02	0.03	0.04	0.02	0.03	0.01	0.01					26											T	26			0.20	
27	T			T		T	T	T					27												27			T	
28													28					T							28			T	
29													29												29			0.00	
30													30												30			0.00	
31													31												31			0.00	

MAXIMUM SHORT DURATION PRECIPITATION (See Note 1)

Time Period (Minutes)	5	10	15	20	30	45	60	80	100	120	150	180
Precipitation (Inches)												
Ending Date												
Ending Time (Hour/Min)												

Date and time are not entered for TRACE amounts.

Note 1: NCDC derives these data from one-minute ASOS values. The table is not printed when inconsistent with ASOS hourly totals.

Note 2: The sum of the hourly totals is given when it differs from the daily total. NWS does not edit ASOS hourly values but may edit daily and monthly totals. Hourly, daily, and monthly totals are printed as reported by the ASOS site.

APPENDIX B

FIELD MEASUREMENTS AND ANALYTICAL DATA IN EXCEL SPREADSHEETS

Lake Number	Name	Date	Lake Depth (meters)
1A 1B 1C	Wolf's Pond	11/10/97	1.5
2A	Richmondton Millpond	11/10/97	0.3
3A 3B 3C	Harlem Meer	11/12/97	2.2
4A 4B	Van Cortlandt Lake	11/12/97	1.2
5A 5B 5C	Prospect Park Lake	11/25/97	2.3
6A 6B	Conselyea's Pond	11/25/97	1.4
7A 7B 7C	Oakland Lake	12/4/97	3.3
8A 8B 8C	Kissena Lake	12/4/97	2
9A 9B	Meadow Lake	12/4/97	1.1

Secchi depth (meters)	Actual Depth of sample (feet)	Temperature (degrees F)	pH
0.54	1 ft below the surface	50.7	7.12
	1 ft above the bottom	50.5	7.21
	Mid-depth, 2 ft below the surface	50.6	7.18
0.24	Mid depth, 0.5 ft below the surface	51.2	7.87
0.73	1 ft below the surface	48.8	7.29
	1 ft above the bottom	48.6	7.11
	Mid-depth, 3 ft below the surface	48.6	7.22
0.5	1 ft below the surface	47	7.73
	1 ft above the bottom	46.8	7.29
1.16	1 ft below the surface	39.5	7.7
	1 ft above the bottom	39.4	7.36
	Mid-depth, 3 ft below the surface	39.5	7.41
0.35	1 ft below the surface	48.4	8.99
	1 ft above the bottom	51.1	7.42
1.79	1 ft below the surface	40.2	7.66
	1 ft above the bottom	40.1	7.44
	Mid-depth, 4.5 ft below the surface	40.1	7.49
1.38	1 ft below the surface	41.5	7.55
	1 ft above the bottom	41.2	7.23
	Mid-depth, 3 ft below the surface	41.3	7.34
0.42	1 ft below the surface	39.1	8.66
	1 ft above the bottom	39	8.67

Conductivity (microsiemens per cm)	Salinity (ppt)	Dissolved Oxygen (mg/l)
181	0.1	9.07
182	0.1	9.25
182	0.1	9.21
452	0.2	7.81
242	0.1	7.19
242	0.1	6.52
244	0.1	6.78
373	0.2	9.77
378	0.2	8.8
93	0	12.49
93	0	11.65
93	0	12.19
16720	7.5	20.22
23360	13.6	17.75
564	0.3	10.5
567	0.3	10.3
566	0.3	10.4
76	0	11.09
76	0	10.98
76	0	10.87
1128	0.6	13.95
1129	0.6	13.87

Percent Saturation	Turbidity (NTU)	Hardness (mg/l)	Chloride (mg/l)
80.8 81.5 82.3	7.5	58	22.1
68.3	7.5	161	66.3
62.3 56.9 58.9	6.1	71	90
83.1 74.4	4.3	110	69.2
95 91 94.9	5	28	8.68
196 181	8	1360	3761
82 79 80	7	211	91.1
88 86.2 86	9	26	1.5
107.2 106.2	17	292	254.7

FALL 1997 SUF

Chlorophyll a (mg/cubic meter)	Chlorophyll b (mg/cubic meter)
13	14.6
3.6	6.24
3.9	5.4
6.64	10.3
12.8	14.2
77.9	110.1
9.07	12.2
68.4	75.3
87.4	95.1

VEY

Chlorophyll c (mg/cubic meter)	ORP millivolts	Lead (ug/l)	Copper (ug/l)	Zinc (ug/l)
2.47	461 458	6.1	7.8	6
2.09	446	11.5	14.3	10.2
1.38	472 467	9.9	9.5	3.6
6.61	458 454	20.2	13.1	5.8
3.15	454 450	8.2	2	12
22.8	394 383	7.3	1.7	9.6
2.29	432 431	1	1	1
11.3	447 447	1.6	1	1.3
11.7	404 391	8.8	1.8	2.2

Cadmium (ug/l)	Color (cu)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)
1	80	0.144	0.05
	80	0.126	0.05
1	80	0.288	0.05
1	80	0.317	0.05
	80	0.359	0.05
1	80	0.05	0.05
	80	0.05	0.05
1	60	0.05	0.05
	60	0.05	0.05
1	60	0.38	0.05
	60	0.27	0.15
1	30	1.52	0.05
	40	1.52	0.05
1	30	0.082	0.05
	30	0.082	0.05
1	180	0.202	0.05
	120	0.202	0.05

Ammonia Nitrogen (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Orthophosphate (mg/l)
0.201	2.1	0.1
0.207	1.54	0.1
0.123	1.4	0.247
0.141	2.52	0.127
0.201	1.26	0.1
0.1	1.4	0.1
0.1	1.68	0.128
0.1	1.4	0.1
0.1	1.54	0.1
0.14	2.8	0.13
0.1	1.26	0.158
0.1	1.4	0.1
0.1	1.54	0.1
0.1	1.12	0.1
0.1	1	0.1
0.116	2.66	0.1
0.13	2.8	0.1

Total Phosphorus (mg/l) Fecal Coliform (cfu/100ml) Fecal Streptococci (cfu/100ml)

0.189	1800	
0.173		
0.274	2500	
0.155	400	46
0.182		
0.139	800	31
0.145		
0.1	1	33
0.1		
0.156	200	49
0.177		
0.149	1	920
0.234		
0.282	1	5
0.231		
0.173	1	2
0.168		

Total Organic Carbon (mg/l)	Carlson Trophic Index (based on Secchi Reading)
10	69
10	79
10	65
10	70
10	59
10	75
10	52
10	56
10	76

Total Nitrogen/Total Phosphorous

12.13756614
9.919075145

6.343065693

18.62580645
9.17032967

10.79136691
12.27586207

15
16.4

20.70512821
9.491525424

19.93288591
13.29059829

4.439716312
4.9004329

16.83236994
18.16666667

Lake Number	Name	Date	Lake Depth (meters)
1A 1B 1C	Wolf's Pond	5/26/98	1.5
2A	Richmondton Millpond	5/26/98	0.3
3A 3B 3C	Harlem Meer	6/4/98	2.2
4A 4B	Van Cortlandt Lake	6/4/98	1.2
5A 5B 5C	Prospect Park Lake	6/8/98	2.3
6A 6B	Conselyea's Pond	6/8/98	1.4
7A 7B 7C	Oakland Lake	6/9/98	3.3
8A 8B 8C	Kissena Lake	6/9/98	2
9A 9B	Meadow Lake	6/9/98	1.1

Secchi depth (meters)	Actual Depth of sample (feet)	Temperature (degrees F)
0.64	1 ft below the surface	71.4
	1 ft above the bottom	70.2
	Mid-depth, 2 ft below the surface	70.6
Visible on the bottom	Mid-depth, 0.5 ft below the surface	62.2
1.52	1 ft below the surface	71
	1 ft above the bottom	70.7
	Mid-depth, 3 ft below the surface	70.9
0.88	1 ft below the surface	68.7
	1 ft above the bottom	66.1
0.4	1 ft below the surface	65.9
	1 ft above the bottom	65.7
	Mid-depth, 3 ft below the surface	65.9
0.6	1 ft below the surface	77.8
	1 ft above the bottom	74.8
2.34	1 ft below the surface	66.3
	1 ft above the bottom	64.6
	Mid-depth, 4.5 ft below the surface	65.7
1.03	1 ft below the surface	68.2
	1 ft above the bottom	66.1
	Mid-depth, 3 ft below the surface	66.2
0.16	1 ft below the surface	64.8
	1 ft above the bottom	64.1

pH	Conductivity (microsiemens per cm)	salinity (ppt)
7.5	177	0.1
7.28	178	0.1
7.33	179	0.1
7.25	606	0.3
9.08	305	0.1
9.07	308	0.1
9.09	306	0.1
7.83	621	0.3
7.98	647	0.3
9.48	109	0
9.48	107	0
9.53	107	0
8.39	16500	9
7.81	19300	11.4
7.49	580	0.3
7.11	582	0.3
7.42	574	0.3
9.88	128	0.1
9.81	126	0.1
9.87	128	0.1
9.31	6480	3.6
9.31	6570	3.6

Dissolved Oxygen (mg/l) Percent Saturation Turbidity (NTU) Hardness (mg/l)

7.1	82	6	58
6.42	73.3		
6.66	74.5		
8.1	84	4	183
9.9	112.9	3.4	95
10.2	116.1		
9.83	112.4		
9.62	107	5.6	155
10.88	120.1		
10.12	109.5	15	35
9.46	101.8		
9.53	106.3		
13.9	183	14	1060
13.6	174		
9.41	102.1	2.4	189
8.18	86.4		
10.35	111.5		
11.56	128.5	5.1	34
10.67	115.4		
10.6	115		
11.53	125.3	30	742
11.34	124		

SPRING 1998 SU

Chloride (mg/l)	Chlorophyll a (mg/cubic meter)	Chlorophyll b (mg/cubic meter)

10.6	14.3	22

82.5	1	3.05

33.6	3.83	6.9

107.1	1.81	1.46

8.4	59.9	71.8

5691	68.8	85.9

83.9	7.56	9.83

12.8	22.2	26.3

186.5	70.4	70.2

IRVEY

Chlorophyll c (mg/cubic meter) ORP millivolts Lead (ug/l) Copper (ug/l) Zinc (ug/l)

4.21 403 7.6 4.2 3.3
403

1 412 6.3 9.8 4.4

1.49 388 16.6 1 5.7
421

1 431 20.2 1.3 3.9
452

1 375 17.1 1 1
398

7.66 429 1 11.9 23.9
442

6.81 398 6.7 5 2.1
307

1.6 309 3 13.9 1.9
297

1 336 22.1 6.6 3
328

Cadmium (ug/l)	Color (cu)	Nitrate Nitrogen (mg/l)	Nitrite Nitrogen (mg/l)
1	70	0.116	0.05
	80	0.129	0.05
1	25	0.85	0.05
1	25	0.05	0.05
	25	0.05	0.05
1	40	0.295	0.05
	40	0.301	0.05
1	40	0.05	0.05
	30	0.05	0.05
1	40	0.05	0.05
	25	0.05	0.05
1	5	0.496	0.05
	5	0.05	0.052
1	10	0.05	0.05
	20	0.069	0.05
1	30	0.05	0.05
	25	0.05	0.05

Ammonia Nitrogen (mg/l) Total Kjeldahl Nitrogen (mg/l) Orthophosphate (mg/l)

0.137	6.86	0.1
0.126	3.5	0.1

0.176	7.98	0.1

0.111	3.22	0.1
0.1	3.08	0.1

0.1	4.2	0.1
0.166	3.5	0.1

0.139	5.46	0.1
0.106	10.8	0.1

0.155	8.28	0.1
0.441	9.66	0.543

0.229	3.22	0.1
0.649	3.36	0.1

0.1	3.5	0.228
0.1	3.64	0.257

0.223	3.36	0.1
0.205	3.5	0.1

Total Phosphorus (mg/l) Fecal Coliform (cfu/100ml) Fecal Streptococci (cfu/100ml)

0.1 0.1	32	1
0.11 TNTC		1
0.1 0.1	12	1
0.1 0.1	16	1
0.1 0.1	8	1
0.131 0.571	100	1
0.1 0.1	3	1
0.258 0.301	1	1
0.1 0.1	18	1

Total Organic Carbon (mg/l) Carlson Trophic Index (based on Secchi Readings)

10	68
10 -	
10	54
10	61
10	74
10	68
10	48
10	60
10	80

Total Nitrogen/Total Phosphorous

70.26
36.79

80.72727273

33.2
31.8

45.45
38.51

55.6
109

63.96946565
17.09281961

37.66
34.62

13.95348837
12.48837209

34.6
36

Lake Number	Name	Date	Lake Depth (meters)
1A 1B 1C	Wolf's Pond	7/29/98	1.5
2A	Richmondton Millpond	7/29/98	0.3
3A 3B 3C	Harlem Meer	8/3/98	2.2
4A 4B	Van Cortlandt Lake	8/3/98	1.2
5A 5B 5C	Prospect Park Lake	8/5/98	2.3
6A 6B	Conselyea's Pond	8/5/98	1.4
7A 7B 7C	Oakland Lake	8/10/98	3.3
8A 8B 8C	Kissena Lake	8/10/98	2
9A 9B	Meadow Lake	8/10/98	1.1

Secchi depth (meters)	Actual Depth of sample (feet)	Temperature (degrees F)
0.6	1 ft below surface	80.4
	1 ft above bottom	78.8
	Mid-depth, 2 ft below the surface	78.8
Visible on the bottom	Mid-depth, 0.5 ft below the surface	69.6
1.28	1 ft below the surface	78.5
	1 ft above the bottom	77.8
	Mid-depth, 3 ft below the surface	78.1
0.46	1 ft below the surface	80.5
	1 ft above the bottom	75.9
0.33	1 ft below the surface	79
	1 ft above the bottom	77.5
	Mid-depth, 3 ft below the surface	78.4
0.7	1 ft below the surface	90.6
	1 ft above the bottom	83.6
1.77	1 ft below the surface	78.3
	1 ft above the bottom	65.4
	Mid-depth, 4.5 ft below the surface	71.7
0.24	1 ft below the surface	81.3
	1 ft above the bottom	77.9
	Mid-depth, 3 ft below the surface	78.5
0.32	1 ft below the surface	83.1
	1 ft above the bottom	81.9

pH	Conductivity (microsiemens per cm)	salinity (ppt)	Dissolved Oxygen (mg/l)
7.72	195	0.1	7.21
7.93	193	0.1	4.6
7.47	194	0.1	4.99
7.18	741	0.4	6.69
9.77	317	0.2	15.52
9.35	315	0.2	9.8
9.77	317	0.2	11.42
9.47	608	0.3	13.65
9.26	609	0.3	14.92
10.22	125	0.1	14.8
7.06	102	0.1	4.73
10.05	118	0.1	12.85
7.69	24000	14.5	12.49
7.2	29730	18.4	0.3
7.64	610	0.3	15.15
6.72	811	0.3	0.41
6.87	641	0.3	0.58
10.44	126	0.1	14.3
7.57	97	0	0.69
10.41	94	0	5.62
10.07	9470	5.3	12.26
10.13	9500	5.4	12.5

Percent Saturation Turbidity (NTU) Hardness (mg/l) Chloride (mg/l)

89.2 57.1 60.2	16	63	19.3
75.6	15	242	109.8
192 120.3 140	4.3	76	57.4
172.3 179.6	8	135	137.5
185.8 63.6 156.5	25	32	11.9
189.6 5.6	10	3100	9099
187.7 4.2 6.5	3.5	226	100.4
182 10.5 68.7	17	23	10.4
165.4 167.6	17	1140	3373

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Chlorophyll a (mg/cubic meter) Chlorophyll b (mg/cubic meter)

32.3	30.2
1.36	129
11.2	11
69.6	64.5
46.1	39
19.6	19.5
10.7	7.64
152.8	126.6
240.5	209.7

/EY

Chlorophyll c (mg/cubic meter) ORP millivolt Lead (ug/l) Copper (ug/l) Zinc (ug/l)

10.4	404 397	11.4	1.8	3.4
1	405	8.5	5.4	9.1
6.57	391 371	5.8	6.4	6.8
16.5	373 393	6.4	2.6	5.2
7.35	351 439	1.5	1.1	2.6
1	431 -146	1	2.7	7.1
3.23	439 236	3.4	1.8	3.6
1	306 308	3.1	1	1
43.3	325 307	1	3	1

Cadmium (ug/l) Color (cu) Nitrate Nitrogen (mg/l) Nitrite Nitrogen (mg/l)

1	160	0.05	0.05
	180	0.05	0.05
1	80	2.14	0.112
1	40	0.05	0.05
		0.05	0.05
1	120	0.05	0.05
		0.05	0.05
1	240	0.05	0.05
		0.05	0.05
1	90	0.05	0.05
		0.05	0.05
1	40	0.242	0.05
		0.05	0.05
1	280	0.05	0.05
		0.05	0.091
1	250	0.31	0.085
		0.28	5.05

Ammonia Nitrogen (mg/l) Total Kjeldahl Nitrogen (mg/l) Orthophosphate (mg/l)

0.14	0.28	0.123
0.12	0.28	0.109

0.2	0.42	0.11

0.28	0.42	0.1
0.28	0.42	0.114

0.42	0.588	0.1
0.42	0.588	0.109

0.14	1.54	0.1
0.28	1.68	0.1

0.1	2.94	0.118
1.05	1.4	1.51

0.1	0.14	0.1
3.22	3.92	0.1

0.1	0.42	0.245
0.56	0.84	0.411

0.42	0.28	0.1
0.28	0.56	0.1

Total Phosphorus (mg/l)	Fecal Coliform (cfu/100ml)	Fecal Streptococci (cfu/100ml)
0.504 0.13	1	1
0.127	1	1
0.1 0.163	1	1
0.123 0.194	30	3
0.1 0.1	1	3
0.138 TNTC 1.67		68
0.208 0.1	68	4
0.294 0.429	41	1
0.1 0.1	12	1

Total Organic Carbon (mg/l) Carlson Trophic Index (based on Secchi Readings)

10	69
13.2 -	
10	57
10	72
10	76
26.6	66
10	52
10	79
10	76

Degree of Artificiality Score Degree of Urbanization Score

2.4	1.4
4	1.7
4.8	4.2
4	2.7
4.4	3.5
4	3.8
0.8	3.2
3.6	2.6
4	3.9

Total Nitrogen/Total Phosphorous

0.753968254
2.923076923

21.03937008

5.2
3.190184049

5.593495935
3.546391753

16.4
17.8

22.02898551
0.898203593

2.076923077
40.2

1.768707483
2.286713287

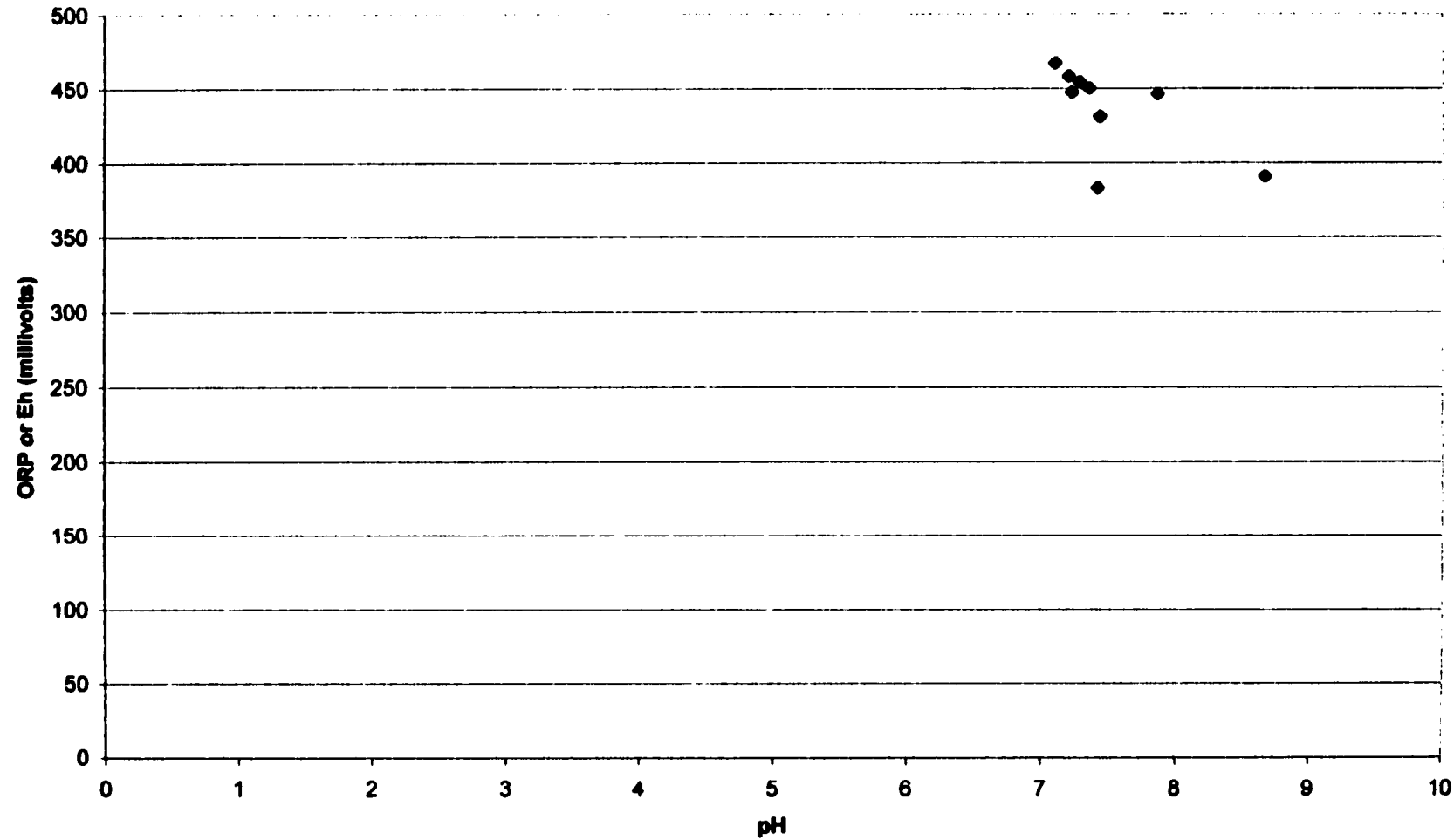
6.75
58.9

APPENDIX C

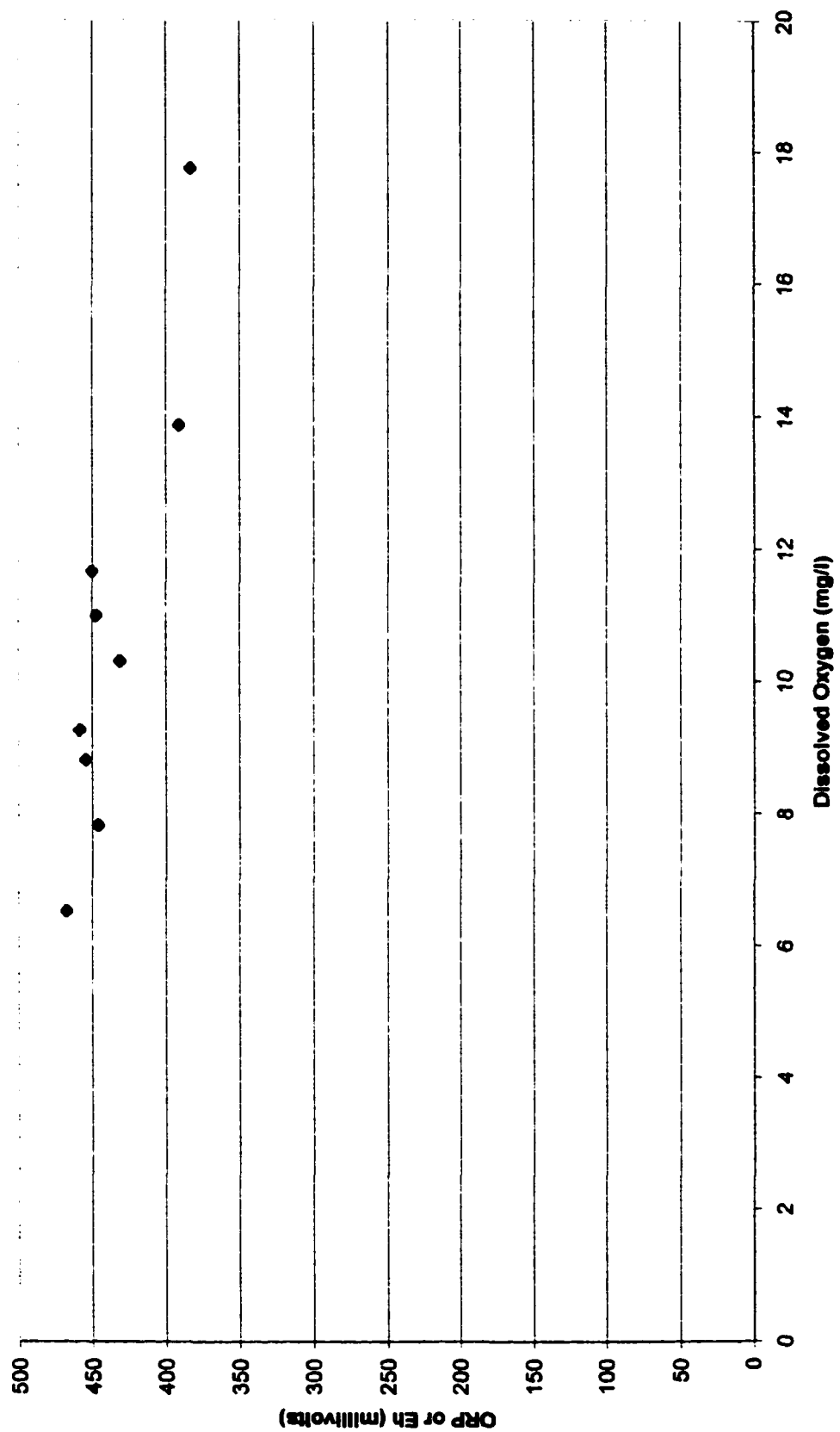
SELECTED SEASONAL DATA SETS IN EXCEL SCATTER PLOTS

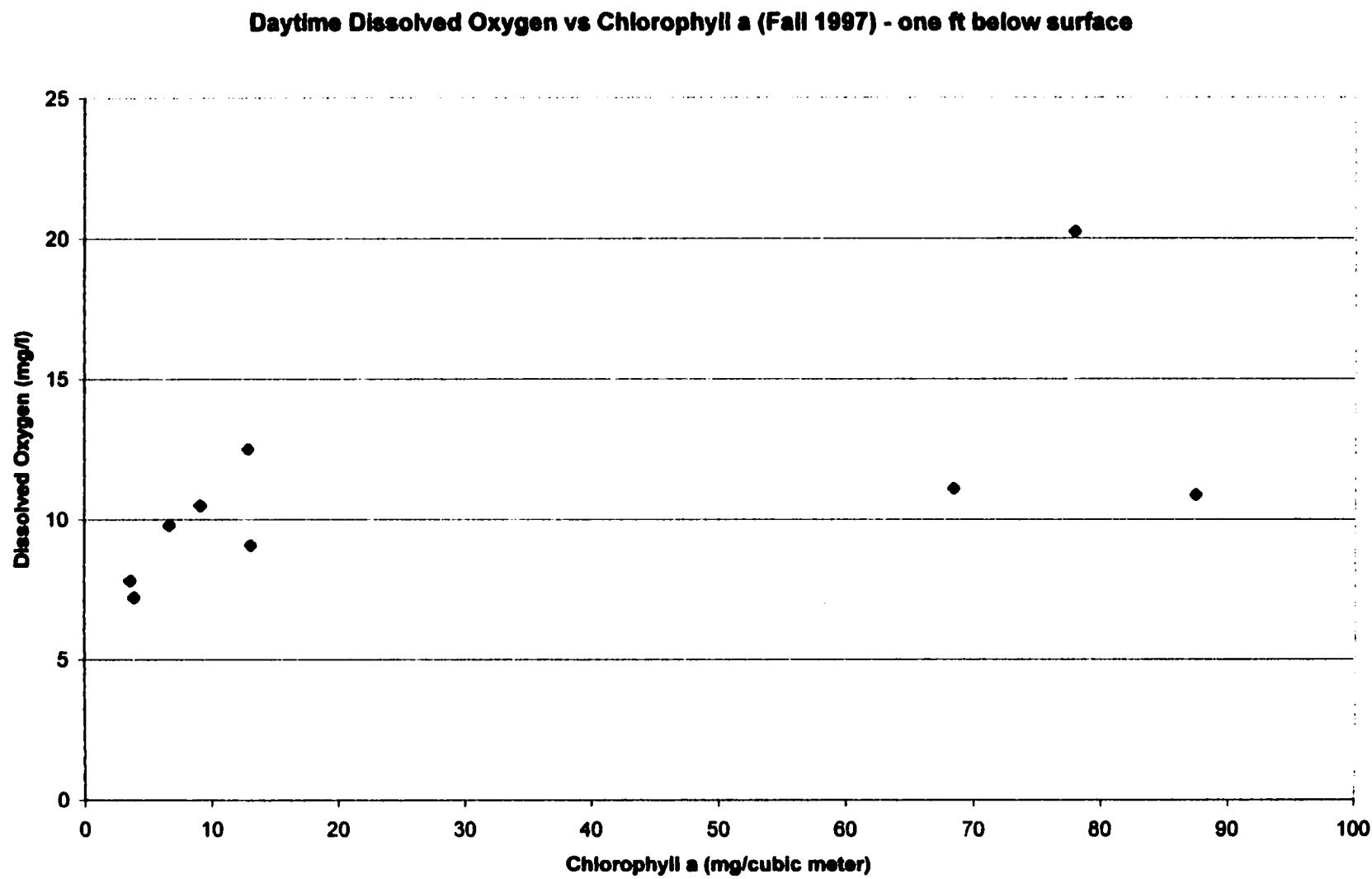
C1 - BETWEEN SELECTED WATER QUALITY PARAMETER PAIRS

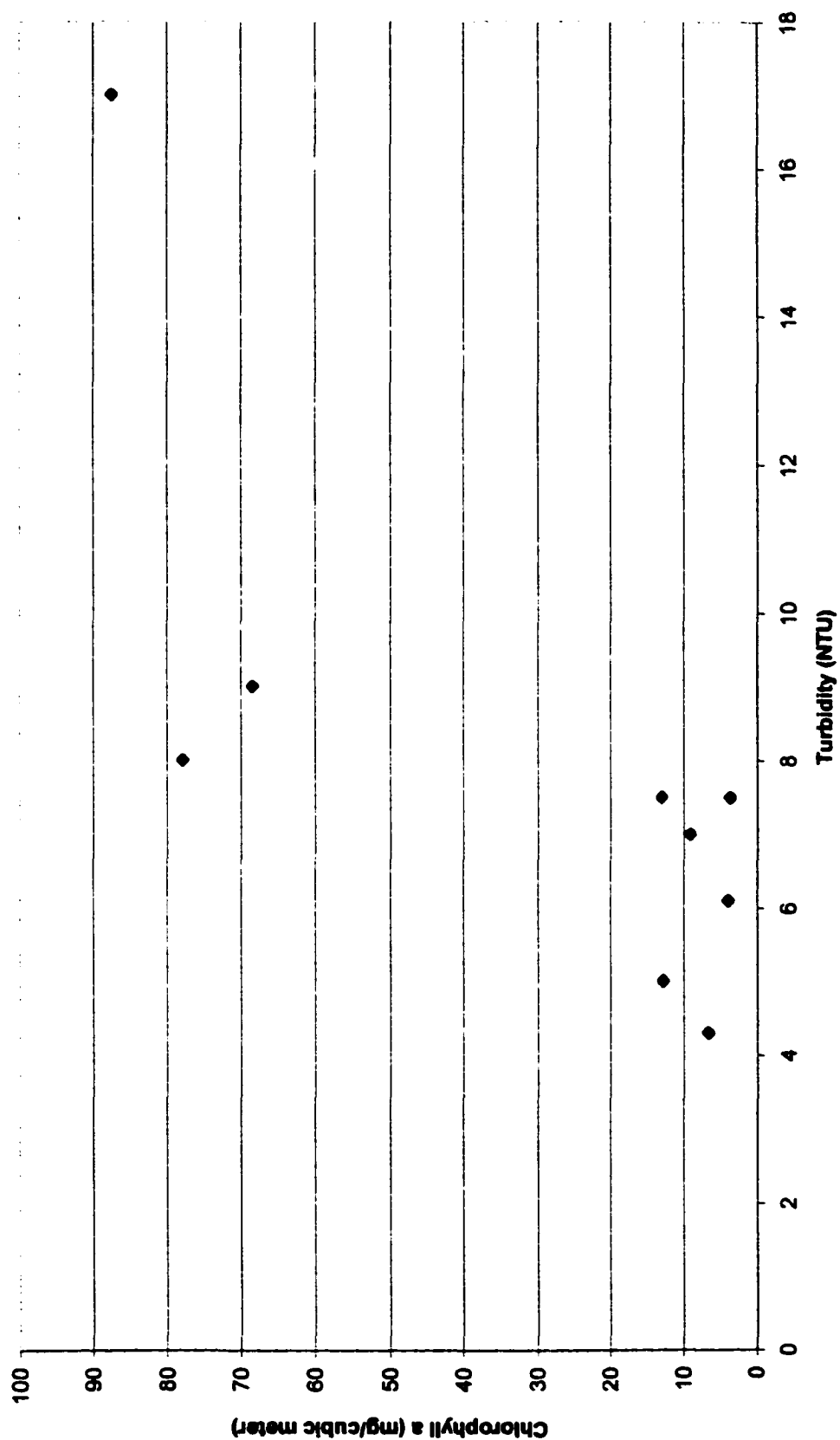
Oxidation - Reduction Potential vs pH (Fall 1997) - one ft above bottom

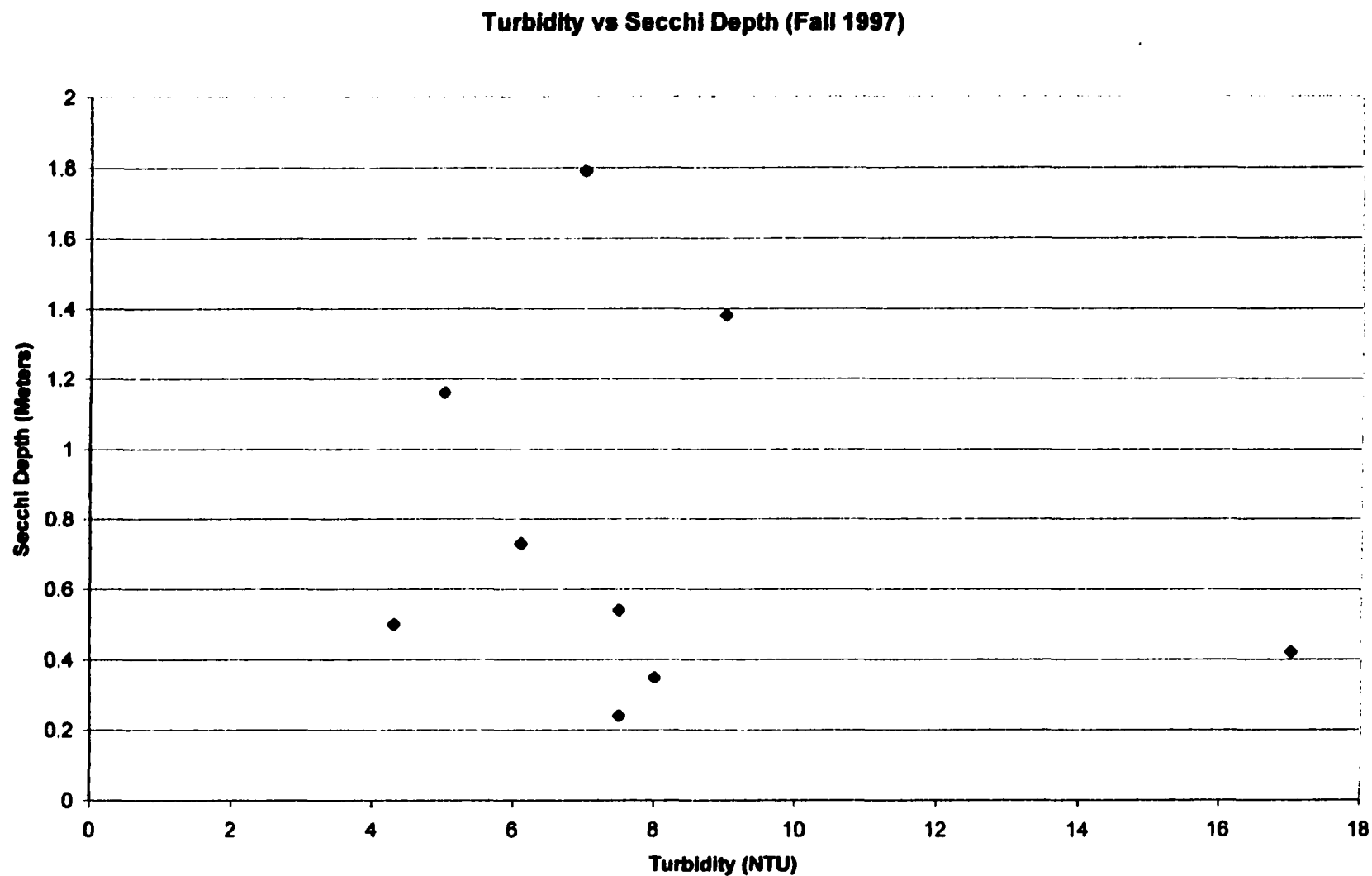


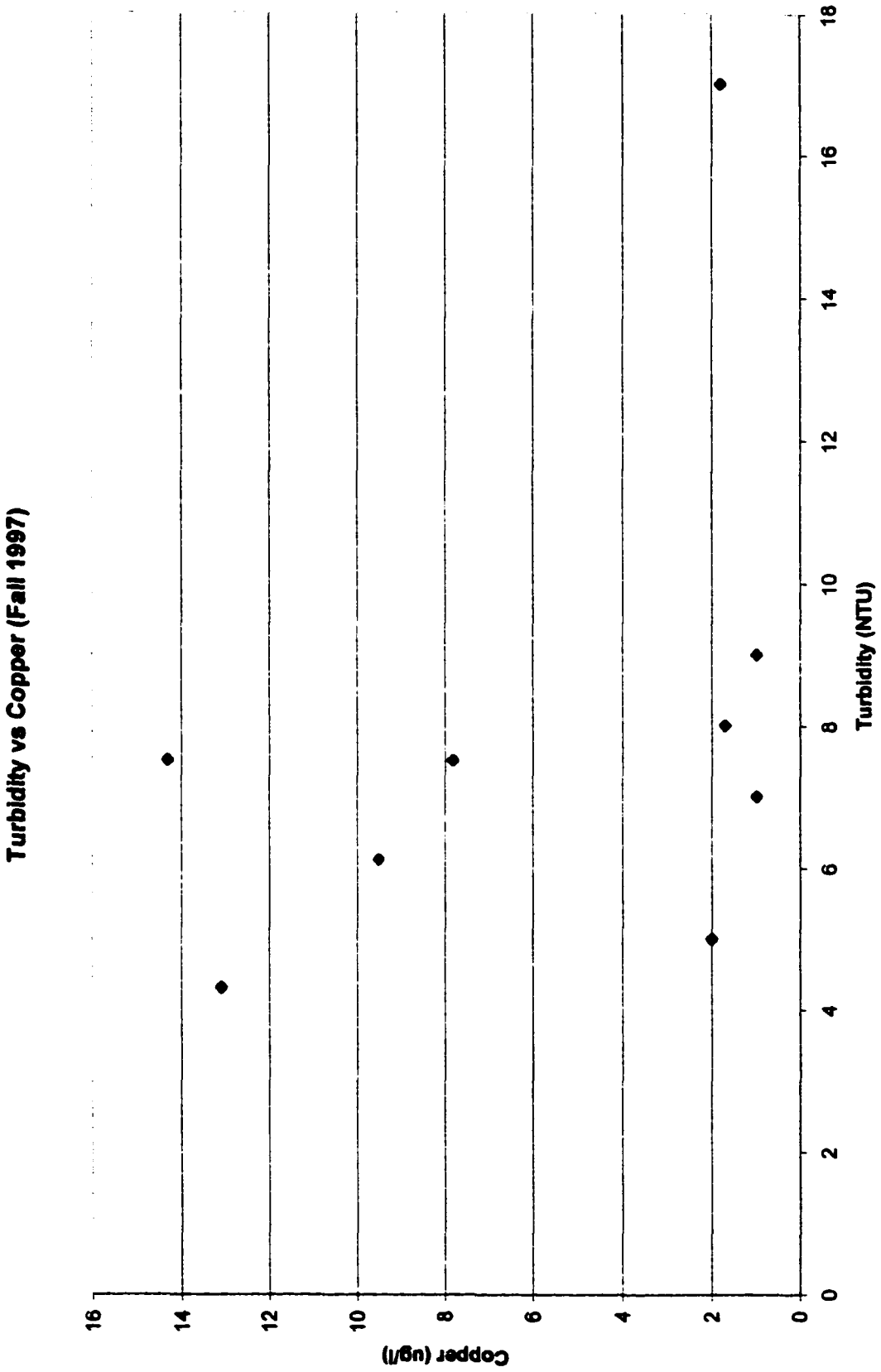
Oxidation - Reduction Potential vs Dissolved Oxygen (Fall 1997) - one ft above bottom

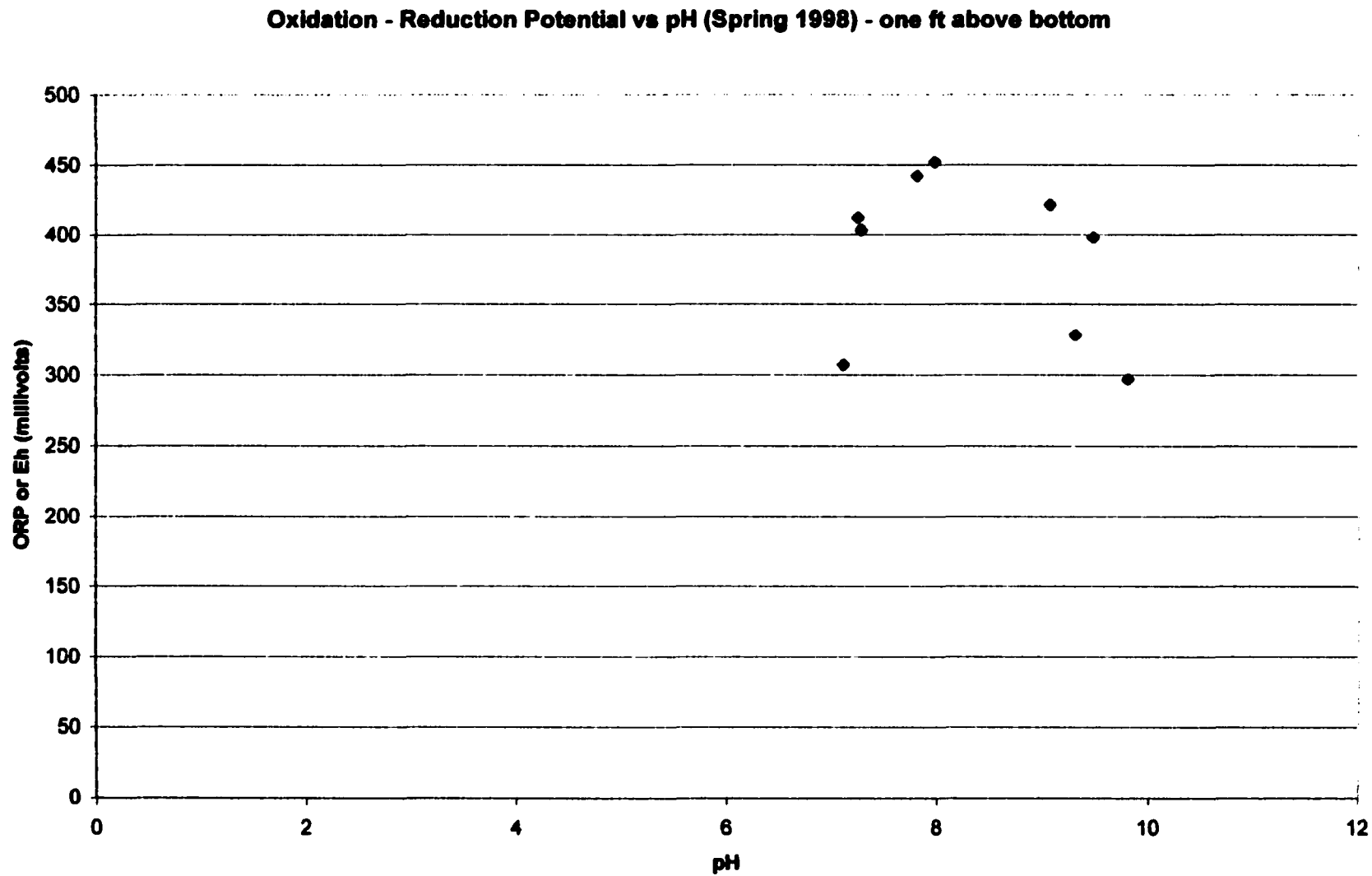




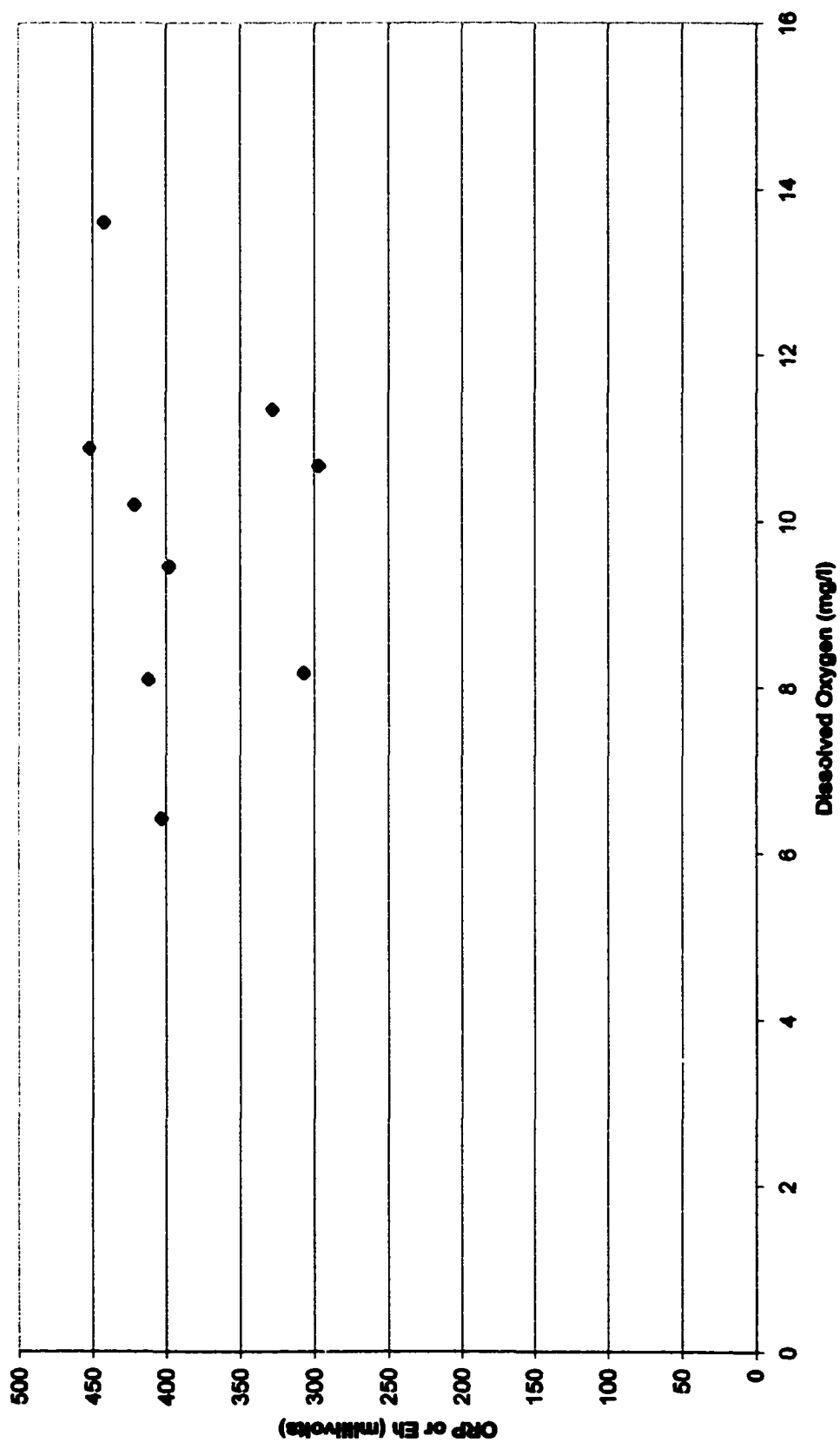
Turbidity vs Chlorophyll a (Fall 1997)



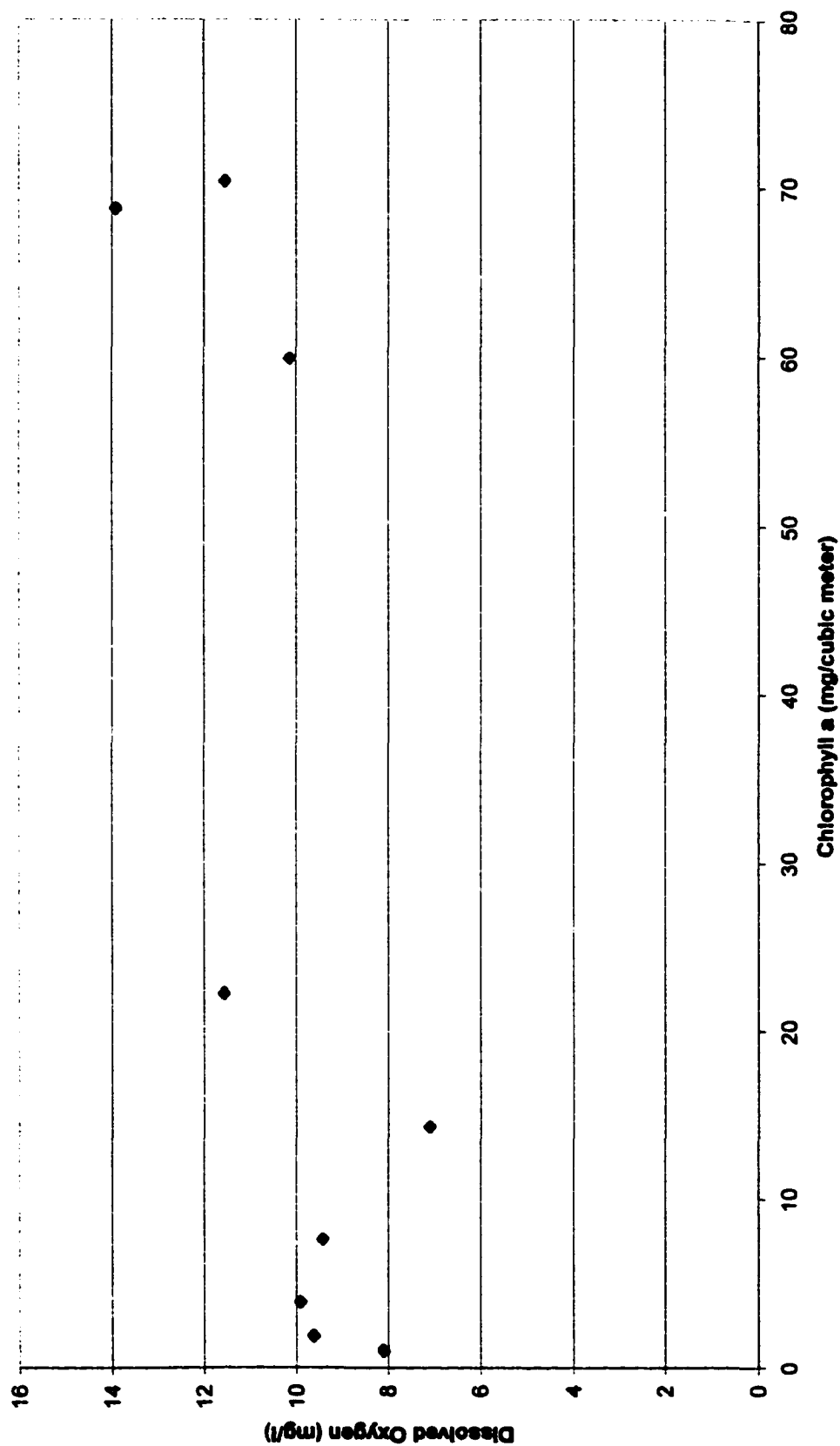




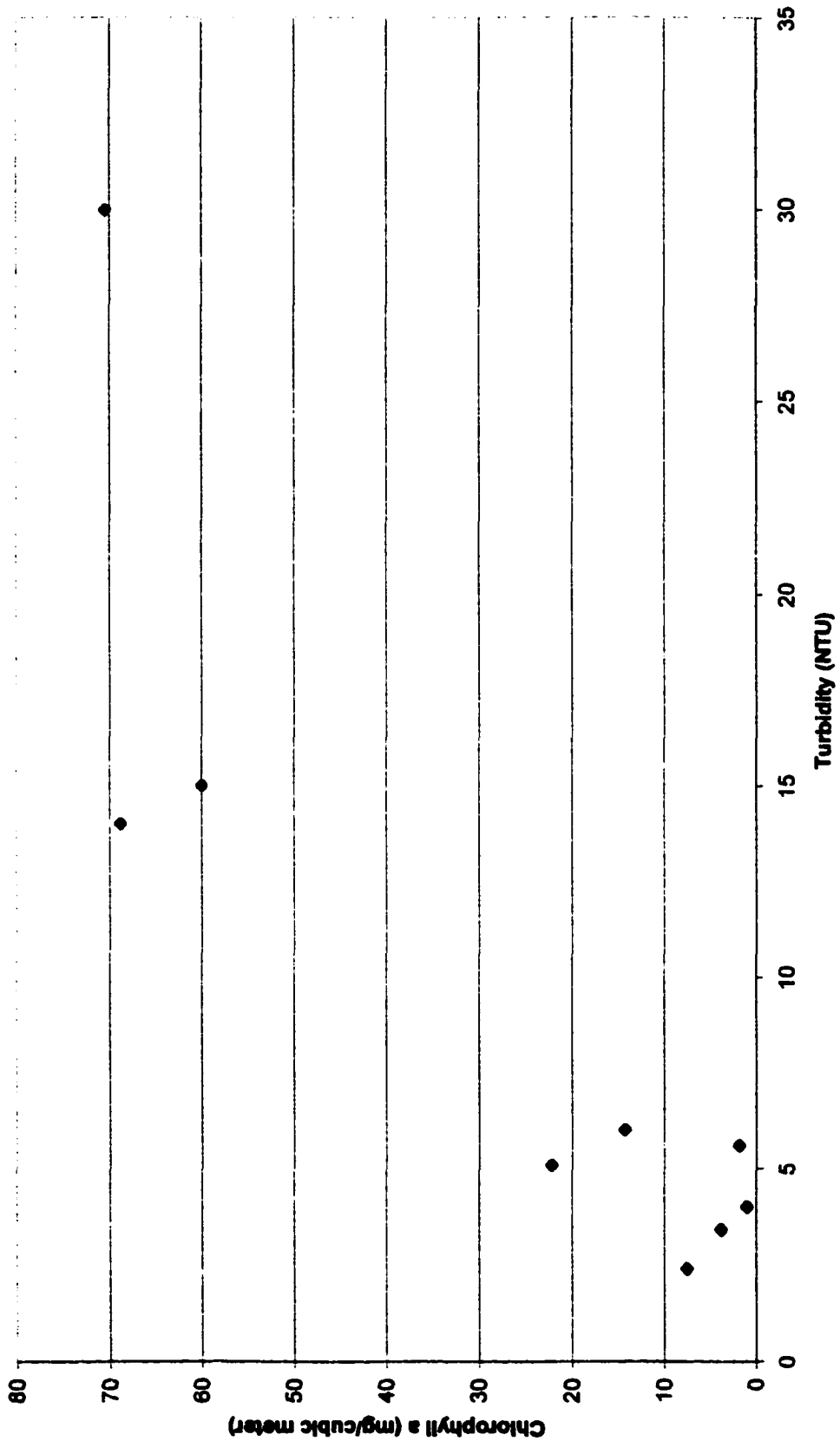
Oxidation - Reduction Potential vs Dissolved Oxygen (Spring 1998) - one ft above bottom

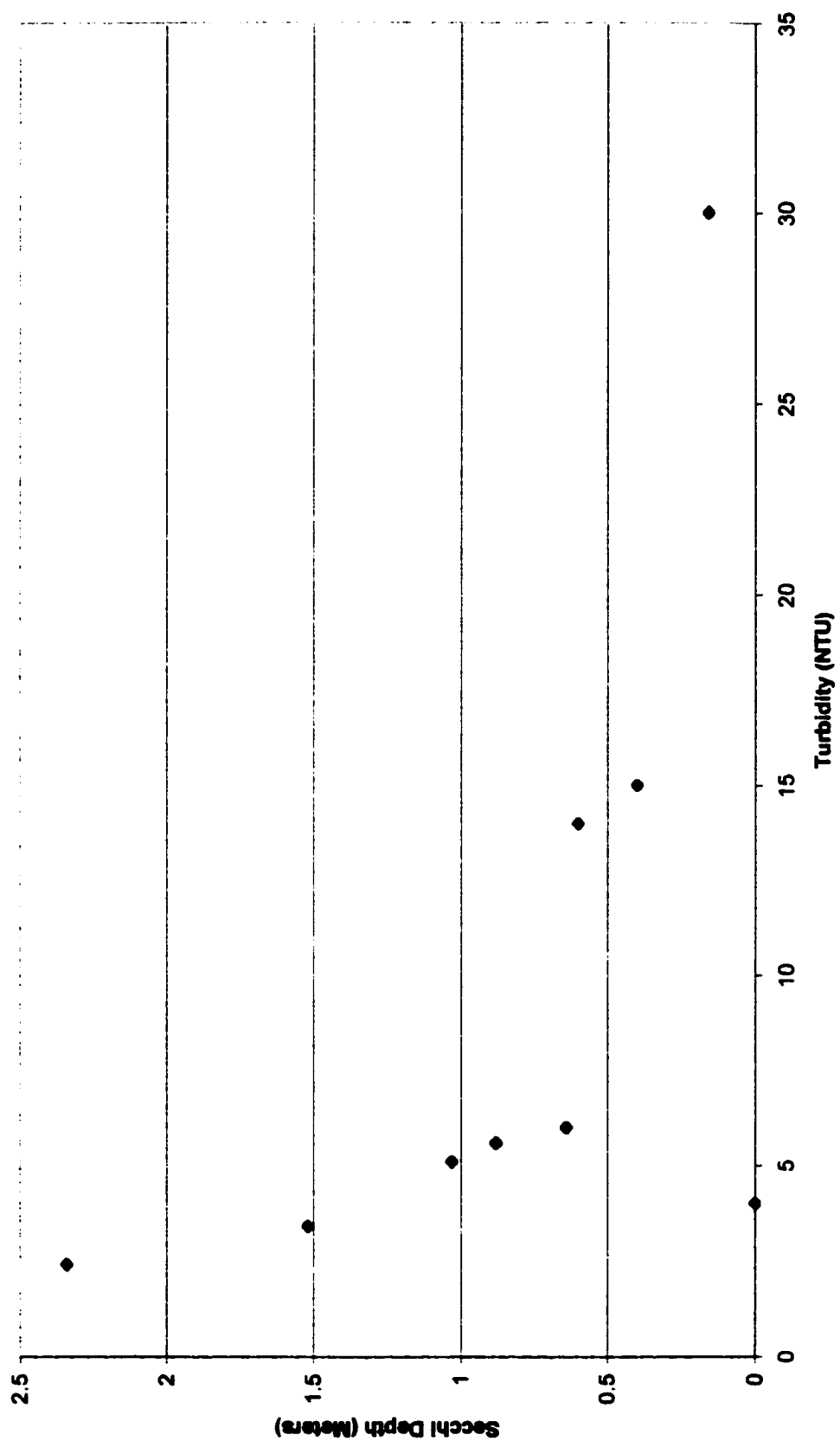


Daytime Dissolved Oxygen vs Chlorophyll a (Spring 1998) - one ft below surface

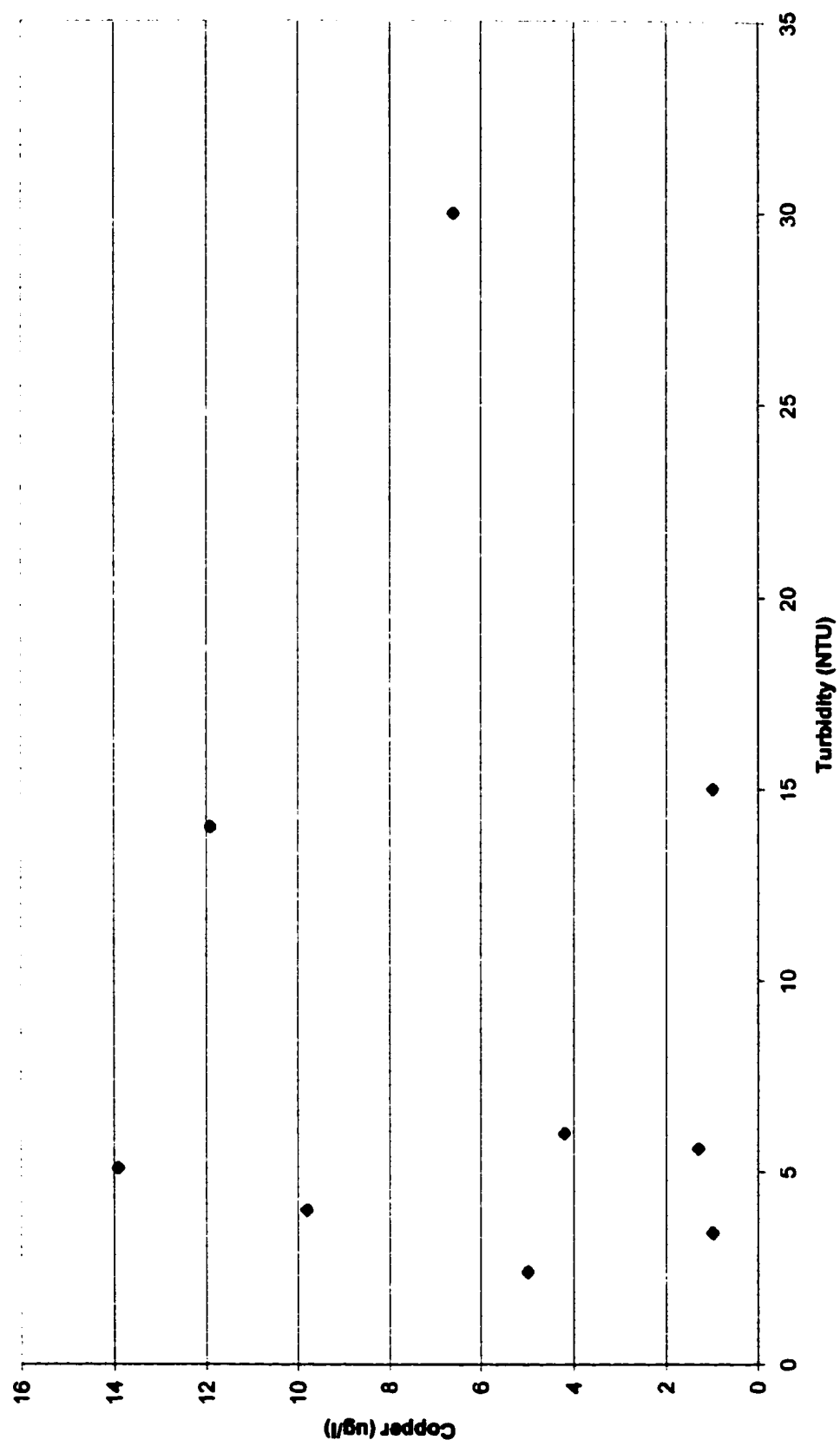


Turbidity vs Chlorophyll a (Spring 1998)

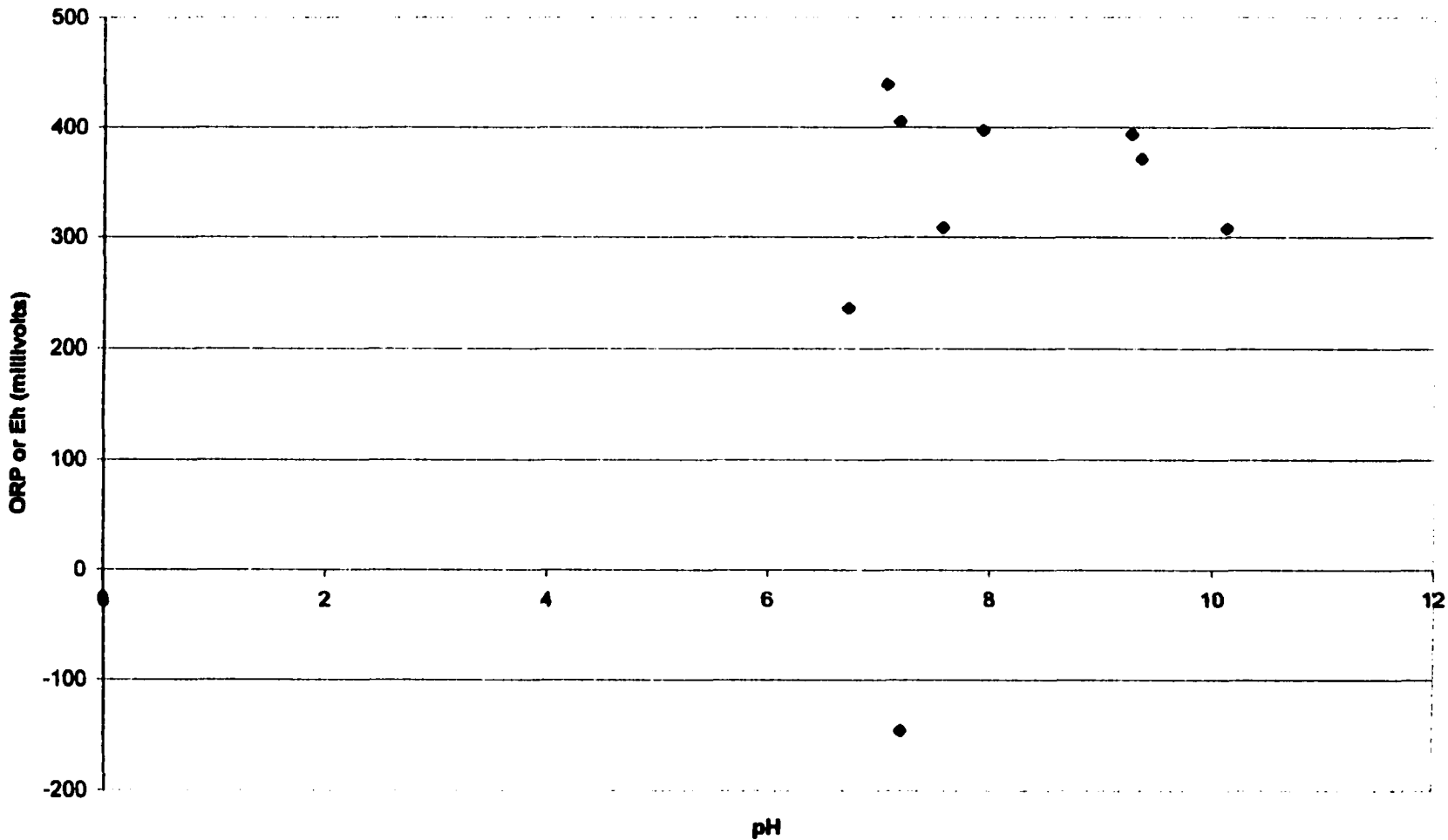


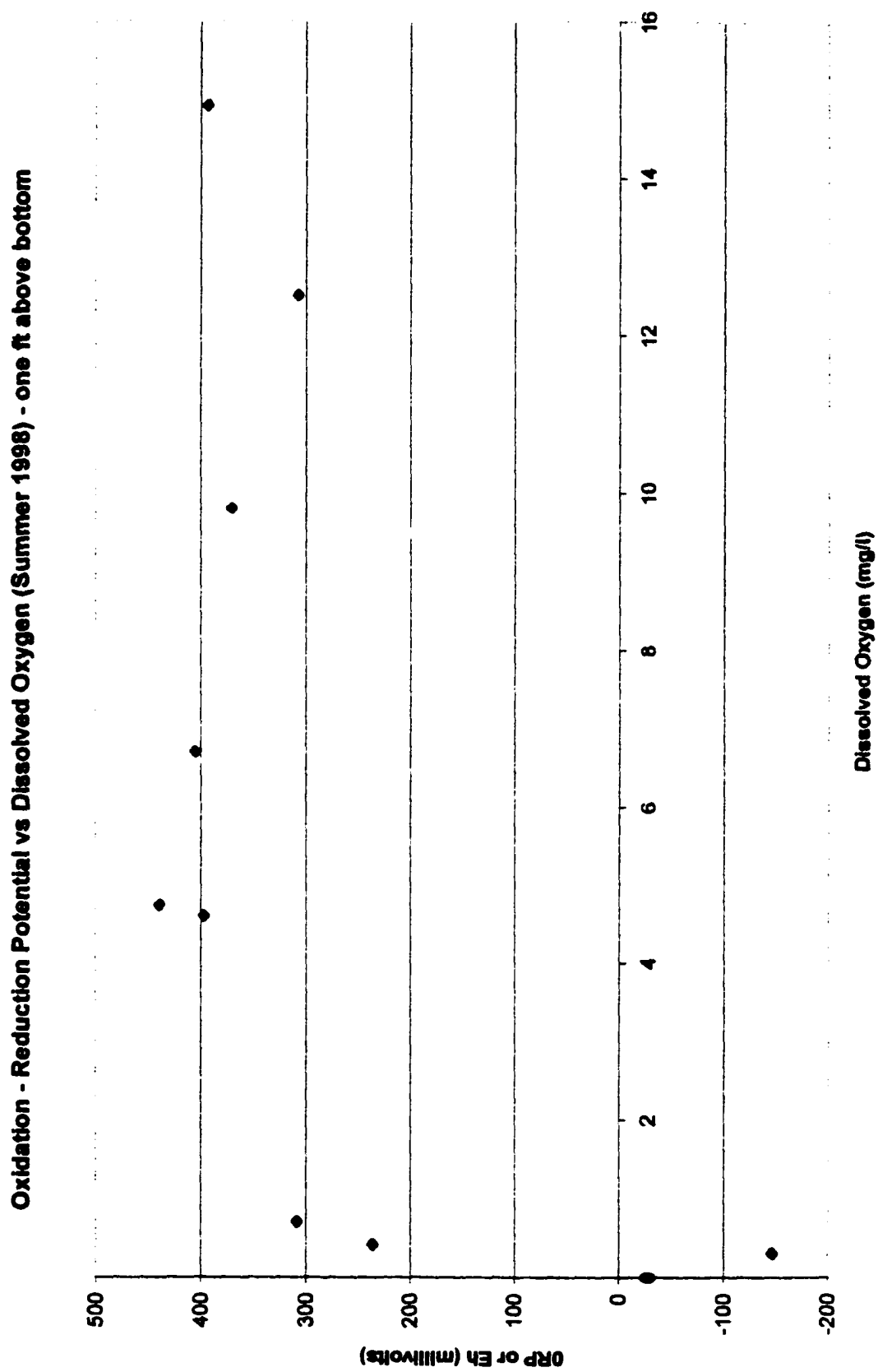
Turbidity vs Secchi Depth (Spring 1998)

Turbidity vs Copper (Spring 1998)

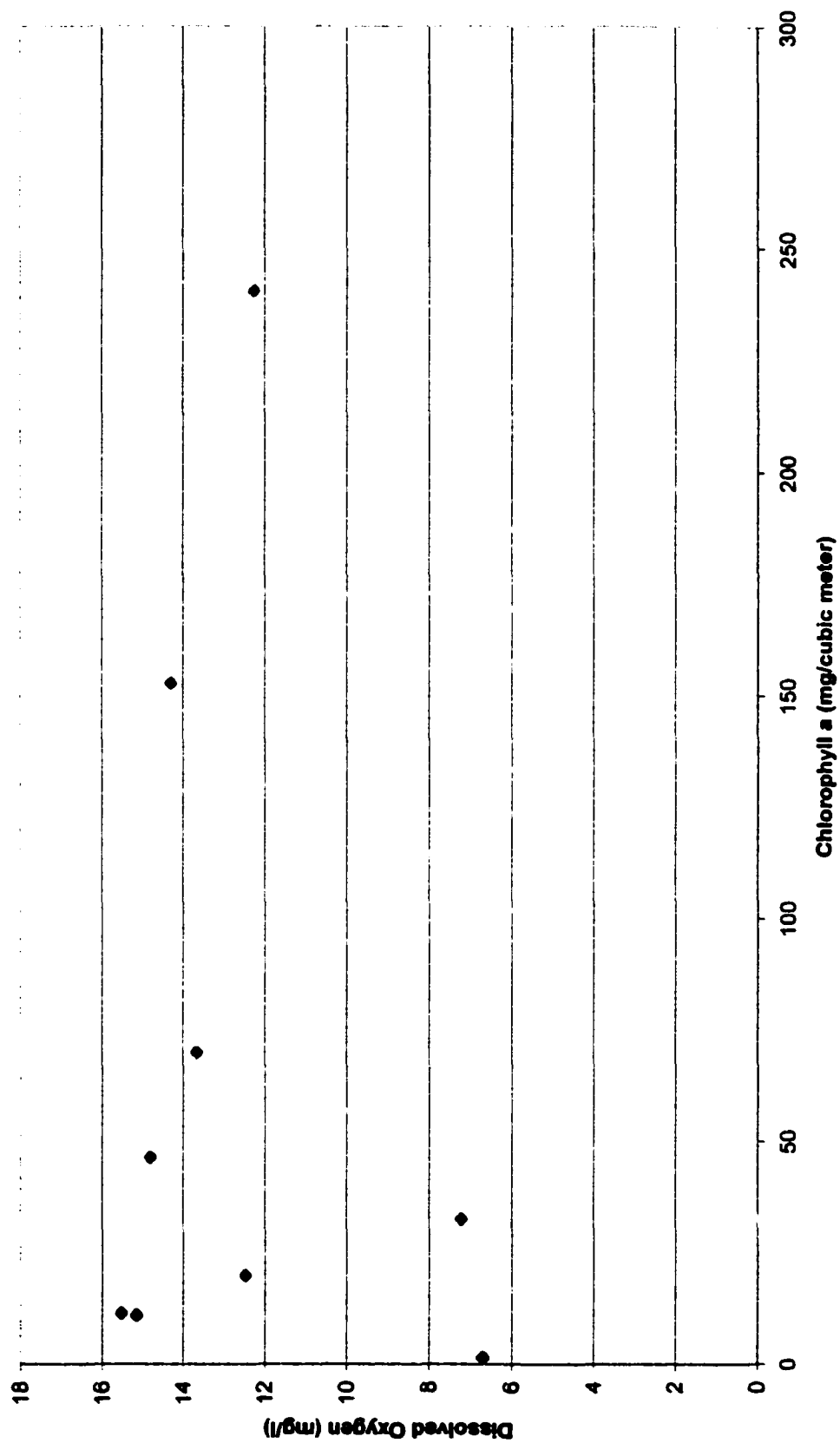


Oxidation - Reduction Potential vs pH (Summer 1998) - one ft above bottom

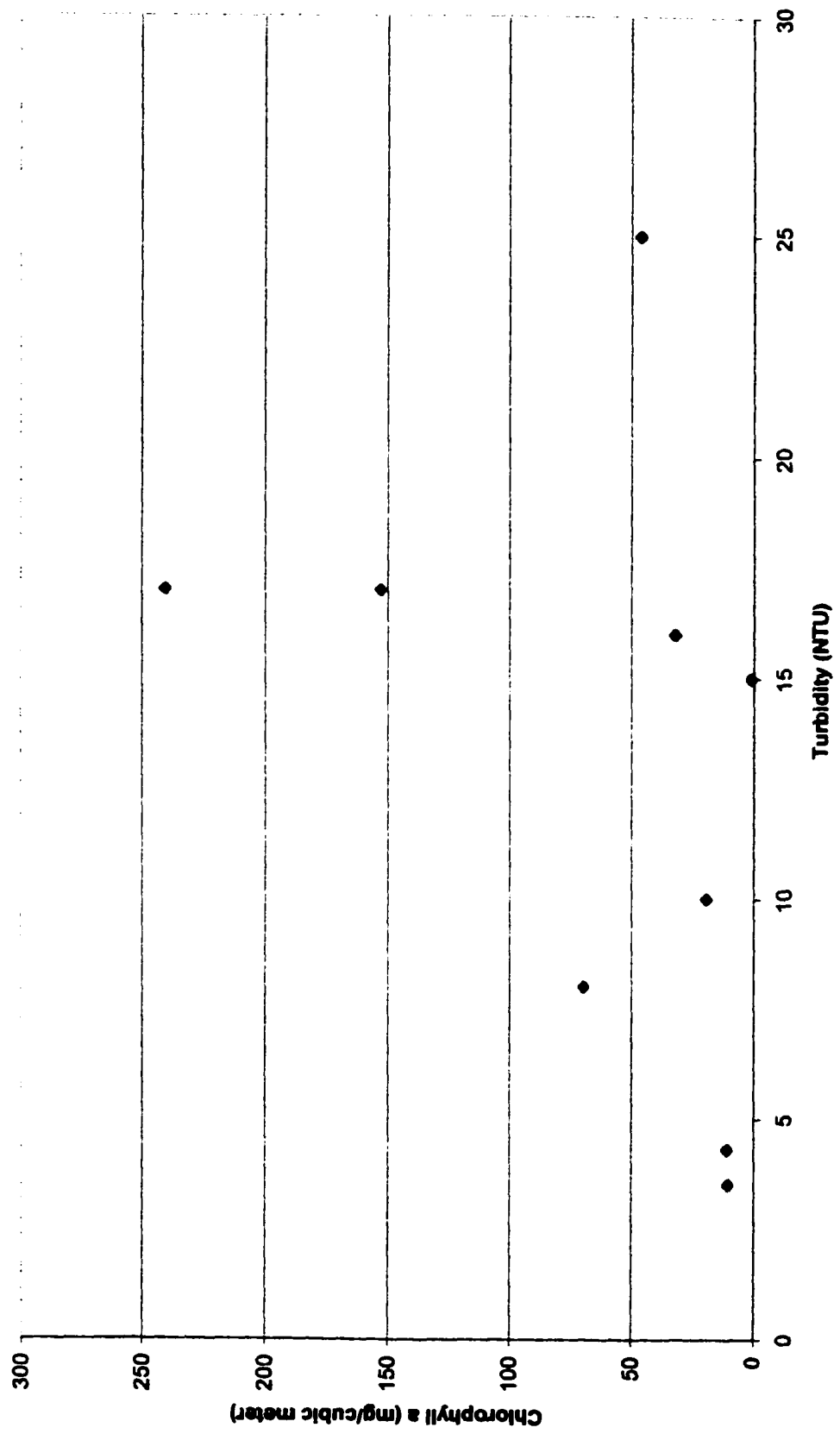


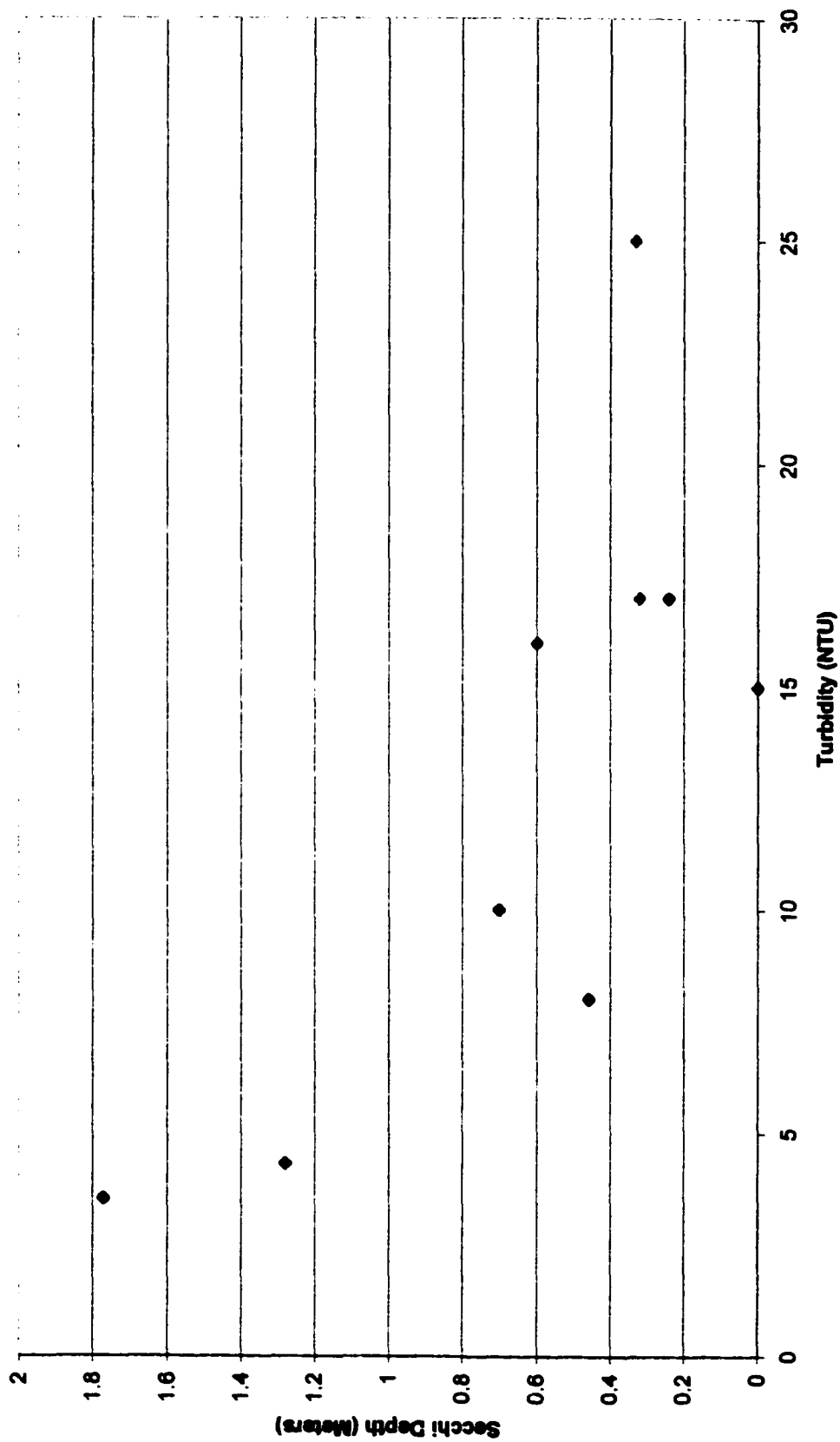


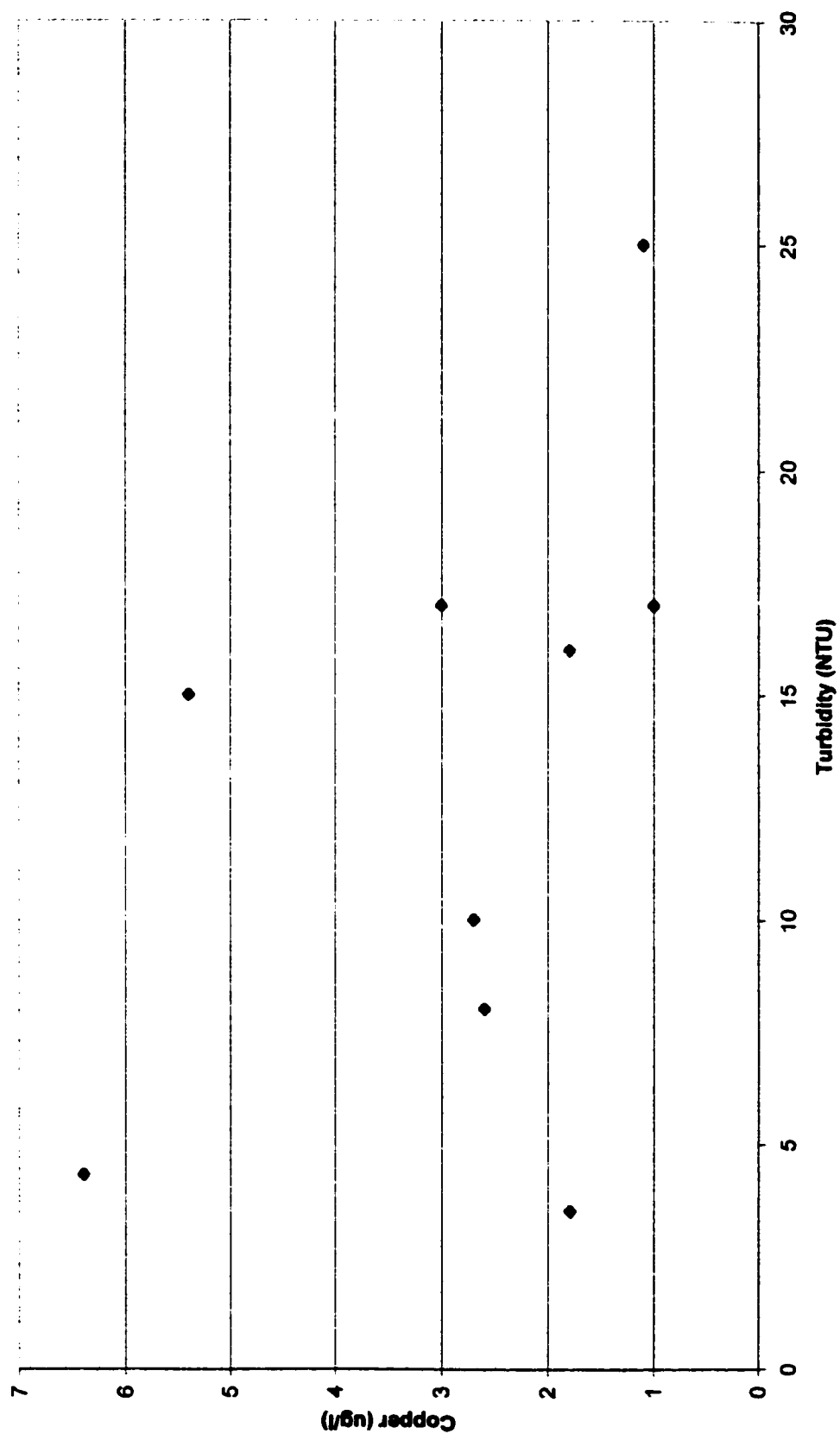
Daytime Dissolved Oxygen vs Chlorophyll a (Summer 1998) - one ft below surface



Turbidity vs Chlorophyll a (Summer 1998)

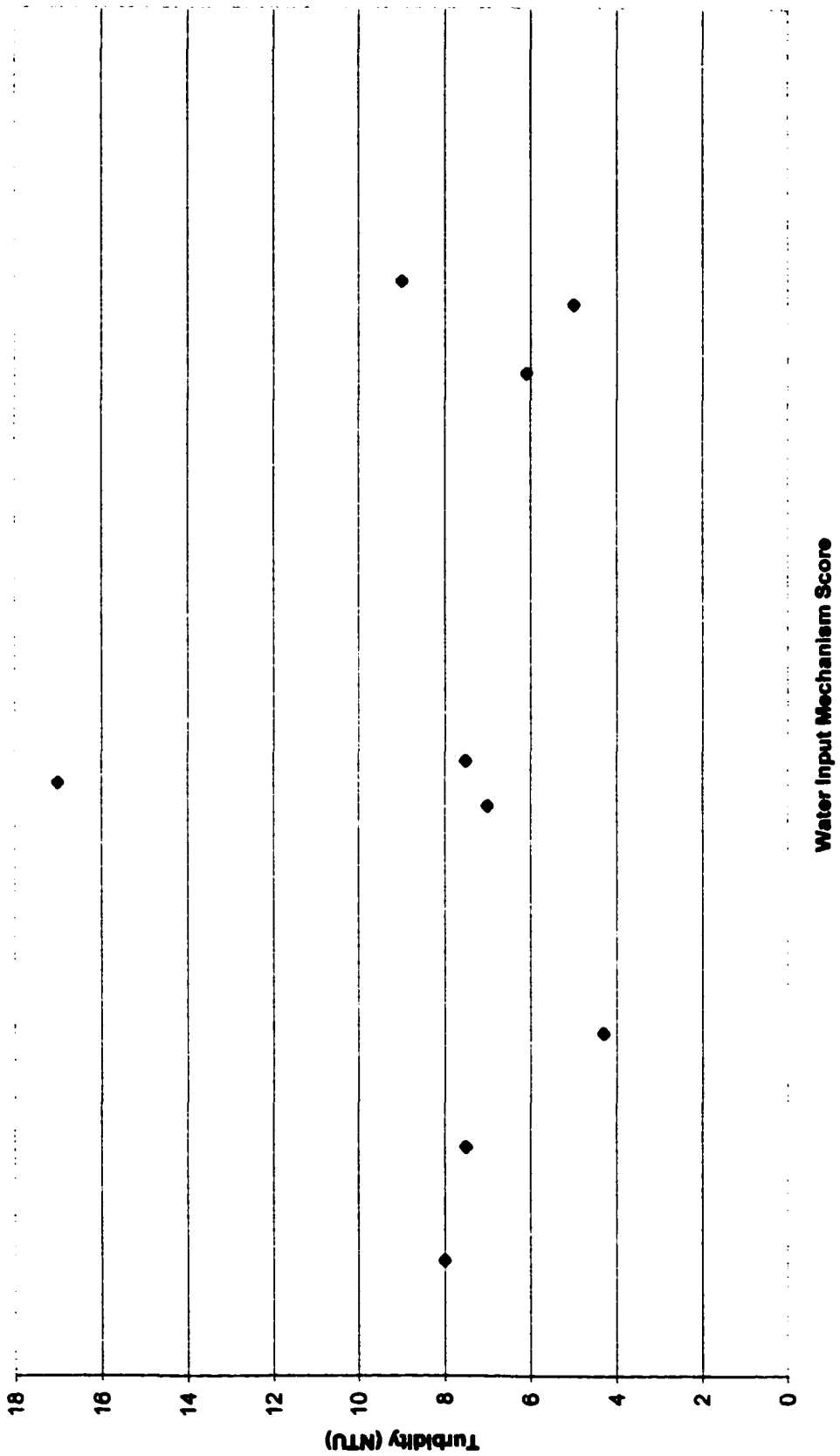


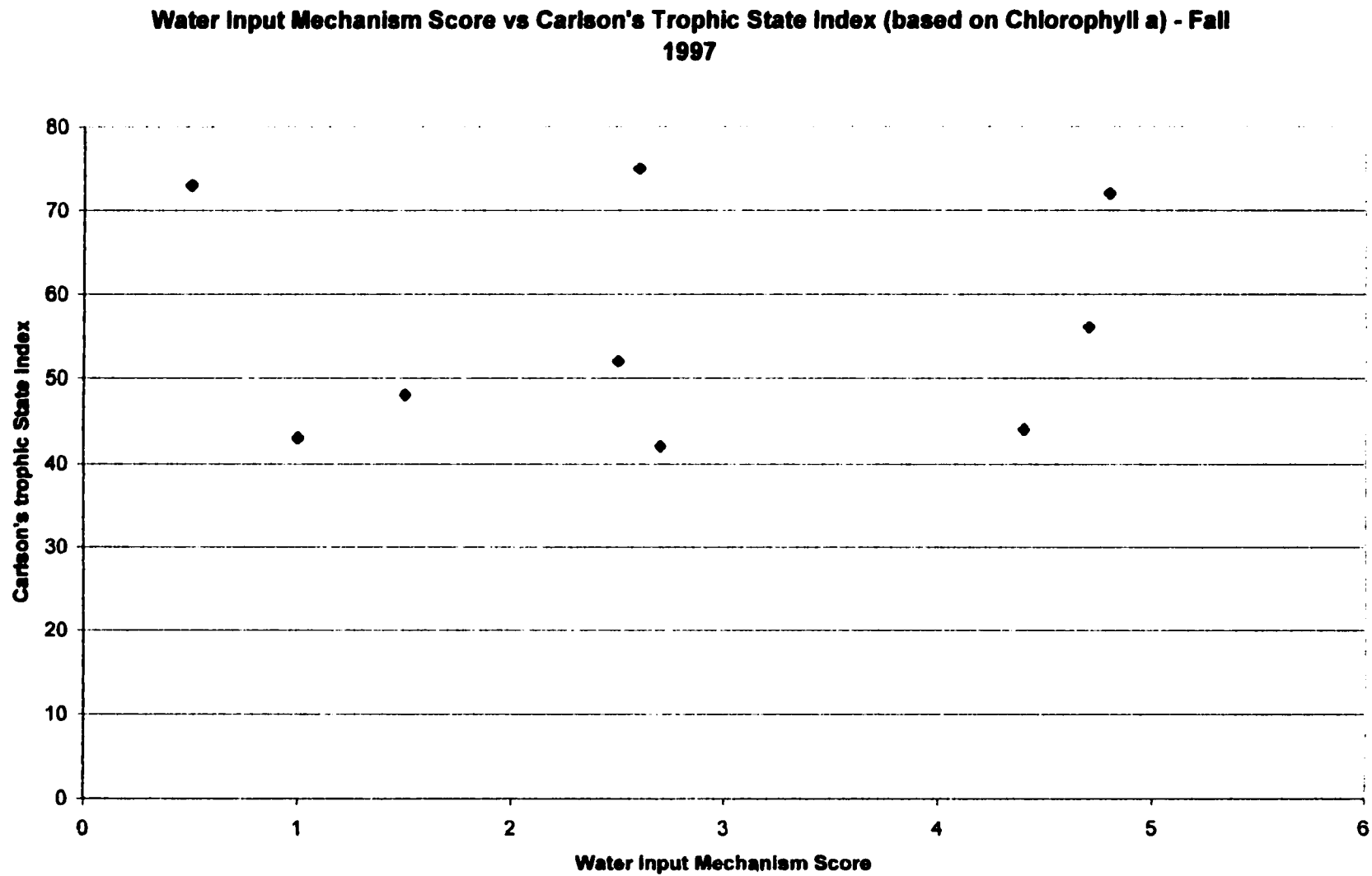
Turbidity vs Secchi Depth (Summer 1998)

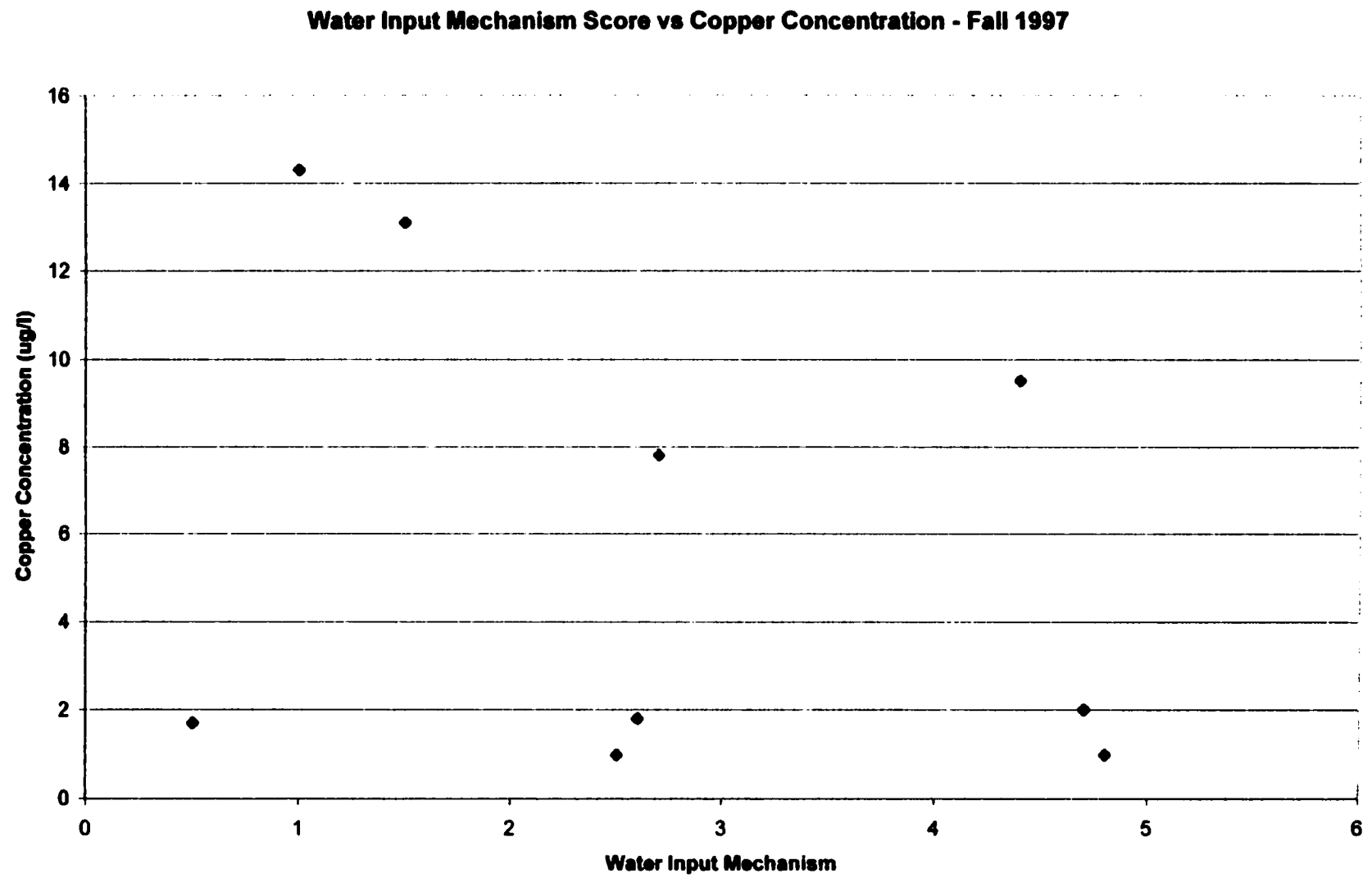
Turbidity vs Copper (Summer 1998)

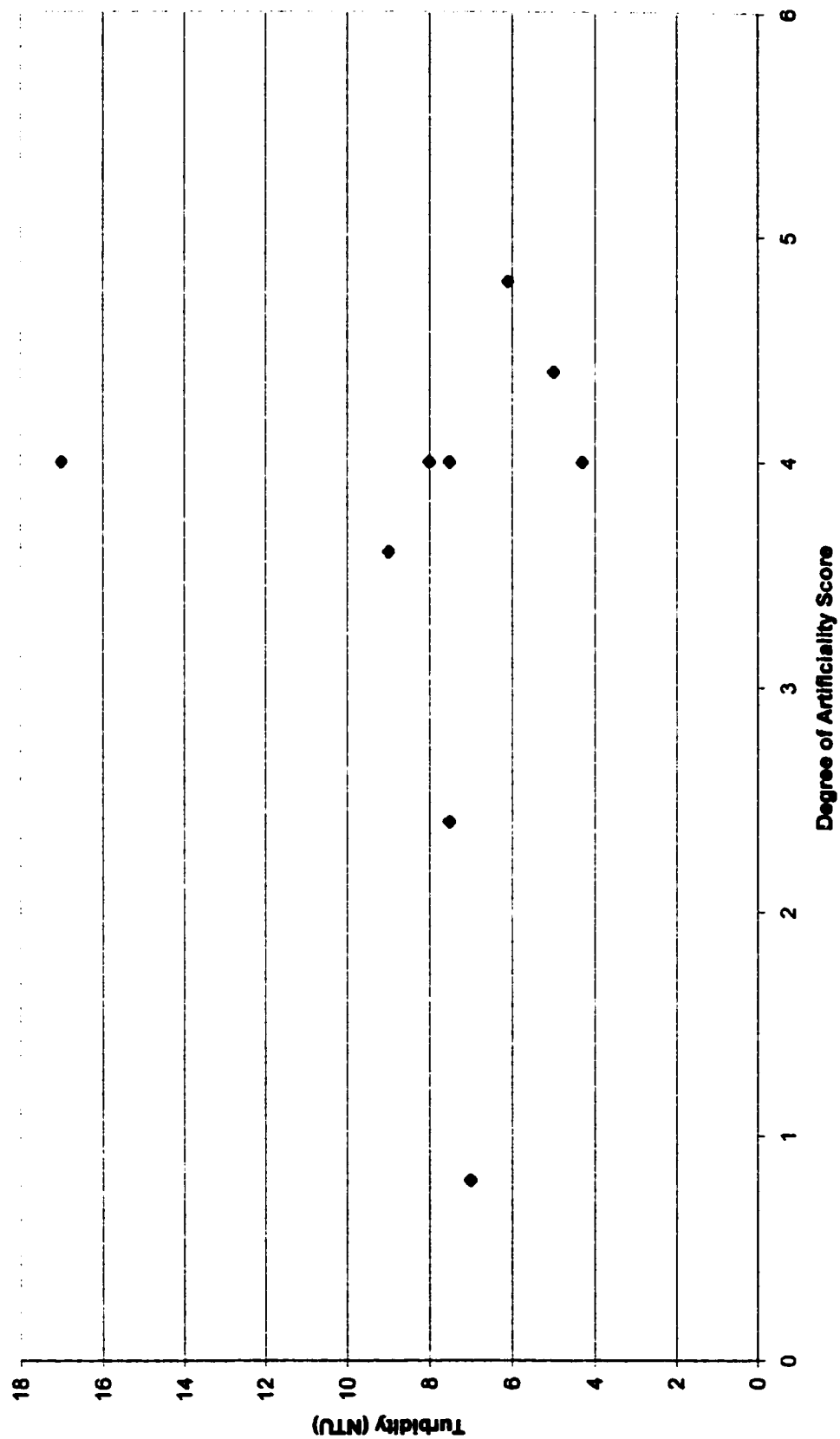
**C2 - BETWEEN CLASSIFICATION SCORES AND
SELECTED WATER QUALITY PARAMETERS**

Water Input Mechanism Score vs Turbidity - Fall 1997

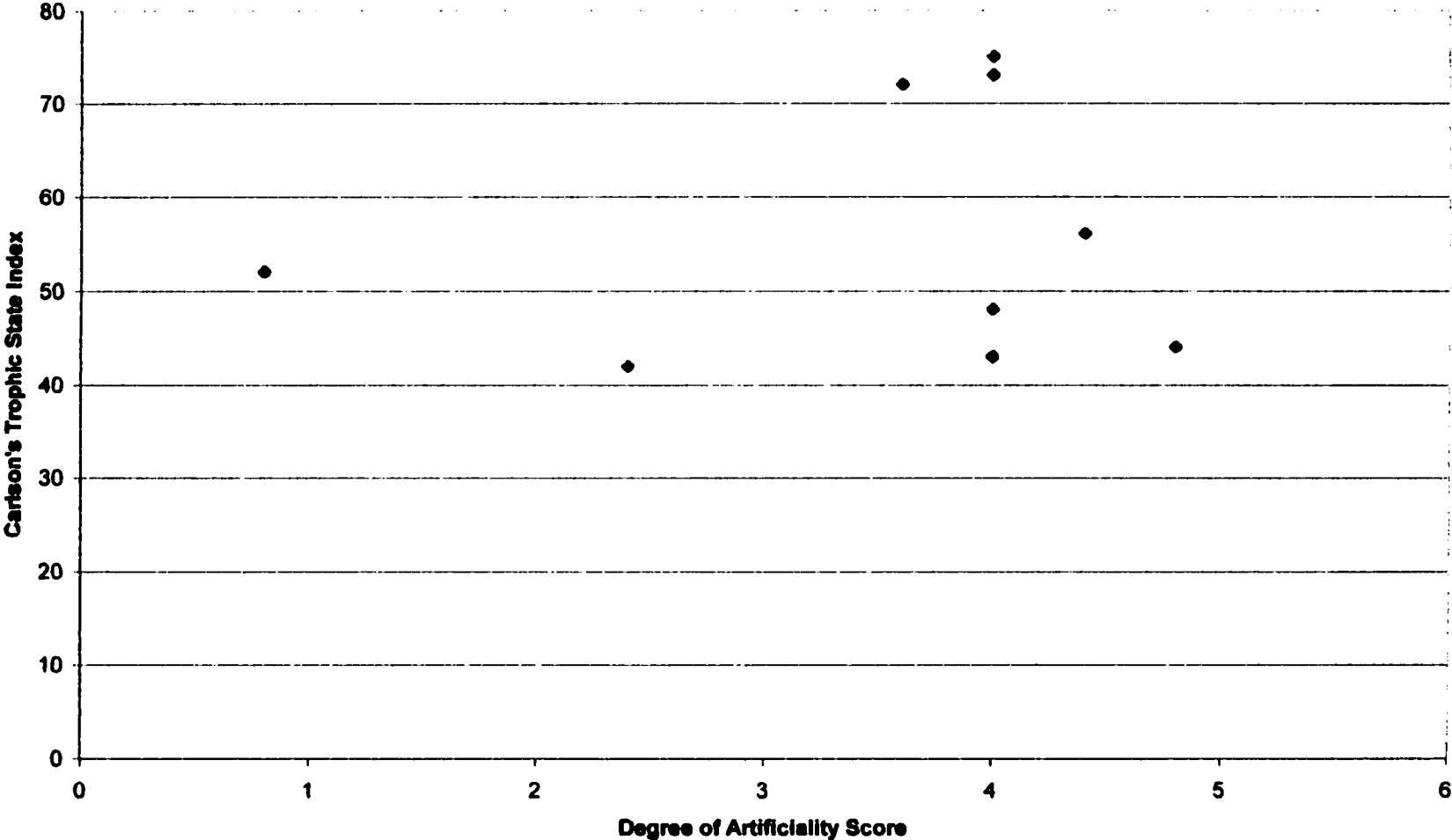




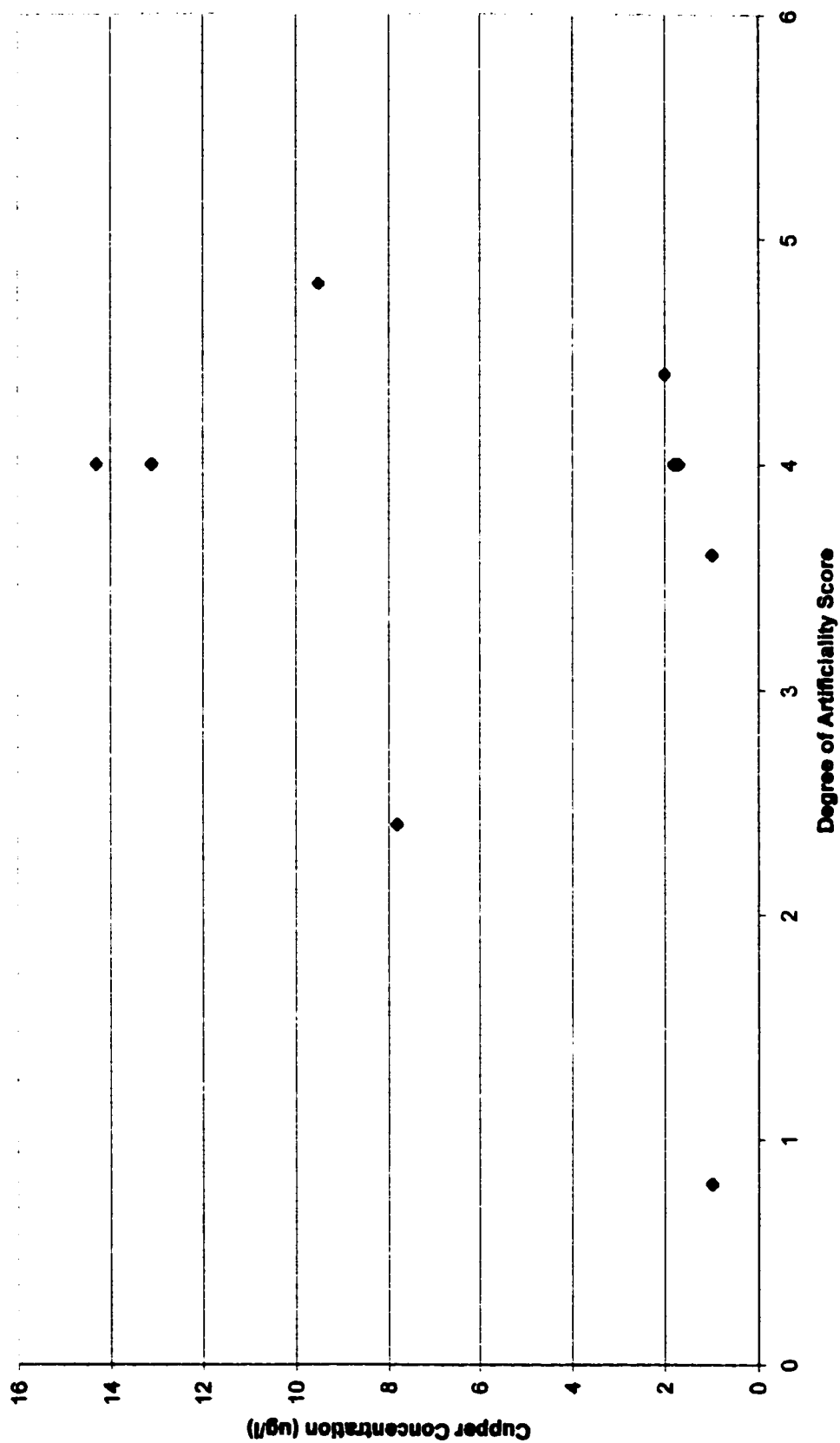


Degree of Artificiality Score vs Turbidity - Fall 1997

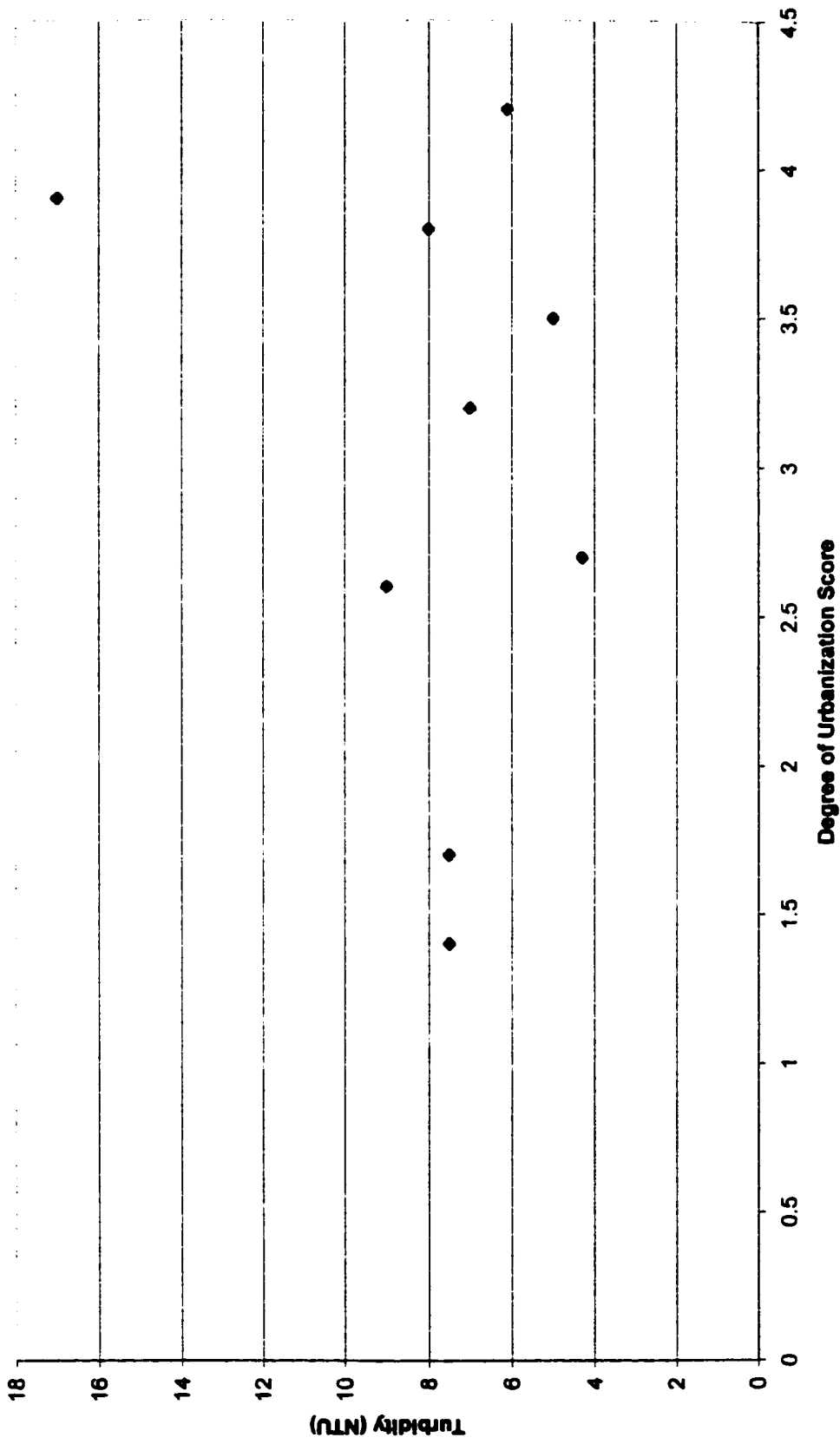
Degree of Artificiality Score vs Carlson's Trophic State Index (based on Chlorophyll a) - Fall 1997

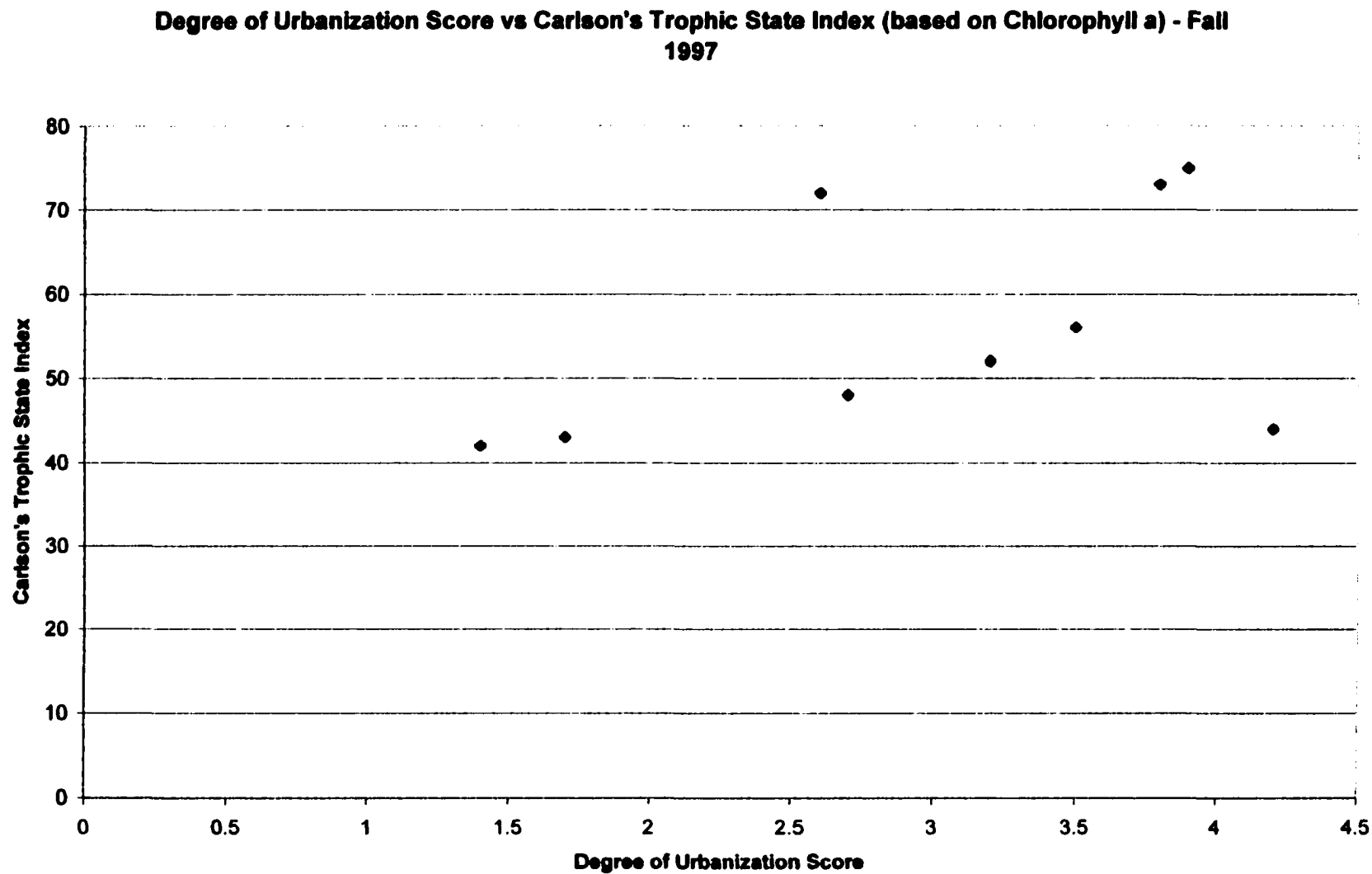


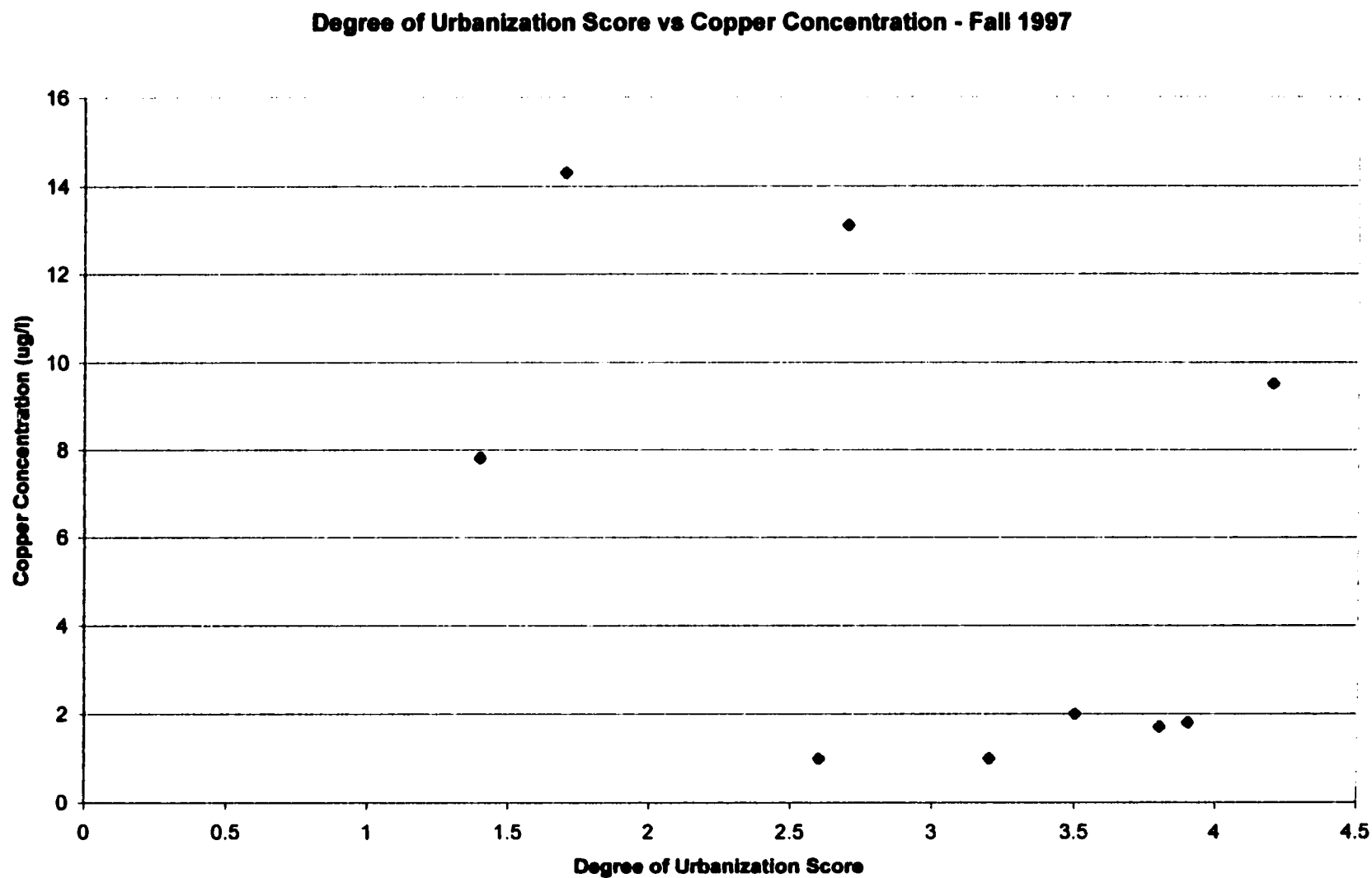
Degree of Artificiality Score vs Copper Concentration - Fall 1997



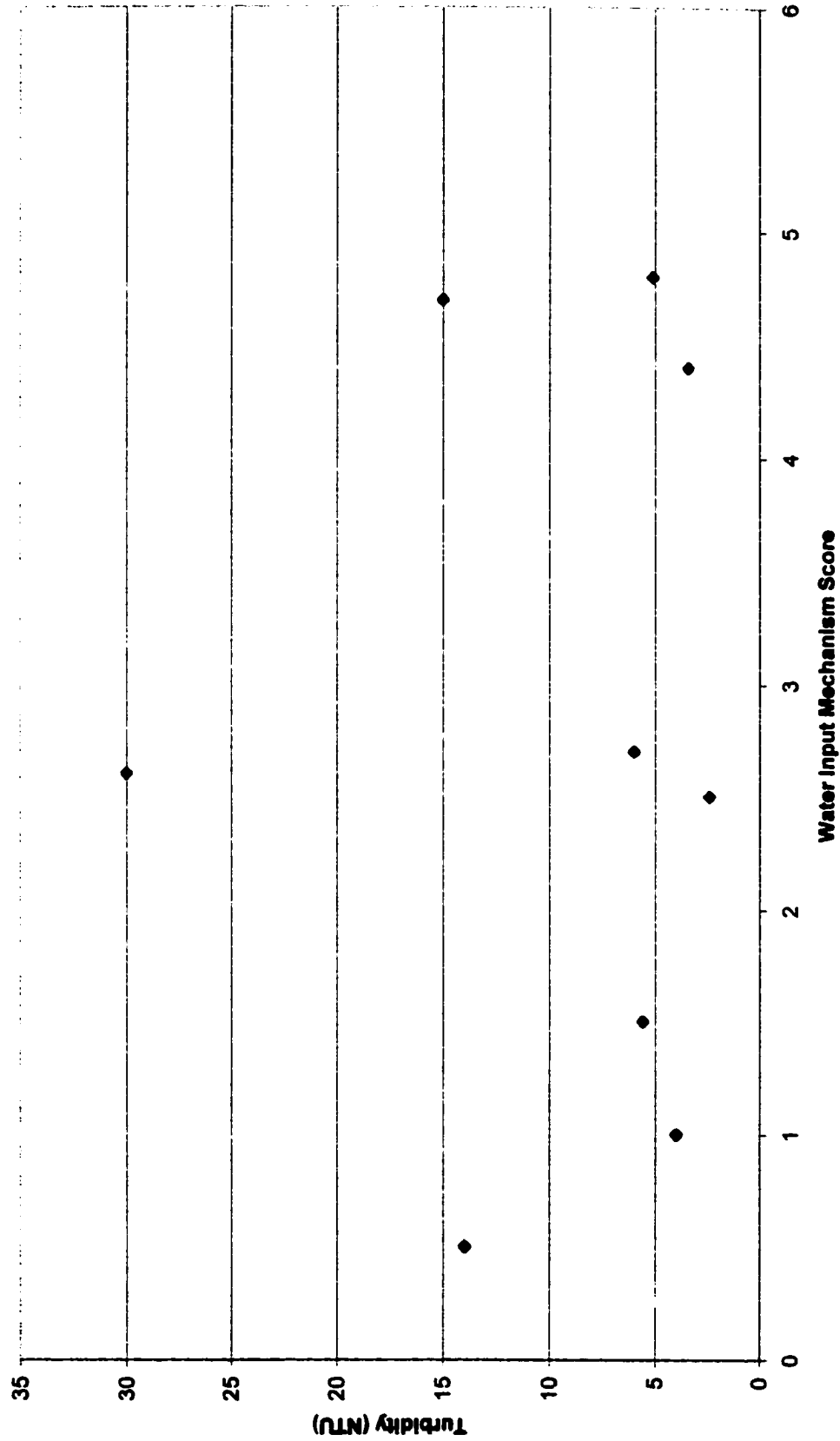
Degree of Urbanization Score vs Turbidity - Fall 1997

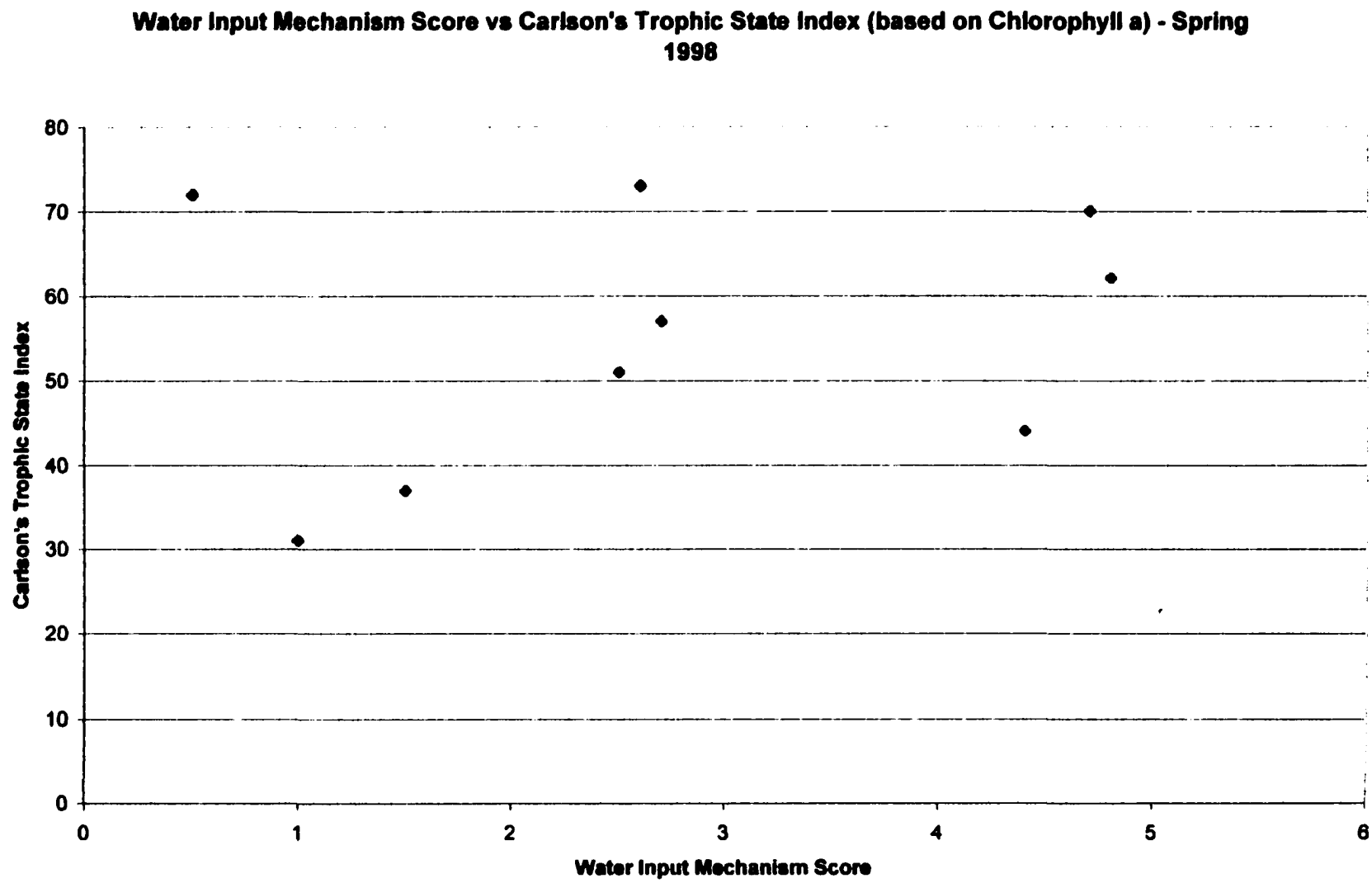


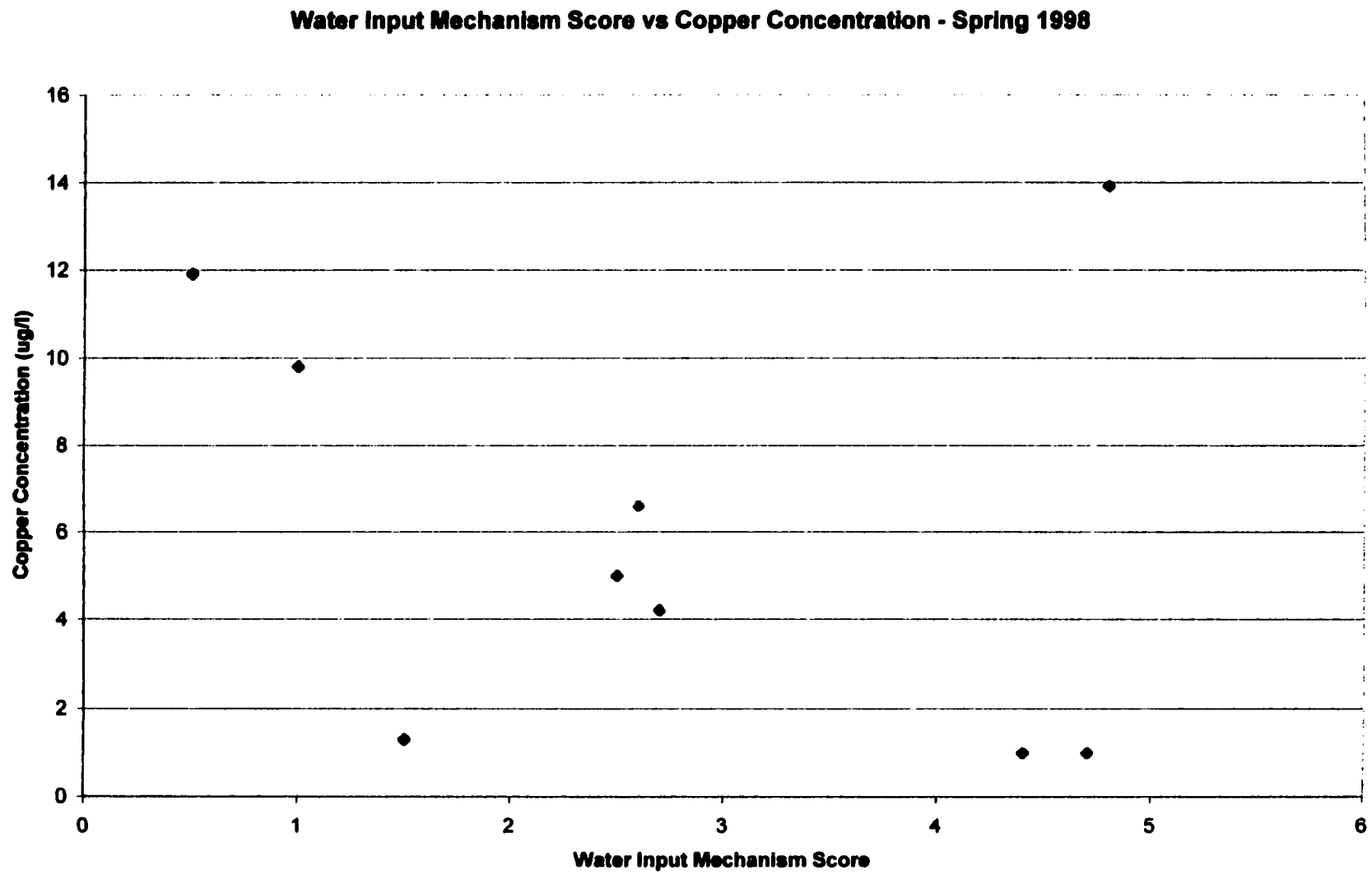




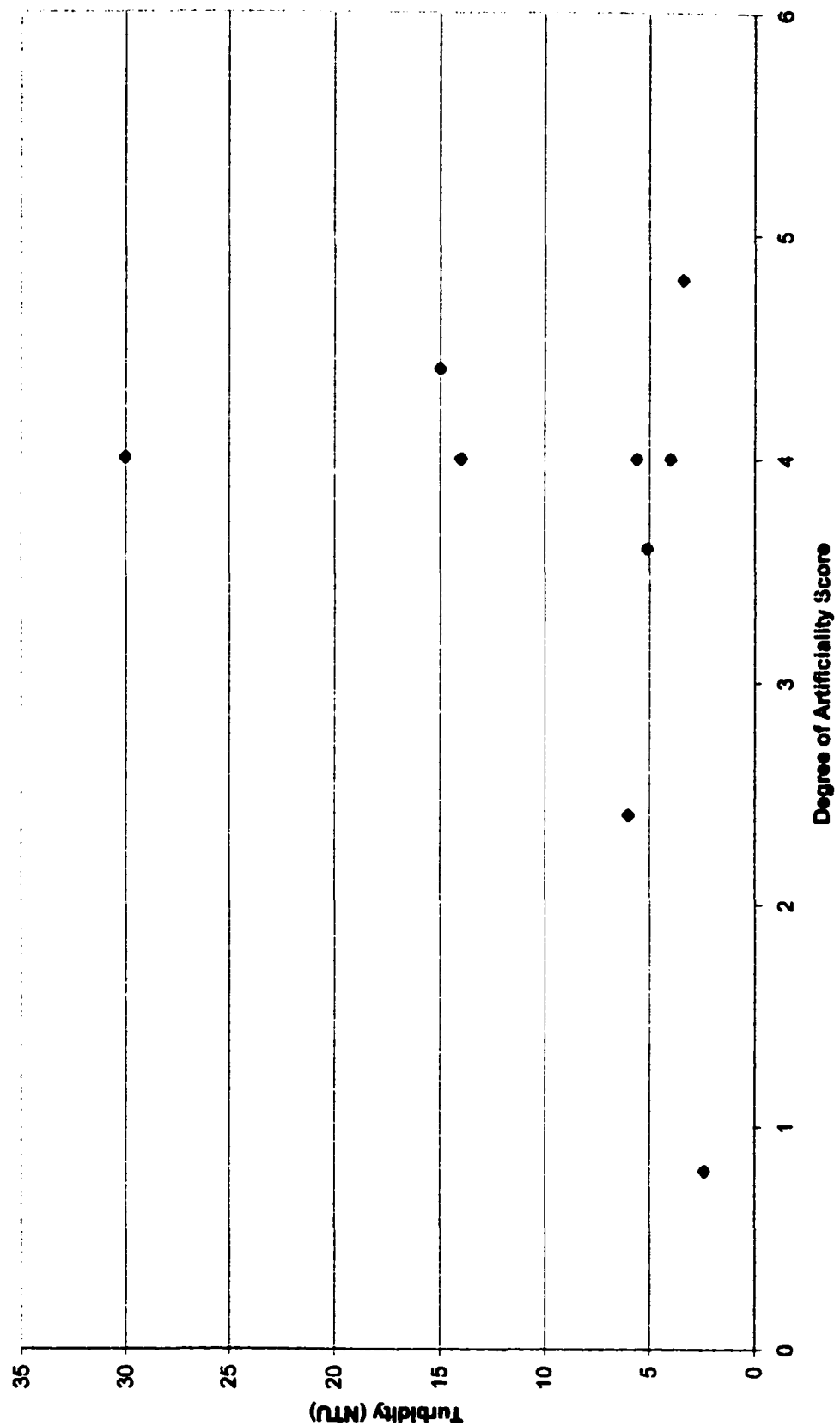
Water Input Mechanism Score vs Turbidity - Spring 1998

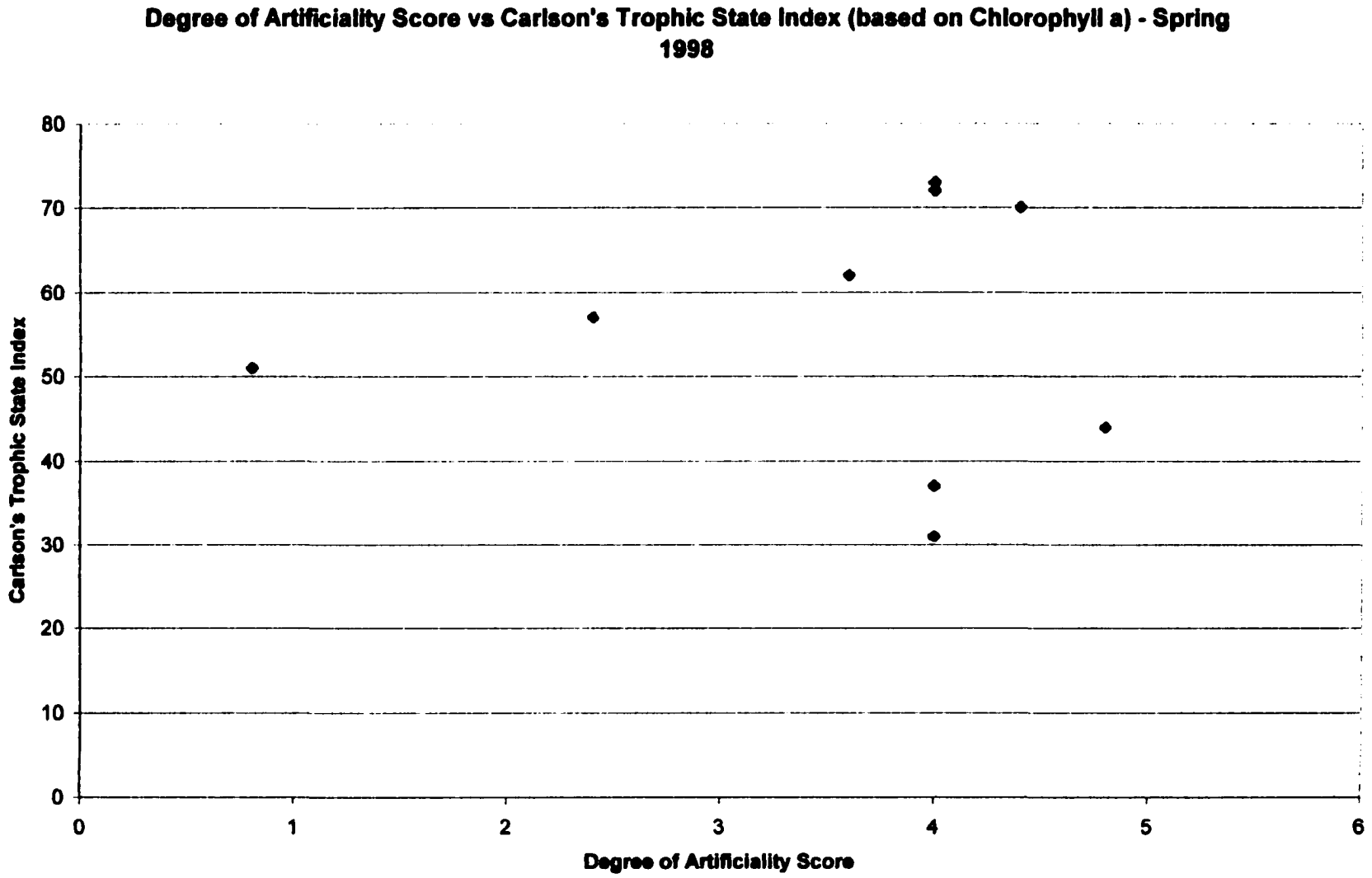




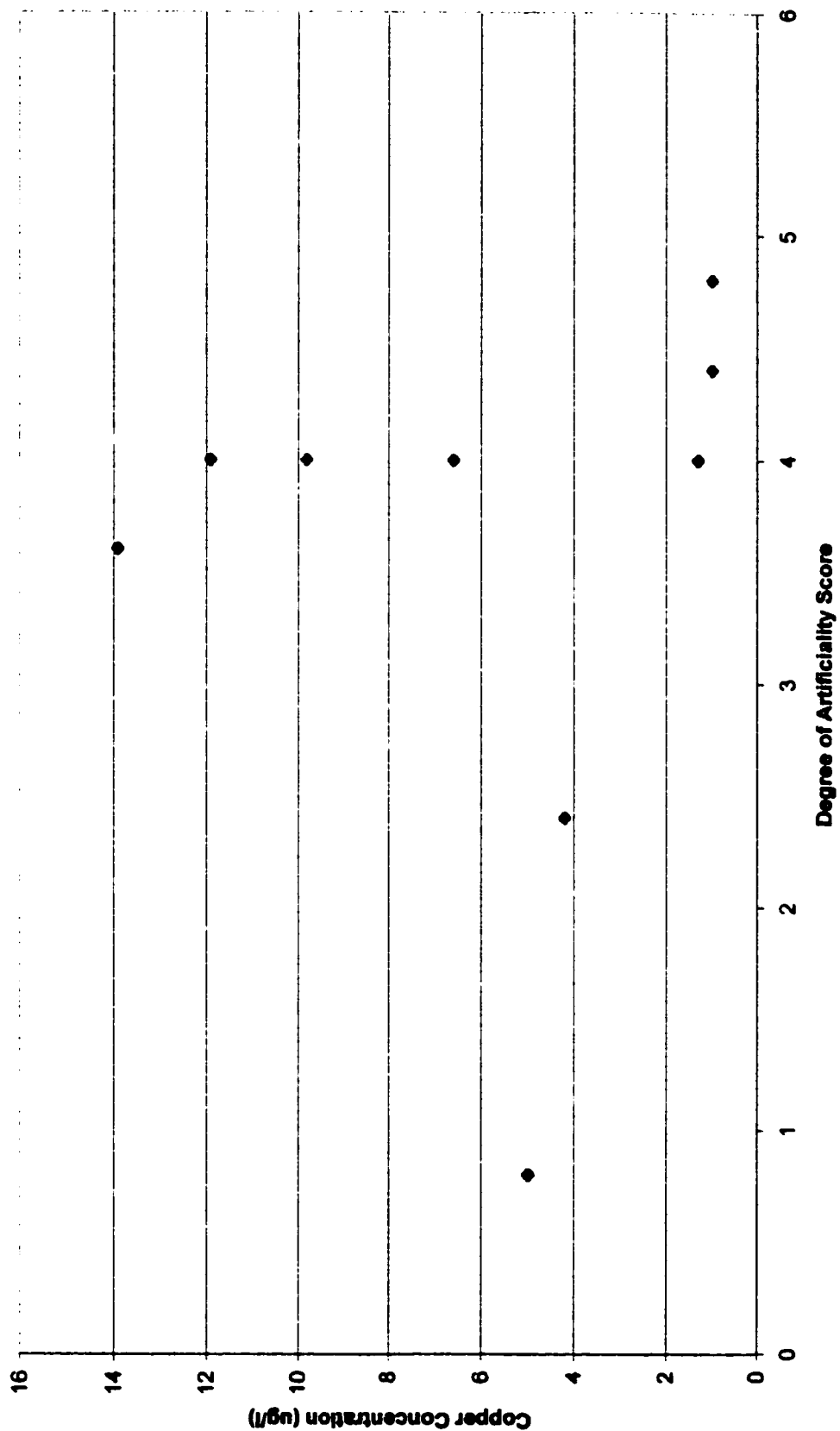


Degree of Artificiality Score vs Turbidity - Spring 1998

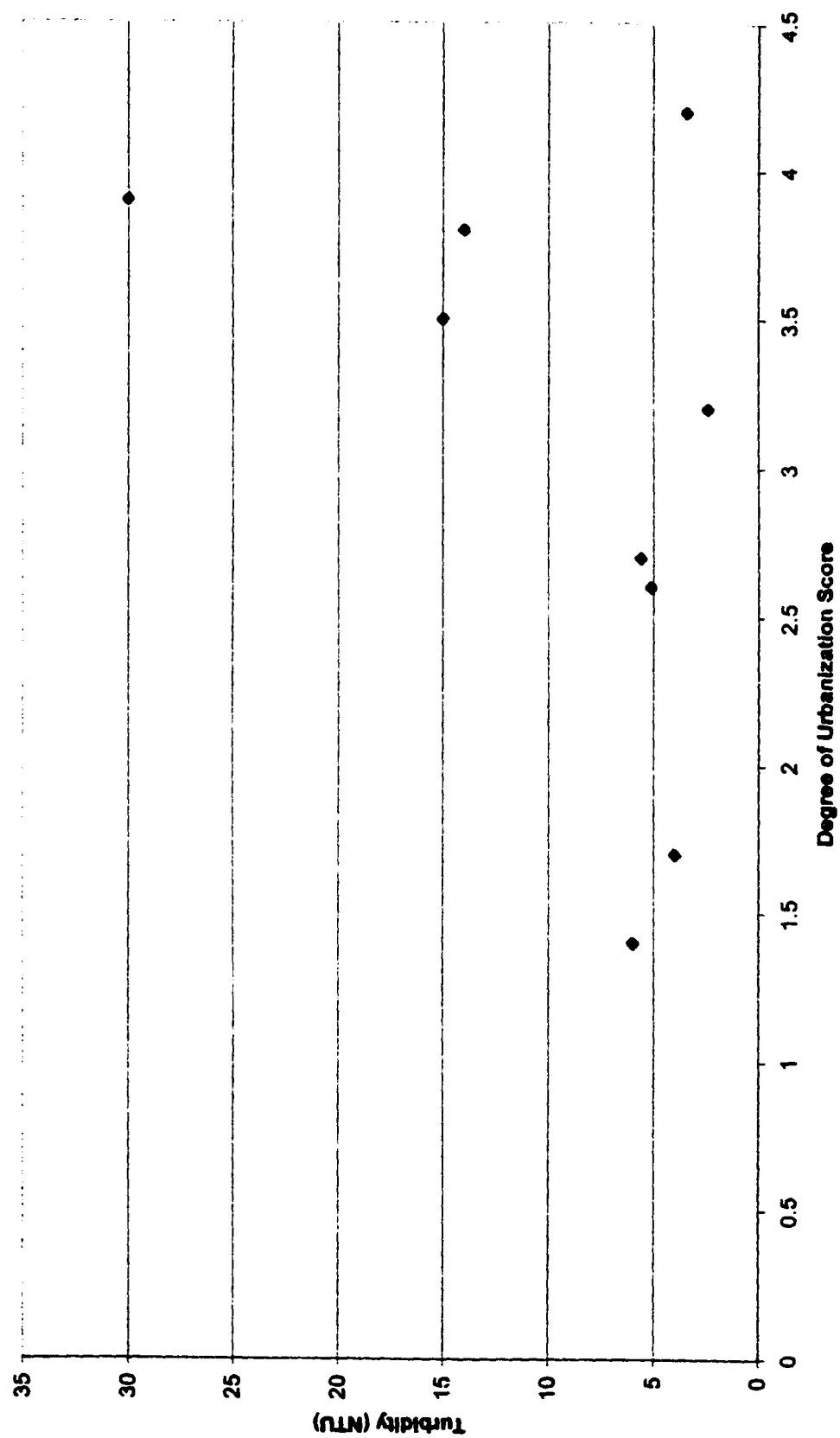




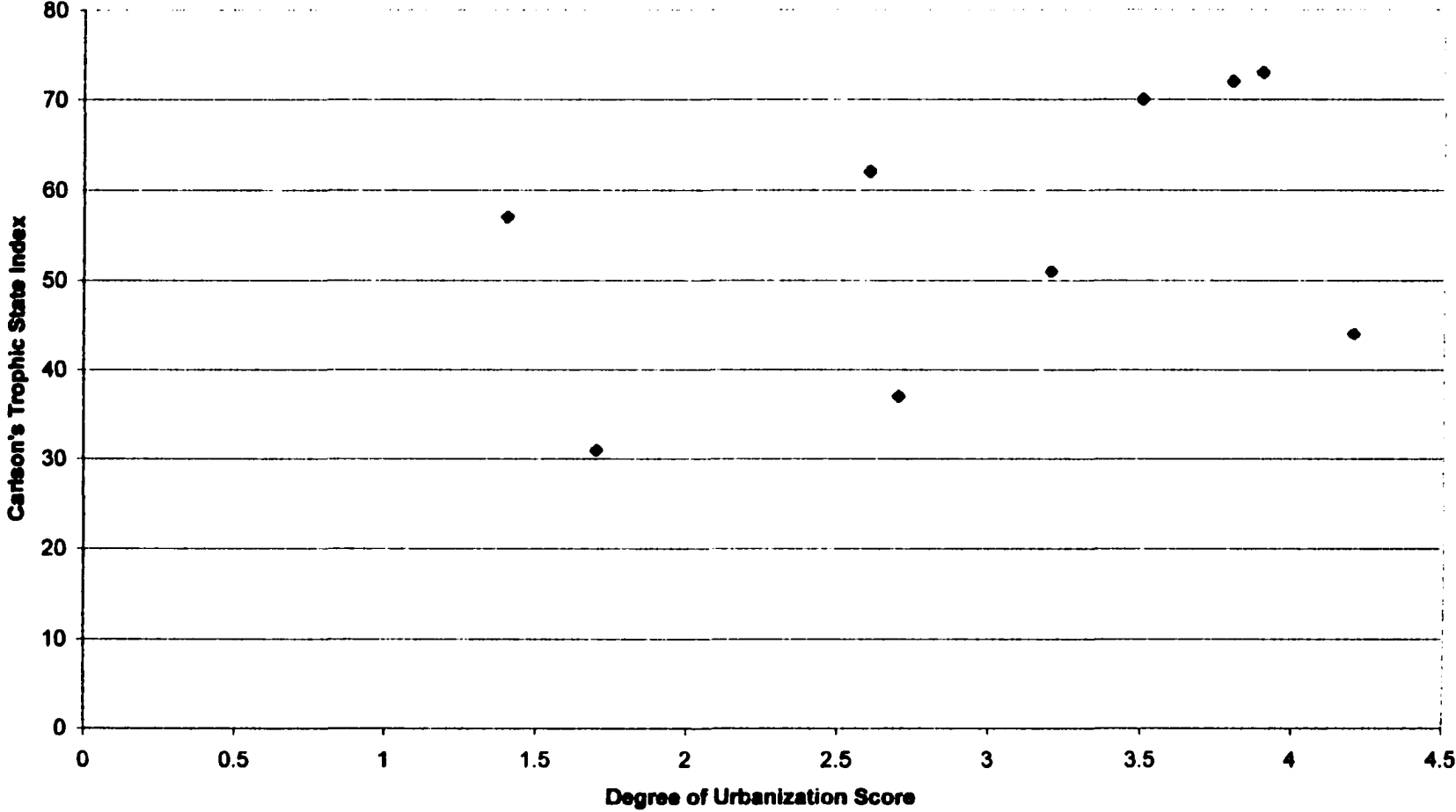
Degree of Artificiality Score vs Copper Concentration - Spring 1998

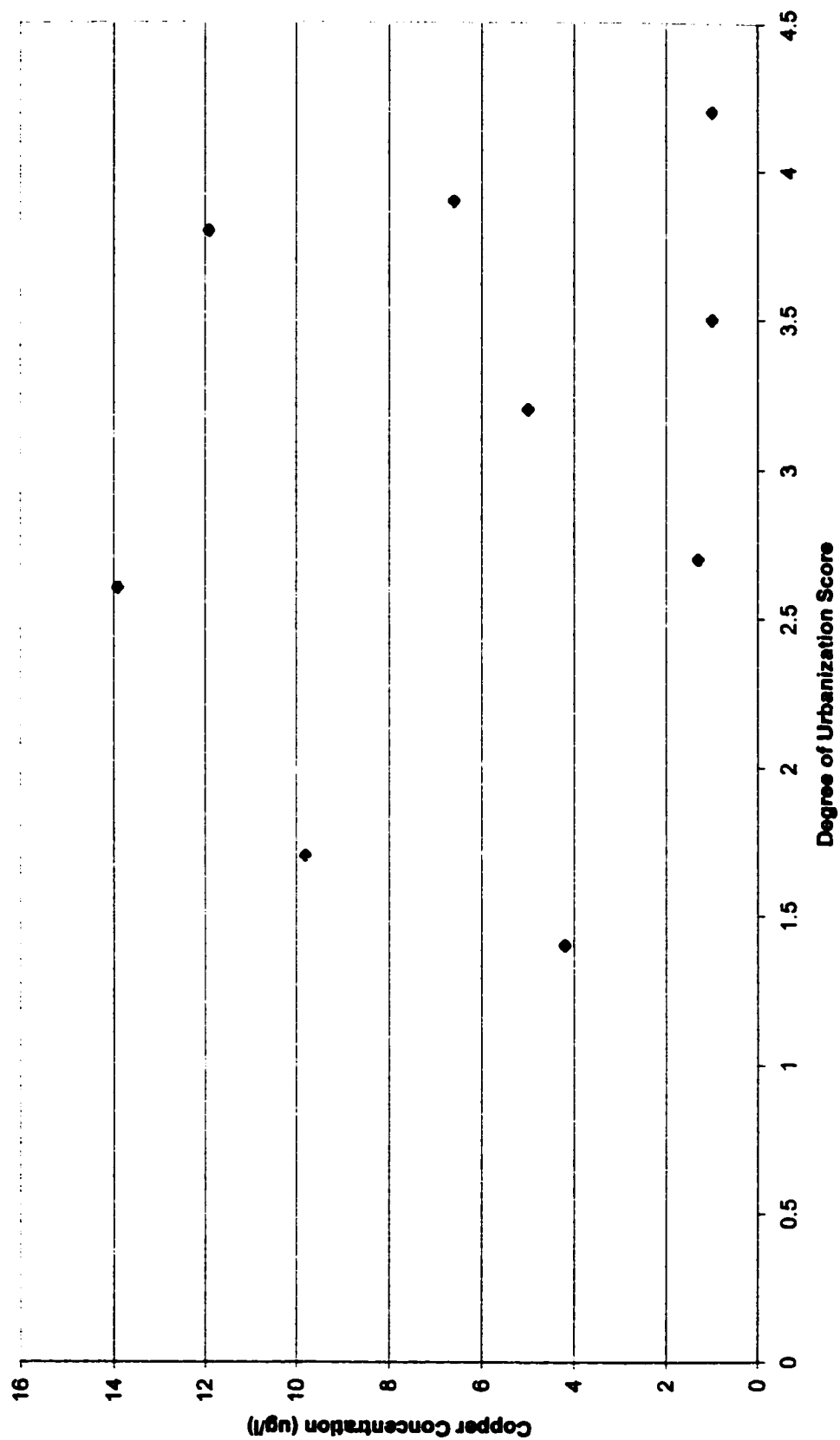


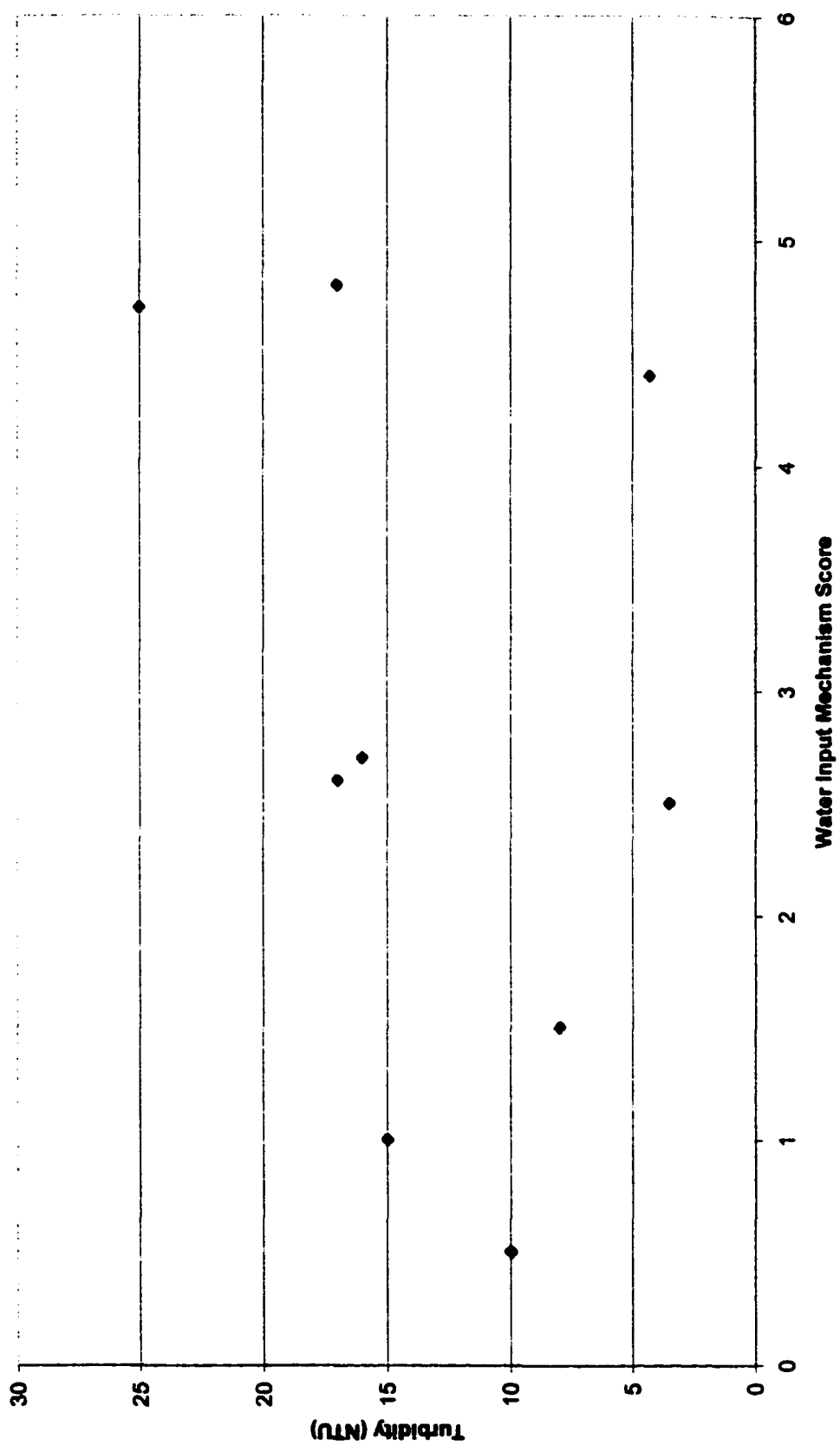
Degree of Urbanization Score vs Turbidity - Spring 1998

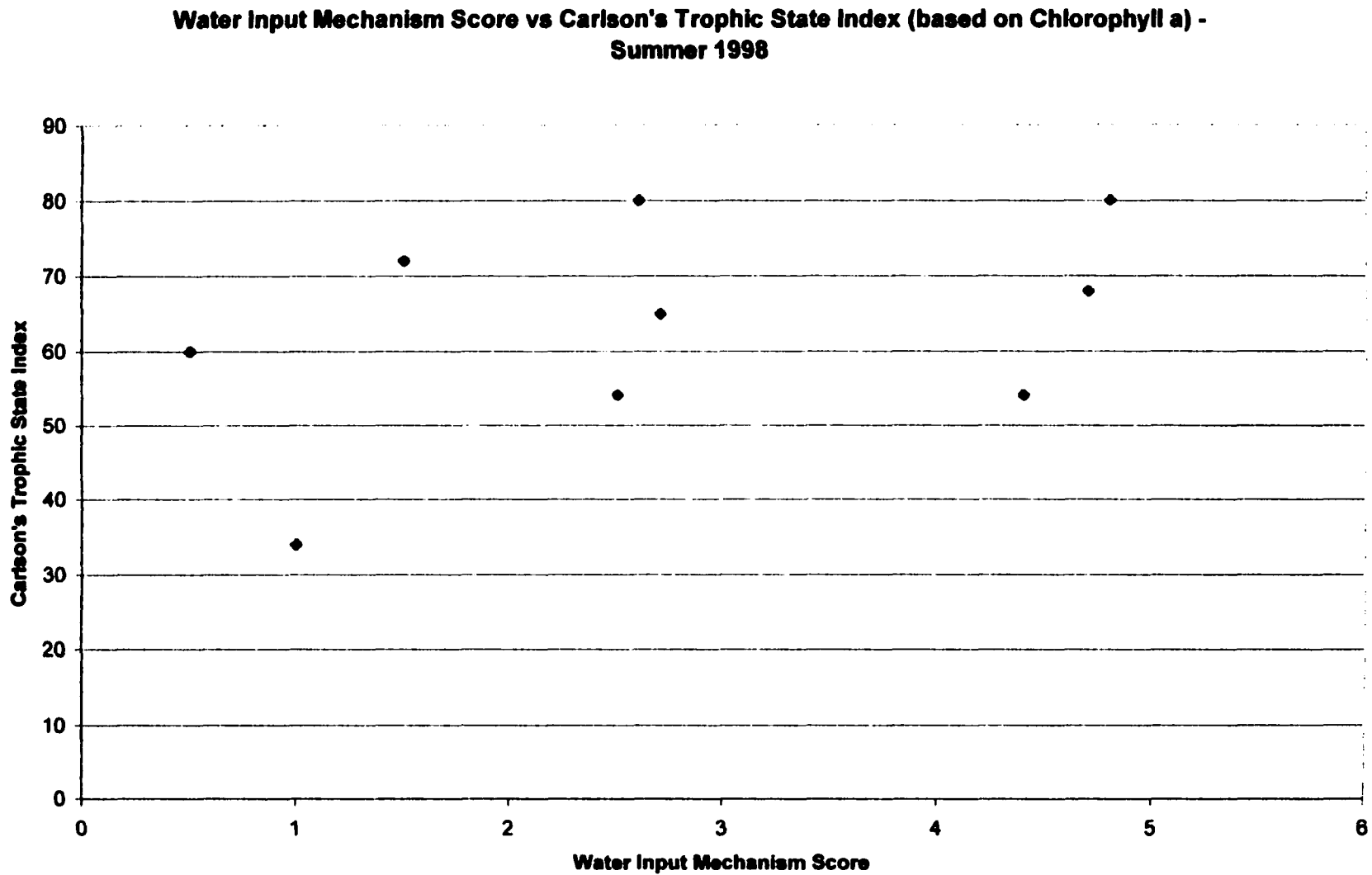


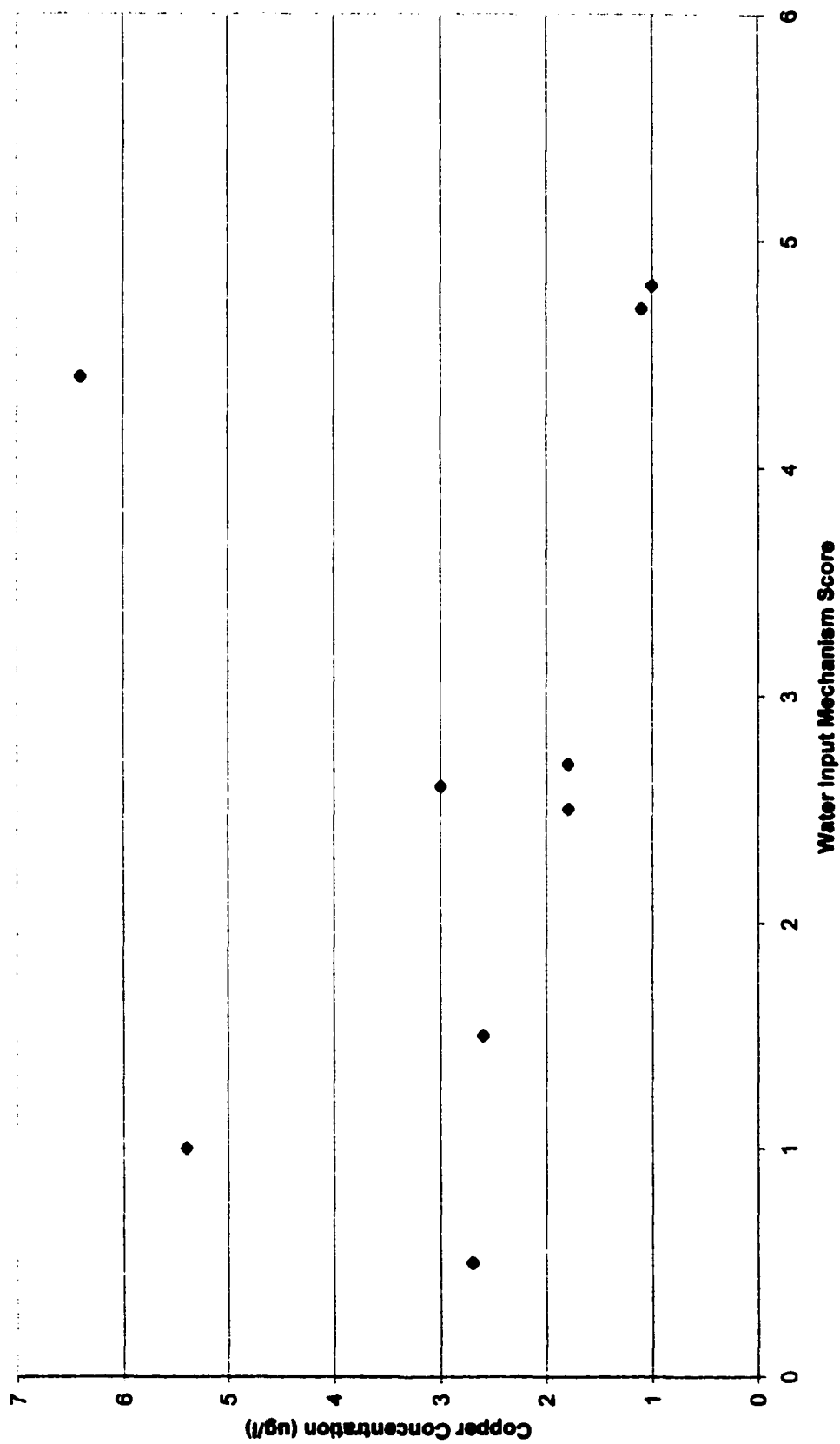
Degree of Urbanization Score vs Carlson's Trophic State Index (based on Chlorophyll a) - Spring 1998

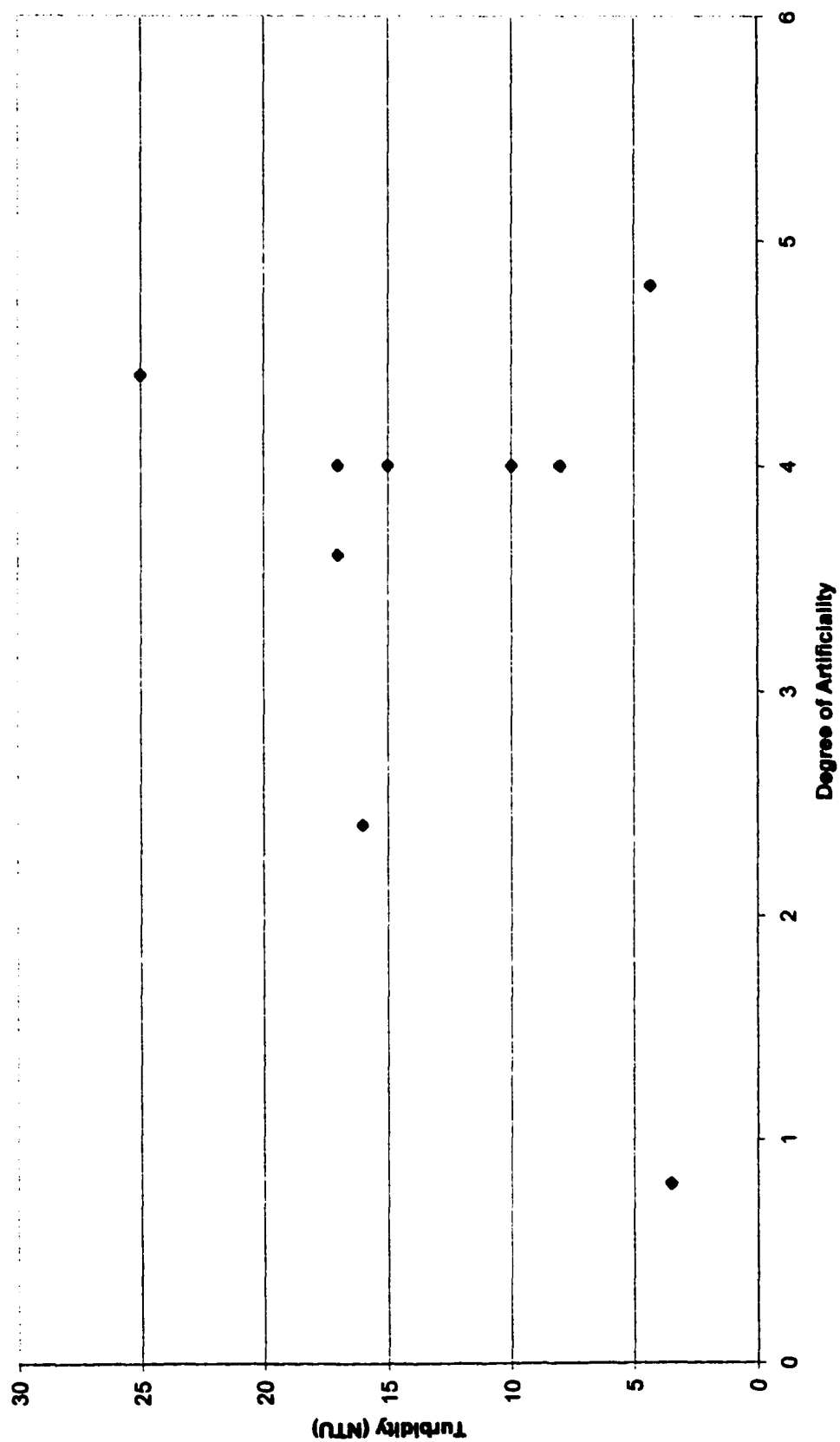


Degree of Urbanization Score vs Copper Concentration - Spring 1998

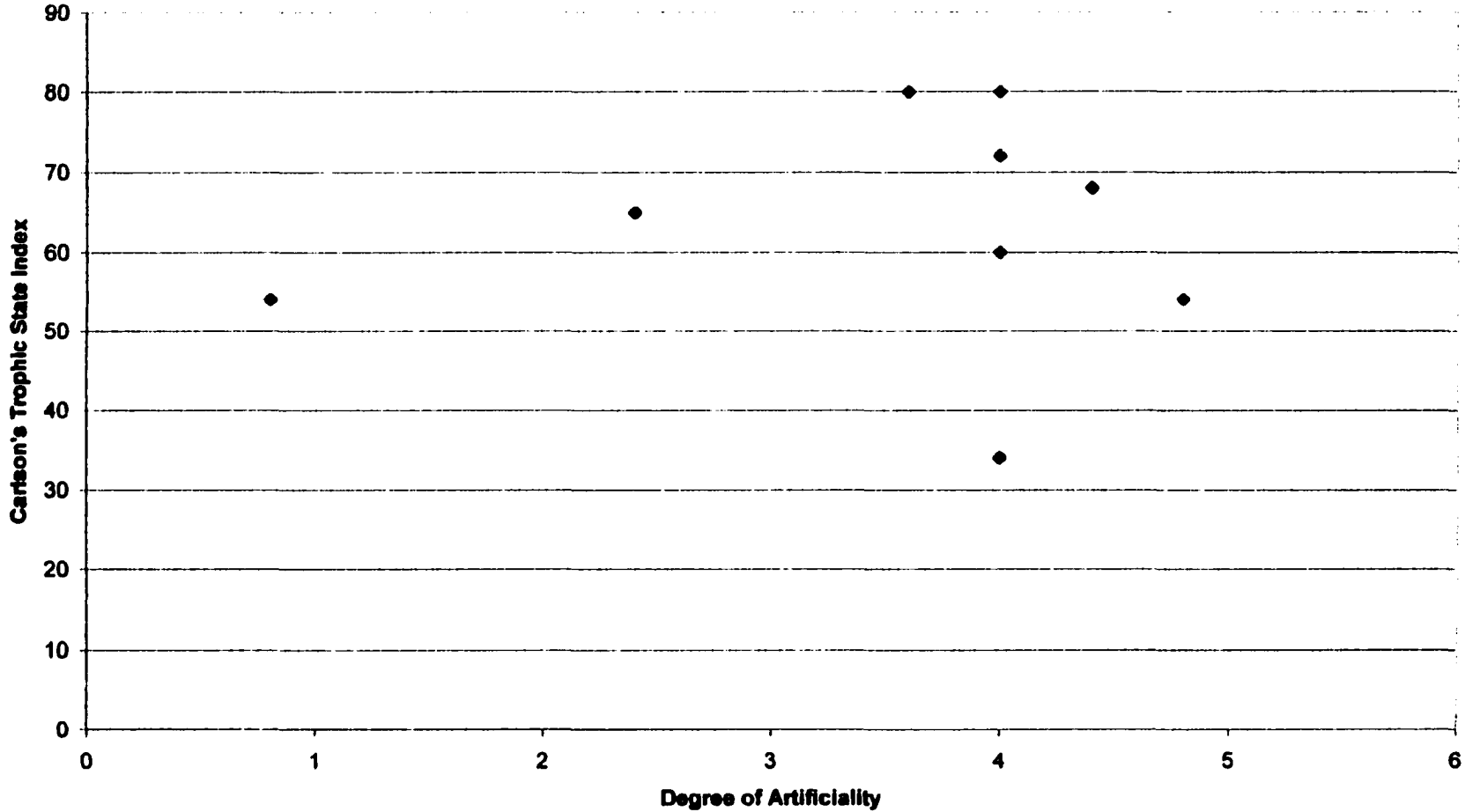
Water Input Mechanism Score vs Turbidity - Summer 1998

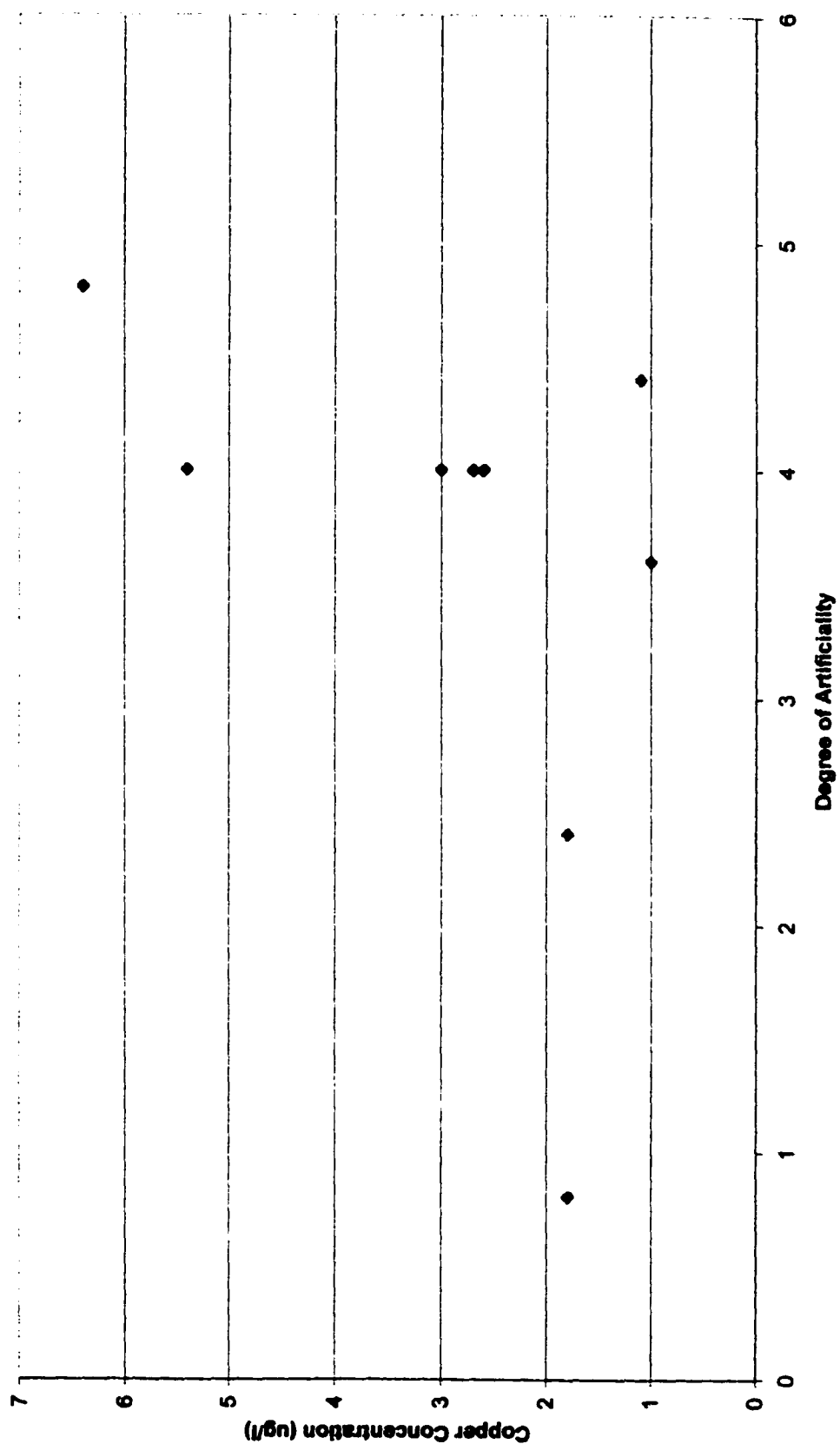


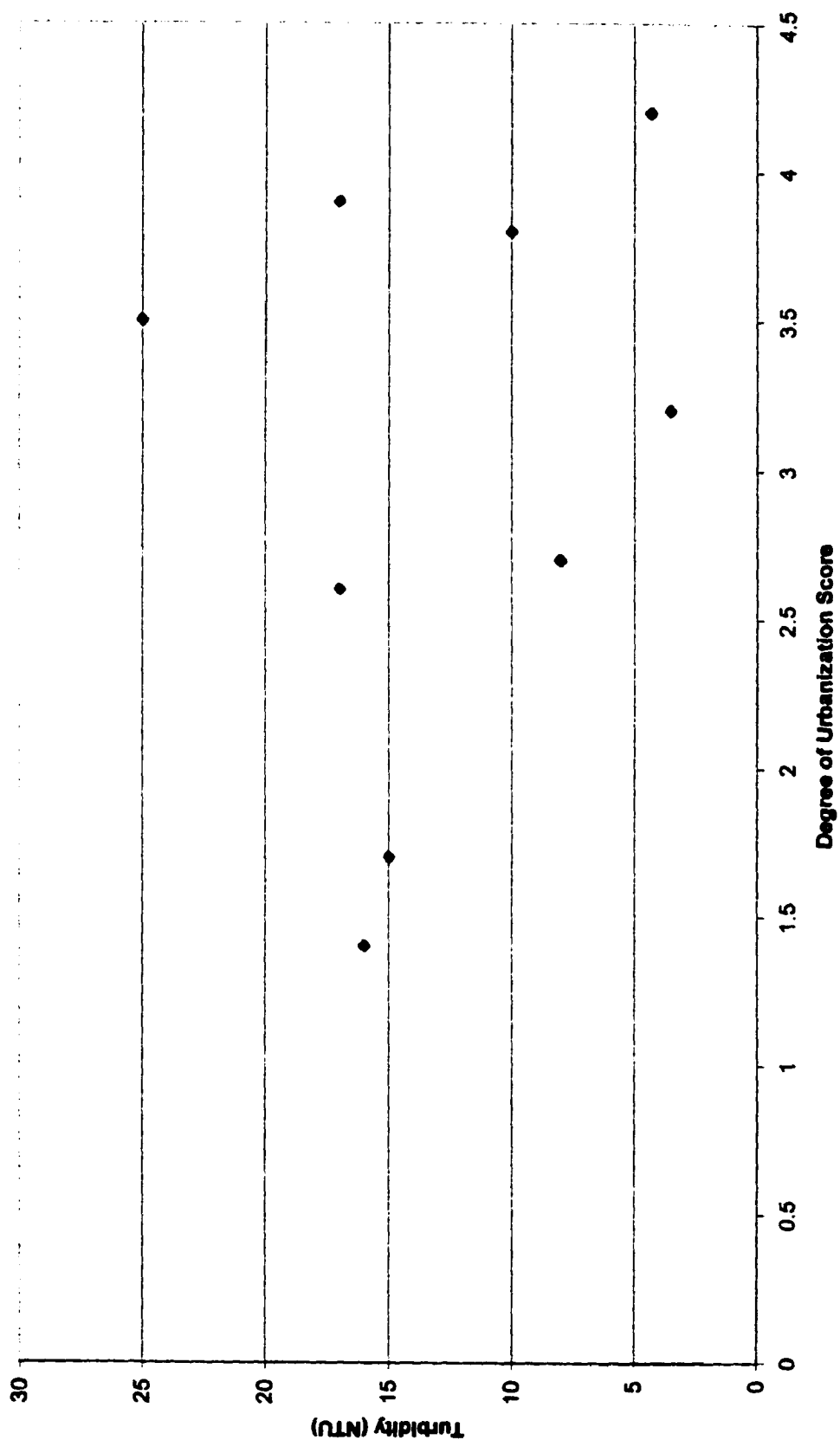
Water Input Mechanism Score vs Copper Concentration - Summer 1998

Degree of Artificiality Score vs Turbidity - Summer 1998

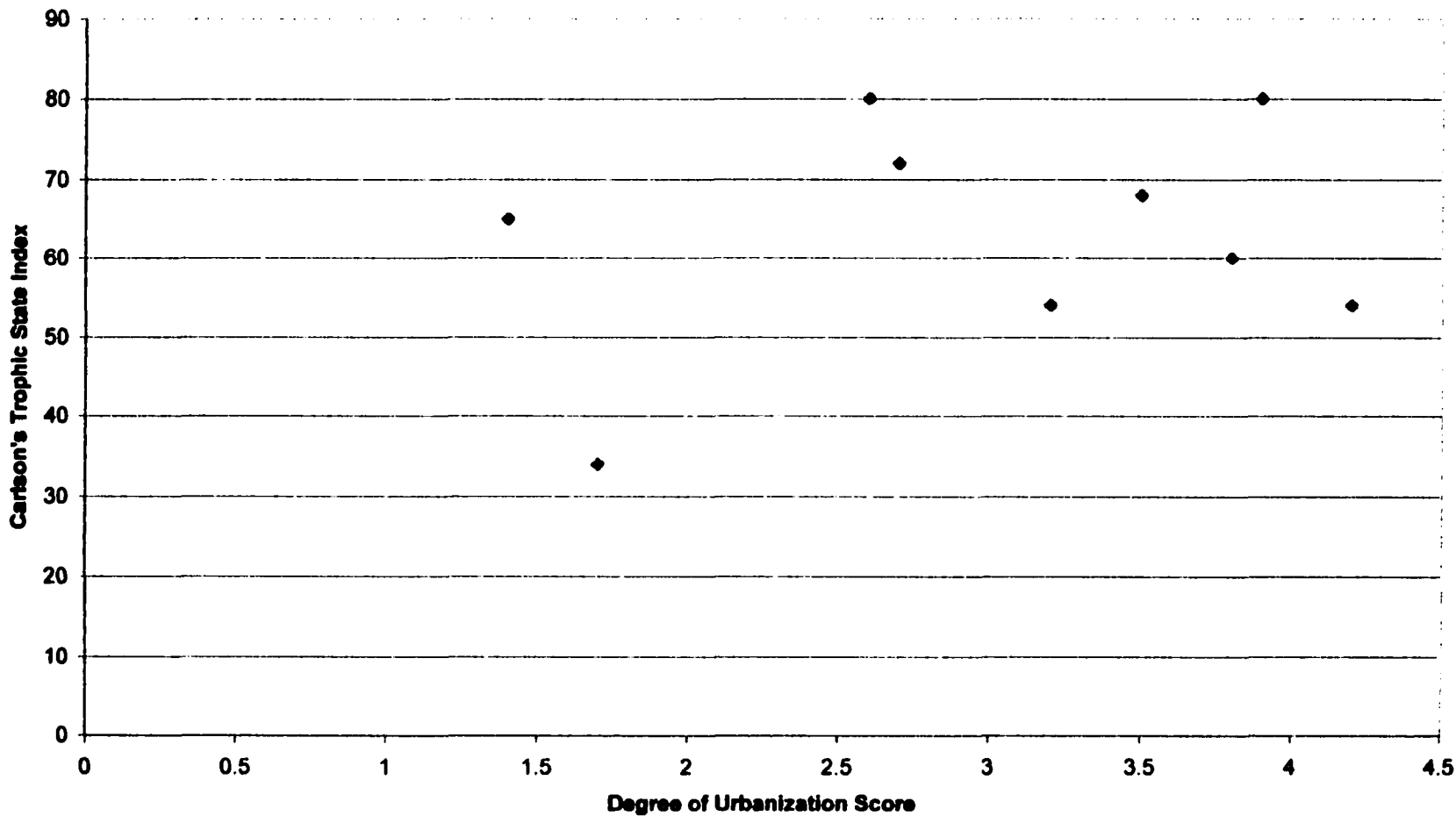
Degree of Artificiality Score vs Carlson's Trophic State Index (based on Chlorophyll a) - Summer 1998



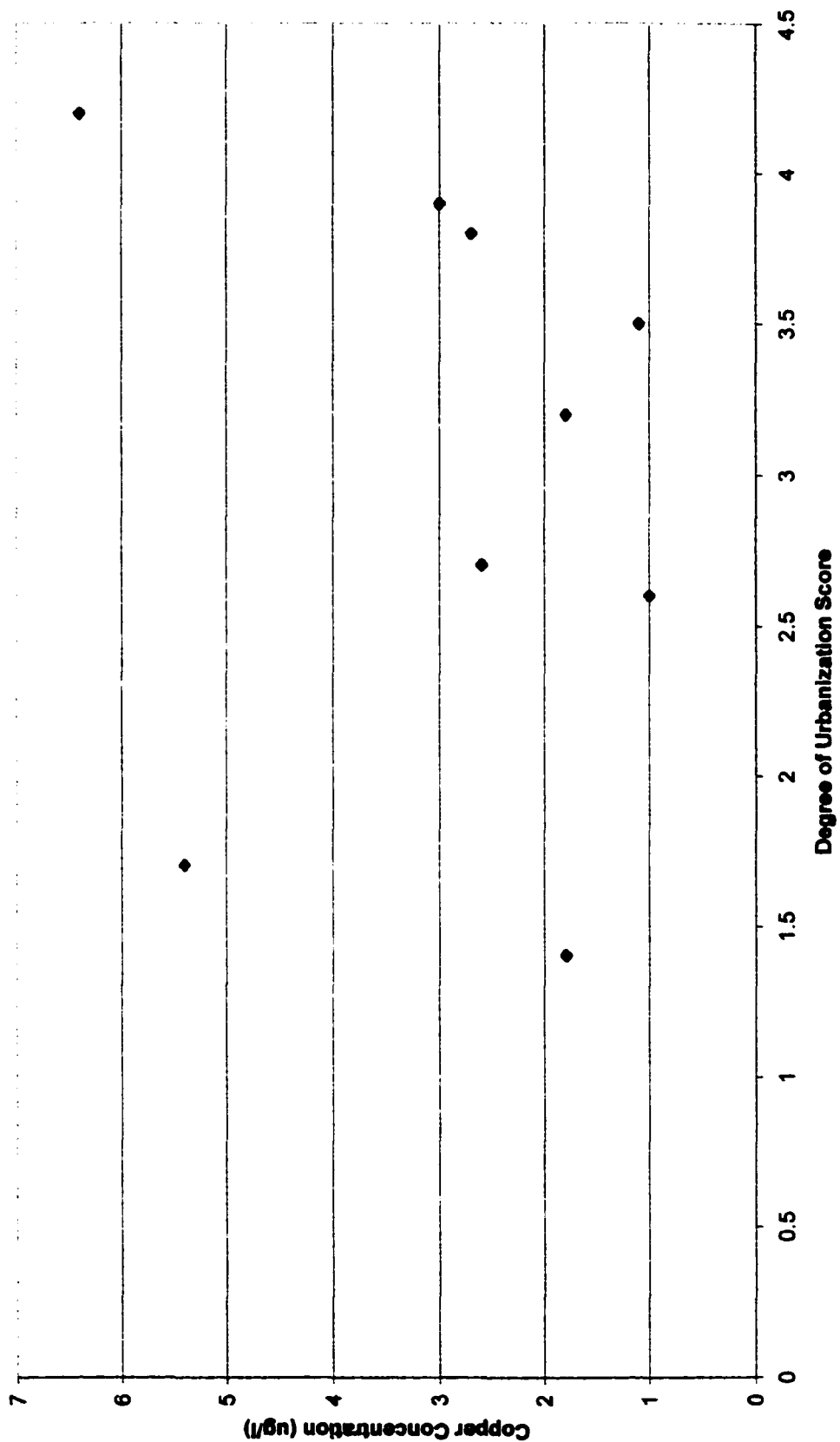
Degree of Artificiality Score vs Copper Concentration - Summer 1998

Degree of Urbanization Score vs Turbidity - Summer 1998

Degree of Urbanization Score vs Carlson's Trophic State Index (based on Chlorophyll a) - Summer 1998



Degree of Urbanization Score vs Copper Concentration - Summer 1998



APPENDIX D

FIELD MEASUREMENTS AND ANALYTICAL DATA IN WINSTAT WORKSHEETS

	Lake Number	Name	Prim Water Input Mec	Date	Lake Depth (meters)	Secchi depth (meters)	Actual Depth of samp
1							
2	1A	Wolf's Pond	Groundwater	11/10/97	1.5	0.54	1 ft below the surfa
3	1B						1 ft above the botto
4	1C						Mid-depth, 2 ft belo
5							
6	2A	Richmondtown Millpon	Tributary	11/10/97	0.3	0.24	Mid depth, 0.5 ft be
7							
8	3A						1 ft below the surfa
9	3B	Harlem Meer	City Water	11/12/97	2.2	0.73	1 ft above the botto
10	3C						Mid-depth, 3 ft belo
11							
12	4A	Van Cortlandt Lake	Tributary	11/12/97	1.2	0.50	1 ft below the surfa
13	4B						1 ft above the botto
14							
15	5A	Prospect Park Lake	City Water	11/25/97	2.3	1.16	1 ft below the surfa
16	5B						1 ft above the botto
17	5C						Mid-depth, 3 ft belo
18							
19	6A	Conselyea's Pond	Tributary	11/25/97	1.4	0.35	1 ft below the surfa
20	6B						1 ft above the botto
21							
22	7A	Oakland Lake	Groundwater	12/4/97	3.3	1.79	1 ft below the surfa
23	7B						1 ft above the botto
24	7C						Mid-depth, 4.5 ft be
25							
26	8A	Kissena Lake	City Water	12/4/97	2.0	1.38	1 ft below the surfa
27	8B						1 ft above the botto
28	8C						Mid-depth, 3 ft belo
29							
30	9A	Meadow Lake	Groundwater	12/4/97	1.1	0.42	1 ft below the surfa
31	9B						1 ft above the botto
32							

	Temperature (degrees)	pH	Conductivity (micros)	Salinity (ppt)	Dissolved Oxygen (m)	Percent Saturation	Turbidity (NTU)	Hardness (mg/l)
1								
2	50.7	7.12	181	0.1	9.07	80.8	7.5	58
3	50.5	7.21	182	0.1	9.25	81.5		
4	50.6	7.18	182	0.1	9.21	82.3		
5								
6	51.2	7.87	452	0.2	7.81	68.3	7.5	161
7								
8	48.8	7.29	242	0.1	7.19	62.3	6.1	71
9	48.6	7.11	242	0.1	6.52	56.9		
10	48.6	7.22	244	0.1	6.78	58.9		
11								
12	47.0	7.73	373	0.2	9.77	83.1	4.3	110
13	46.8	7.29	378	0.2	8.80	74.4		
14								
15	39.5	7.70	93	0.0	12.49	95.0	5.0	28
16	39.4	7.36	93	0.0	11.65	91.0		
17	39.5	7.41	93	0.0	12.19	94.9		
18								
19	48.4	8.99	16720	7.5	20.22	196.0	8.0	1360
20	51.1	7.42	23360	13.6	17.75	181.0		
21								
22	40.2	7.66	564	0.3	10.50	82.0	7.0	211
23	40.1	7.44	567	0.3	10.30	79.0		
24	40.1	7.49	566	0.3	10.40	80.0		
25								
26	41.5	7.55	76	0.0	11.09	88.0	9.0	26
27	41.2	7.23	76	0.0	10.98	86.2		
28	41.3	7.34	76	0.0	10.87	86.0		
29								
30	39.1	8.66	1128	0.6	13.95	107.2	17.0	292
31	39.0	8.67	1129	0.6	13.87	106.2		
32								

	Chloride (mg/l)	Chlorophyll a (mg/cu)	Chlorophyll b (mg/cu)	Chlorophyll c (mg/cu)	ORP millivolts	Lead (ug/l)	Copper (ug/l)	Zinc (ug/l)
1								
2	22.10	13.00	14.60	2.47	481	6.1	7.8	6.0
3					458			
4								
5								
6	66.30	3.60	6.24	2.09	446	11.5	14.3	10.2
7								
8	90.00	3.90	5.40	1.38	472	9.9	9.5	3.6
9					467			
10								
11								
12	69.20	6.64	10.30	6.61	458	20.2	13.1	5.8
13					454			
14								
15	8.68	12.80	14.20	3.15	454	8.2	2.0	12.0
16					450			
17								
18								
19	3761.00	77.90	110.10	22.80	394	7.3	1.7	9.6
20					383			
21								
22	91.10	9.07	12.20	2.29	432	1.0	1.0	1.0
23					431			
24								
25								
26	1.50	68.40	75.30	11.30	447	1.6	1.0	1.3
27					447			
28								
29								
30	254.70	87.40	95.10	11.70	404	8.8	1.8	2.2
31					391			
32								

	Cadmium (ug/l)	Color (cu)	Nitrate Nitrogen (mg)	Nitrite Nitrogen (mg)	Ammonia Nitrogen (	Total Kjeldahl Nitro	Orthophosphate (mg/l)
1							
2	1	80	0.144	0.05	0.201	2.10	0.100
3		80	0.126	0.05	0.207	1.54	0.100
4							
5							
6	1	80	0.288	0.05	0.123	1.40	0.247
7							
8	1	80	0.317	0.05	0.141	2.52	0.127
9		80	0.359	0.05	0.201	1.26	0.100
10							
11							
12	1	80	0.050	0.05	0.100	1.40	0.100
13		80	0.050	0.05	0.100	1.68	0.128
14							
15	1	60	0.050	0.05	0.100	1.40	0.100
16		60	0.050	0.05	0.100	1.54	0.100
17							
18							
19	1	60	0.380	0.05	0.140	2.80	0.130
20		60	0.270	0.15	0.100	1.26	0.158
21							
22	1	30	1.520	0.05	0.100	1.40	0.100
23		40	1.520	0.05	0.100	1.54	0.100
24							
25							
26	1	30	0.082	0.05	0.100	1.12	0.100
27		30	0.082	0.05	0.100	1.00	0.100
28							
29							
30	1	180	0.202	0.05	0.116	2.66	0.100
31		120	0.202	0.05	0.130	2.80	0.100
32							

	Total Phosphorous (m	Fecal Colliform (cfu/	Fecal Streptococci (	Total Organic Carbon	Carlson Trophic Inde	Carlson Trophic Inde
1						
2	0.189	1800		10	69	42
3	0.173					
4						
5						
6	0.274	2500		10	79	43
7						
8	0.155	400	46	10	65	44
9	0.182					
10						
11						
12	0.139	800	31	10	70	48
13	0.145					
14						
15	0.100	1	33	10	59	56
16	0.100					
17						
18						
19	0.156	200	49	10	75	73
20	0.177					
21						
22	0.149	1	920	10	52	52
23	0.234					
24						
25						
26	0.282	1	5	10	56	72
27	0.231					
28						
29						
30	0.173	1	2	10	76	75
31	0.168					
32						

	Water Input Mechanis	Degree of Artificial	Degree of Urbanizati	Dissolved Oxygen (m	VAR40	VAR41	VAR42	pH	ORP millivolts
1									
2	2.7	2.4	1.4						
3								7.21	458
4									
5									
6	1.0	4.0	1.7					7.87	446
7									
8	4.4	4.8	4.2						
9								7.11	467
10									
11									
12	1.5	4.0	2.7						
13								7.29	454
14									
15	4.7	4.4	3.5						
16								7.36	450
17									
18									
19	0.5	4.0	3.8						
20								7.42	383
21									
22	2.5	0.8	3.2						
23								7.44	431
24									
25									
26	4.8	3.6	2.6						
27								7.23	447
28									
29									
30	2.6	4.0	3.9						
31								8.67	391
32									

	Dissolved Oxygen (m	Dissolved Oxygen (m	Chlorophyl l a (mg/cu
1			
2		9.07	13.00
3	9.25		
4			
5			
6	7.81	7.81	3.60
7			
8		7.19	3.90
9	6.52		
10			
11			
12		9.77	6.64
13	8.80		
14			
15		12.49	12.80
16	11.65		
17			
18			
19		20.22	77.90
20	17.75		
21			
22		10.50	9.07
23	10.30		
24			
25			
26		11.09	68.40
27	10.98		
28			
29			
30		13.95	87.40
31	13.87		
32			

	Lake Number	Name	Prim Water Input Mec	Date	Lake Depth (meters)	Secchi depth (meters)	Actual Depth of samp
1							
2	1A	Wolf's Pond	Groundwater	5/26/98	1.5		0.64 ft below the surfa
3	1B						ft above the botto
4	1C						lid-depth, 2 ft belo
5							
6	2A	mondtown Millpon	Tributary	5/26/98	0.3		0.30lid-depth, 0.5 ft be
7							
8	3A	Harlem Meer	City water	6/4/98	2.2		1.52 ft below the surfa
9	3B						ft above the botto
10	3C						lid-depth, 3 ft belo
11							
12	4A	Van Cortlandt Lake	Tributary	6/4/98	1.2		0.88 ft below the surfa
13	4B						ft above the botto
14							
15	5A	Prospect Park Lake	City water	6/8/98	2.3		0.40 ft below the surfa
16	5B						ft above the botto
17	5C						lid-depth, 3 ft belo
18							
19	6A	Consetyea's Pond	Tributary	6/8/98	1.4		0.60 ft below the surfa
20	6B						ft above the botto
21							
22	7A	Oakland Lake	Groundwater	6/9/98	3.3		2.34 ft below the surfa
23	7B						ft above the botto
24	7C						lid-depth, 4.5 ft be
25							
26	8A	Kissena	City water	6/9/98	2.0		1.03 ft below the surfa
27	8B						ft above the botto
28	8C						lid-depth, 3 ft belo
29							
30	9A	Meadow Lake	Groundwater	6/9/98	1.1		0.16 ft below the surfa
31	9B						ft above the botto
32							

	Temperature (degrees)	pH	Conductivity (micros)	salinity (ppt)	Dissolved Oxygen (m	Percent Saturation	Turbidity (NTU)	Hardness (mg/l)	Chloride (mg/l)
1									
2	71.4	7.50	177	0.1	7.10	82.0	6.0	58	10.6
3	70.2	7.28	178	0.1	6.42	73.3			
4	70.6	7.33	179	0.1	6.66	74.5			
5									
6	62.2	7.25	606	0.3	8.10	84.0	4.0	183	82.5
7									
8	71.0	9.08	305	0.1	9.90	112.9	3.4	95	33.6
9	70.7	9.07	308	0.1	10.20	116.1			
10	70.9	9.09	306	0.1	9.83	112.4			
11									
12	68.7	7.83	621	0.3	9.62	107.0	5.6	155	107.1
13	66.1	7.88	647	0.3	10.88	120.1			
14									
15	65.9	9.48	109	0.0	10.12	109.5	15.0	35	8.4
16	65.7	9.48	107	0.0	9.46	101.8			
17	65.9	9.53	107	0.0	9.53	106.3			
18									
19	77.8	8.39	16500	9.0	13.90	183.0	14.0	1060	5691.0
20	74.8	7.81	19300	11.4	13.60	174.0			
21									
22	66.3	7.49	580	0.3	9.41	102.1	2.4	189	83.9
23	64.6	7.11	582	0.3	8.18	86.4			
24	65.7	7.42	574	0.3	10.35	111.5			
25									
26	68.2	9.88	128	0.1	11.56	128.5	5.1	34	12.8
27	66.1	9.81	126	0.1	10.67	115.4			
28	66.2	9.87	128	0.1	10.60	115.0			
29									
30	64.8	9.31	6480	3.6	11.53	125.3	30.0	742	186.5
31	64.1	9.31	6570	3.6	11.34	124.0			
32									

	Chlorophyll a (mg/cu)	Chlorophyll b (mg/cu)	Chlorophyll c (mg/cu)	ORP millivolts	Lead (ug/l)	Copper (ug/l)	Zinc (ug/l)	Cadmium (ug/l)
1								
2	14.30	22.00	4.21	403	7.6	4.2	3.3	1
3				403				
4								
5								
6	1.00	3.05	1.00	412	6.3	9.8	4.4	1
7								
8	3.83	6.90	1.49	388	16.6	1.0	5.7	1
9				421				
10								
11								
12	1.81	1.46	1.00	431	20.2	1.3	3.9	1
13				452				
14								
15	59.90	71.80	1.00	375	17.1	1.0	1.0	1
16				398				
17								
18								
19	68.80	85.90	7.66	429	1.0	11.9	23.9	1
20				442				
21								
22	7.56	9.83	6.81	398	6.7	5.0	2.1	1
23				307				
24								
25								
26	22.20	26.30	1.60	309	3.0	13.9	1.9	1
27				297				
28								
29								
30	70.40	70.20	1.00	336	22.1	6.6	3.0	1
31				328				
32								

	Color (cu)	Nitrate Nitrogen (mg)	Nitrite Nitrogen (mg)	Ammonia Nitrogen (	Total Kjeldahl Nitro	Orthophosphate (mg/l	Total Phosphorous (m
1							
2	70	0.116	0.050	0.137	6.86	0.100	0.100
3	80	0.129	0.050	0.126	3.50	0.100	0.100
4							
5							
6	25	0.850	0.050	0.176	7.98	0.100	0.110
7							
8	25	0.050	0.050	0.111	3.22	0.100	0.100
9	25	0.050	0.050	0.100	3.08	0.100	0.100
10							
11							
12	40	0.295	0.050	0.100	4.20	0.100	0.100
13	40	0.301	0.050	0.166	3.50	0.100	0.100
14							
15	40	0.050	0.050	0.139	5.46	0.100	0.100
16	30	0.050	0.050	0.106	10.80	0.100	0.100
17							
18							
19	40	0.050	0.050	0.155	8.28	0.100	0.131
20	25	0.050	0.050	0.441	9.86	0.543	0.571
21							
22	5	0.496	0.050	0.229	3.22	0.100	0.100
23	5	0.050	0.052	0.649	3.36	0.100	0.100
24							
25							
26	10	0.050	0.050	0.100	3.50	0.228	0.258
27	20	0.069	0.050	0.100	3.64	0.257	0.301
28							
29							
30	30	0.050	0.050	0.223	3.36	0.100	0.100
31	25	0.050	0.050	0.205	3.50	0.100	0.100
32							

	Fecal Coliform (cfu/	Fecal Streptococci (	Total Organic Carbon	Carlson Trophic Inde	Carlson Trophic Inde	Water Input Mechanis	Degree of Artificial
1							
2	32	1	10	68	57	2.7	2.4
3							
4							
5							
6	TNTC	1	10	0	31	1.0	4.0
7							
8	12	1	10	54	44	4.4	4.8
9							
10							
11							
12	16	1	10	61	37	1.5	4.0
13							
14							
15	8	1	10	74	70	4.7	4.4
16							
17							
18							
19	100	1	10	68	72	0.5	4.0
20							
21							
22	3	1	10	48	51	2.5	0.8
23							
24							
25							
26	1	1	10	60	62	4.8	3.6
27							
28							
29							
30	18	1	10	80	73	2.6	4.0
31							
32							

	Degree of Urbanizati	VAR39	VAR40	VAR41	VAR42	pH	ORP millivolts	Dissolved Oxygen (m	Dissolved Oxygen (m
1									
2	1.4								7.10
3						7.28	403	6.42	
4									
5									
6	1.7					7.25	412	8.10	8.10
7									
8	4.2								9.90
9						9.07	421	10.20	
10									
11									
12	2.7								9.62
13						7.98	452	10.88	
14									
15	3.5								10.12
16						9.48	398	9.46	
17									
18									
19	3.8								13.90
20						7.81	442	13.60	
21									
22	3.2								9.41
23						7.11	307	8.18	
24									
25									
26	2.6								11.56
27						9.81	297	10.67	
28									
29									
30	3.9								11.53
31						9.31	328	11.34	
32									

	Chlorophyll a (mg/cu)
1	
2	14.30
3	
4	
5	
6	1.00
7	
8	3.83
9	
10	
11	
12	1.81
13	
14	
15	59.90
16	
17	
18	
19	68.80
20	
21	
22	7.56
23	
24	
25	
26	22.20
27	
28	
29	
30	70.40
31	
32	

	Lake Number	Name	Prim Water Input Mec	Date	Lake Depth (meters)	Secchi depth (meters)
1						
2	1A	Wolf's Pond	Groundwater	7/29/98	1.5	0.60
3	1B					
4	1C					
5						
6	2A	Richmondtown Millpond	Tributary	7/29/98	0.3	0.30
7						
8	3A	Harlem Meer	City water	8/3/98	2.2	1.28
9	3B					
10	3C					
11						
12	4A	Van Cortlandt Lake	Tributary	8/3/98	1.2	0.46
13	4B					
14						
15	5A	Prospect Park Lake	City water	8/5/98	2.3	0.33
16	5B					
17	5C					
18						
19	6A	Conseelyea's Pond	Tributary	8/5/98	1.4	0.70
20	6B					
21						
22	7A	Oakland Lake	Groundwater	8/10/98	3.3	1.77
23	7B					
24	7C					
25						
26	8A	Kissena Lake	City water	8/10/98	2.0	0.24
27	8B					
28	8C					
29						
30	9A	Meadow Lake	Groundwater	8/10/98	1.1	0.32
31	9B					
32						

	Actual Depth of samp	Temperature (degrees	pH	Conductivity (micros	salinity (ppt)	Dissolved Oxygen (mg
1						
2	1 ft below surface	80.4	7.72	195	0.1	7.21
3	1 ft above bottom	78.8	7.93	193	0.1	4.60
4	Mid-depth, 2 ft belo	78.8	7.47	194	0.1	4.99
5						
6	Mid-depth, 0.5 ft be	69.6	7.18	741	0.4	6.69
7						
8	1 ft below the surfa	78.5	9.77	317	0.2	15.52
9	1 ft above the botto	77.8	9.35	315	0.2	9.80
10	Mid-depth, 3 ft belo	78.1	9.77	317	0.2	11.42
11						
12	1 ft below the surfa	80.5	9.47	608	0.3	13.65
13	1 ft above the botto	75.9	9.26	609	0.3	14.92
14						
15	1 ft below the surfa	79.0	10.22	125	0.1	14.80
16	1 ft above the botto	77.5	7.06	102	0.1	4.73
17	Mid-depth, 3 ft belo	78.4	10.05	118	0.1	12.85
18						
19	1 ft below the surfa	90.6	7.69	24000	14.5	12.49
20	1 ft above the botto	83.6	7.20	29730	18.4	0.30
21						
22	1 ft below the surfa	78.3	7.64	610	0.3	15.15
23	1 ft above the botto	65.4	6.72	811	0.3	0.41
24	Mid-depth, 4.5 ft be	71.7	6.87	641	0.3	0.58
25						
26	1 ft below the surfa	81.3	10.44	126	0.1	14.30
27	1 ft above the botto	77.9	7.57	97	0.0	0.69
28	Mid-depth, 3 ft belo	78.5	10.41	94	0.0	5.62
29						
30	1 ft below the surfa	83.1	10.07	9470	5.3	12.26
31	1 ft above the botto	81.9	10.13	9500	5.4	12.50
32						

	Percent Saturation	Turbidity (NTU)	Hardness (mg/l)	Chloride (mg/l)	Chlorophyll a (mg/cu)	Chlorophyll b (mg/cu)	Chlorophyll c (mg/cu)	ORP millivolts
1								
2	89.20	16.0	63	19.3	32.30	30.20	10.40	404
3	57.10							397
4	60.20							
5								
6	75.60	15.0	242	109.8	1.36	129.00	1.00	405
7								
8	192.00	4.3	76	57.4	11.20	11.00	6.57	391
9	120.30							371
10	140.00							
11								
12	172.30	8.0	135	137.5	69.60	64.50	16.50	373
13	179.60							393
14								
15	185.80	25.0	32	11.9	46.10	39.00	7.35	351
16	63.60							439
17	156.50							
18								
19	189.60	10.0	3100	9099.0	19.60	19.50	1.00	431
20	5.60							-146
21								
22	187.70	3.5	226	100.4	10.70	7.64	3.23	439
23	4.20							236
24	6.50							
25								
26	182.00	17.0	23	10.4	152.80	126.60	1.00	306
27	10.50							308
28	68.70							
29								
30	165.40	17.0	1140	3373.0	240.50	209.70	43.30	325
31	167.60							307
32								

	Lead (ug/l)	Copper (ug/l)	Zinc (ug/l)	Cadmium (ug/l)	Color (cu)	Nitrate Nitrogen (mg)	Nitrite Nitrogen (mg)	Ammonia Nitrogen (mg)
1								
2	11.4	1.8	3.4	1	160	0.050	0.050	0.14
3					180	0.050	0.050	0.12
4								
5								
6	8.5	5.4	9.1	1	80	2.140	0.112	0.20
7								
8	5.8	6.4	6.8	1	40	0.050	0.050	0.28
9						0.050	0.050	0.28
10								
11								
12	6.4	2.6	5.2	1	120	0.050	0.050	0.42
13						0.050	0.050	0.42
14								
15	1.5	1.1	2.6	1	240	0.050	0.050	0.14
16						0.050	0.050	0.28
17								
18								
19	1.0	2.7	7.1	1	90	0.050	0.050	0.10
20						0.050	0.050	1.05
21								
22	3.4	1.8	3.6	1	40	0.242	0.050	0.10
23						0.050	0.050	3.22
24								
25								
26	3.1	1.0	1.0	1	280	0.050	0.050	0.10
27						0.050	0.091	0.56
28								
29								
30	1.0	3.0	1.0	1	250	0.310	0.085	0.42
31						0.280	5.050	0.28
32								

	Total Kjeldahl Nitro	Orthophosphate (mg/l)	Total Phosphorous (m	Fecal Coliform (cfu/	Fecal Streptococci (	Total Organic Carbon
1						
2	0.280	0.123	0.504	1	1	10.0
3	0.280	0.109	0.130			
4						
5						
6	0.420	0.110	0.127	1	1	13.2
7						
8	0.420	0.100	0.100	1	1	10.0
9	0.420	0.114	0.163			
10						
11						
12	0.588	0.100	0.123	30	3	10.0
13	0.588	0.109	0.194			
14						
15	1.540	0.100	0.100	1	3	10.0
16	1.680	0.100	0.100			
17						
18						
19	2.940	0.118	0.138	TNTC	68	26.6
20	1.400	1.510	1.670			
21						
22	0.140	0.100	0.208	68	4	10.0
23	3.920	0.100	0.100			
24						
25						
26	0.420	0.245	0.294	41	1	10.0
27	0.640	0.411	0.429			
28						
29						
30	0.280	0.100	0.100	12	1	10.0
31	0.560	0.100	0.100			
32						

	Carlson Trophic Inde	Carlson Trophic Inde	Water Input Mechanis	Degree of Artificial	Degree of Urbanizati	VAR39	VAR40
1							
2	69	65	2.7	2.4	1.4		
3							
4							
5							
6	0	34	1.0	4.0	1.7		
7							
8	57	54	4.4	4.8	4.2		
9							
10							
11							
12	72	72	1.5	4.0	2.7		
13							
14							
15	78	68	4.7	4.4	3.5		
16							
17							
18							
19	66	60	0.5	4.0	3.8		
20							
21							
22	52	54	2.5	0.8	3.2		
23							
24							
25							
26	79	80	4.8	3.6	2.6		
27							
28							
29							
30	76	80	2.6	4.0	3.9		
31							
32							

	VAR41	VAR42	pH	ORP millivolts	Dissolved Oxygen (m	Dissolved Oxygen (m	Chlorophyl l a (mg/cu	VAR49	VAR50
1									
2						7.21	32.30		
3			7.93	397	4.60				
4									
5									
6			7.18	405	6.69	6.69	1.36		
7									
8						15.52	11.20		
9			9.35	371	9.80				
10									
11									
12						13.65	69.60		
13			9.26	393	14.92				
14									
15						14.80	46.10		
16			7.06	439	4.73				
17									
18									
19						12.49	19.60		
20			7.20	-146	0.30				
21									
22						15.15	10.70		
23			6.72	236	0.41				
24									
25									
26						14.30	152.80		
27			7.57	308	0.69				
28									
29									
30						12.26	240.50		
31			10.13	307	12.50				
32									

	VAR51	VAR52	VAR53	VAR54
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
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APPENDIX E

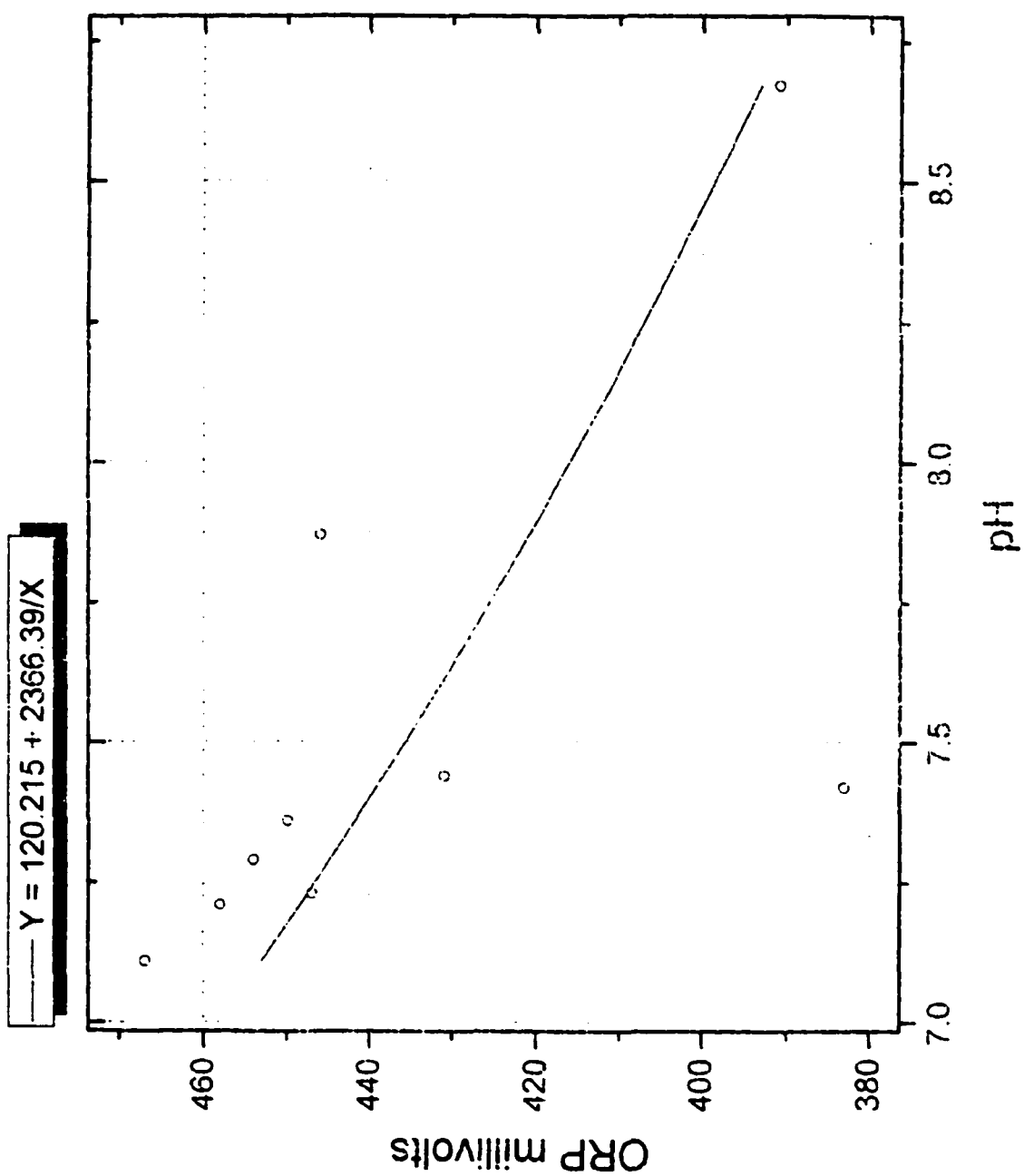
WINSTAT REGRESSION EQUATIONS, CORRELATION COEFFICIENTS, AND REGRESSION CURVES

E1 - BETWEEN SELECTED WATER QUALITY PARAMETER PAIRS

.

Variable: ORP millivolts
Independent variable: pH

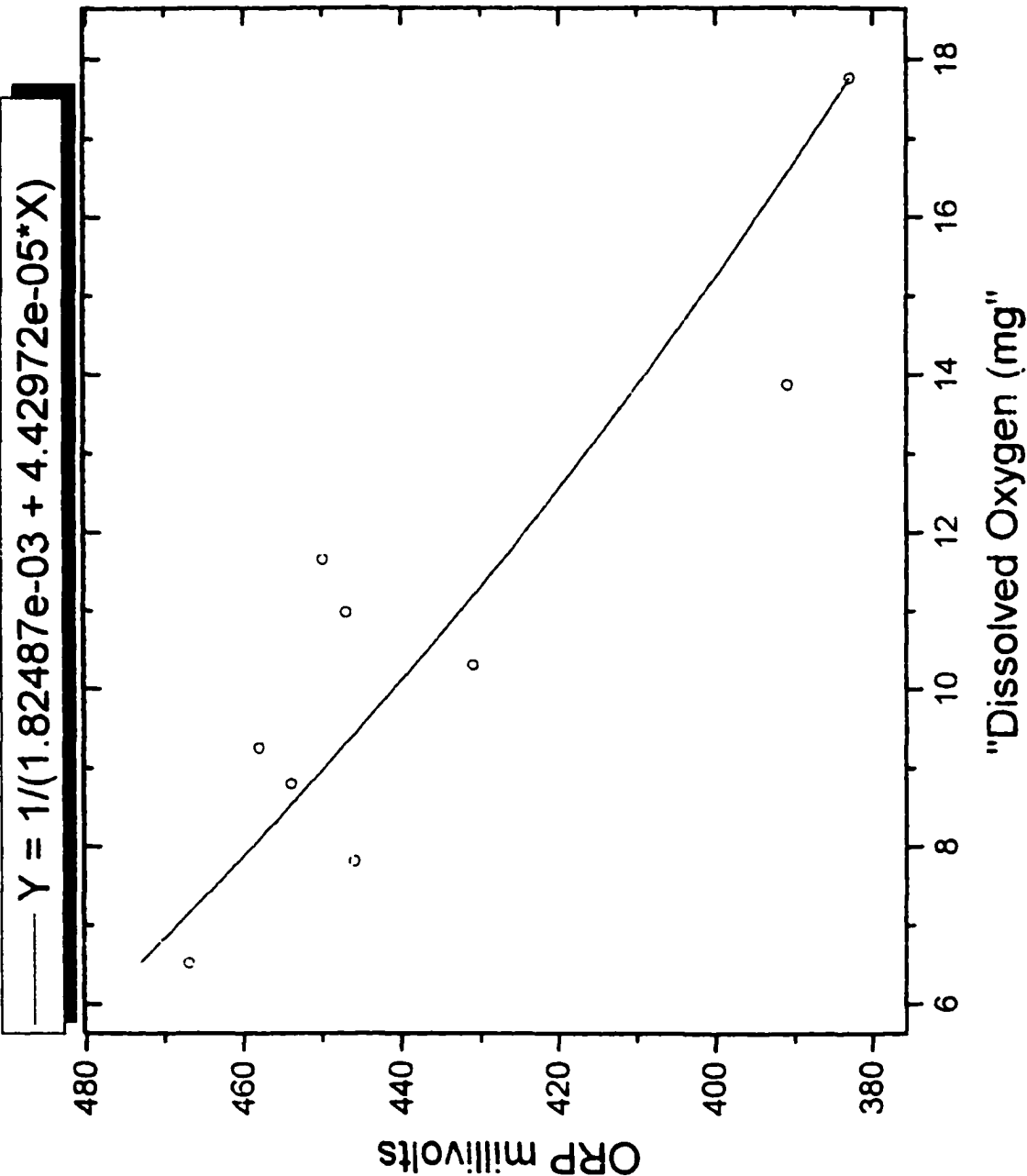
	N	A	B	R	R square
$Y = A + B \cdot X$	9	721.353	-37.9464	-0.62115	0.38583
$Y = A \cdot X^B$	9	1806.37	-0.70624	-0.61832	0.38232
$Y = A \cdot \exp(B \cdot X)$	9	851.572	-8.93119e-02	-0.61588	0.37931
$Y = A + B \cdot \log(X)$	9	1041.14	-300.205	-0.62391	0.38927
$Y = A + B/X$	9	120.215	2386.39	0.62661	0.39265
$Y = 1/(A + B \cdot X)$	9	7.19571e-04	2.10672e-04	0.61018	0.37232
$Y = X/(A + B \cdot X)$	9	-1.31138e-02	4.05378e-03	0.61441	0.3775



4/8/01 07:11:43 FALL97.WST

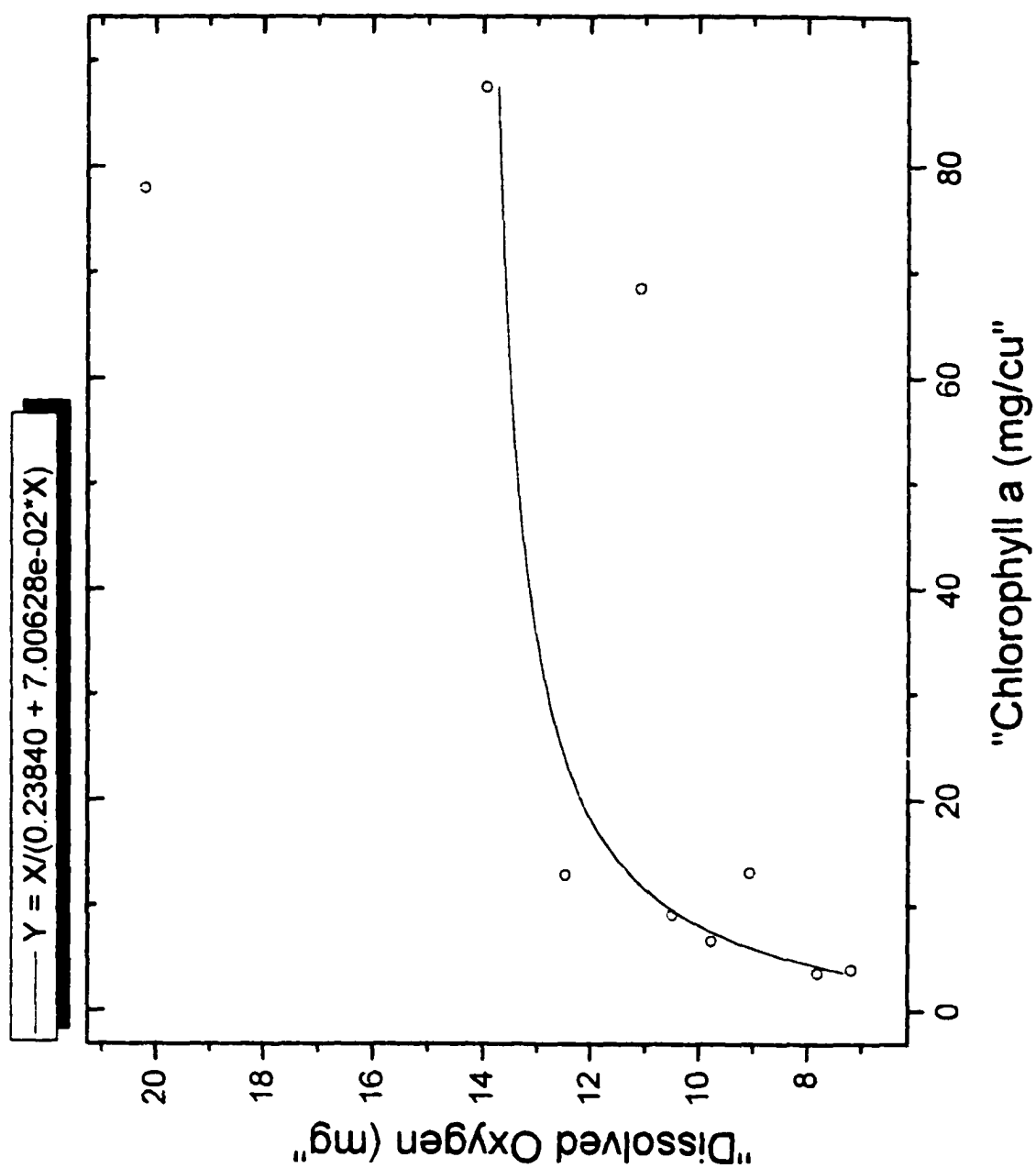
Variable: ORP millivolts
 Independent variable: Dissolved Oxygen (mg)

	N	A	B	R	R square
$Y = A + B \cdot X$	9	520.585	-7.82279	-0.89588	0.80261
$Y = A \cdot X^B$	9	698.164	-0.20218	-0.86465	0.74763
$Y = A \cdot \exp(B \cdot X)$	9	531.907	-1.85902e-02	-0.89687	0.80438
$Y = A + B \cdot \log(X)$	9	635.673	-85.3530	-0.86647	0.75077
$Y = A + B/X$	9	353.500	823.217	0.81221	0.65969
$Y = 1/(A + B \cdot X)$	9	1.82487e-03	4.42972e-05	0.8976	0.80569
$Y = X/(A + B \cdot X)$	9	-4.59892e-03	2.76470e-03	0.80284	0.64455



Variable: Dissolved Oxygen (mg)
Independent variable: Chlorophyll a (mg/cu)

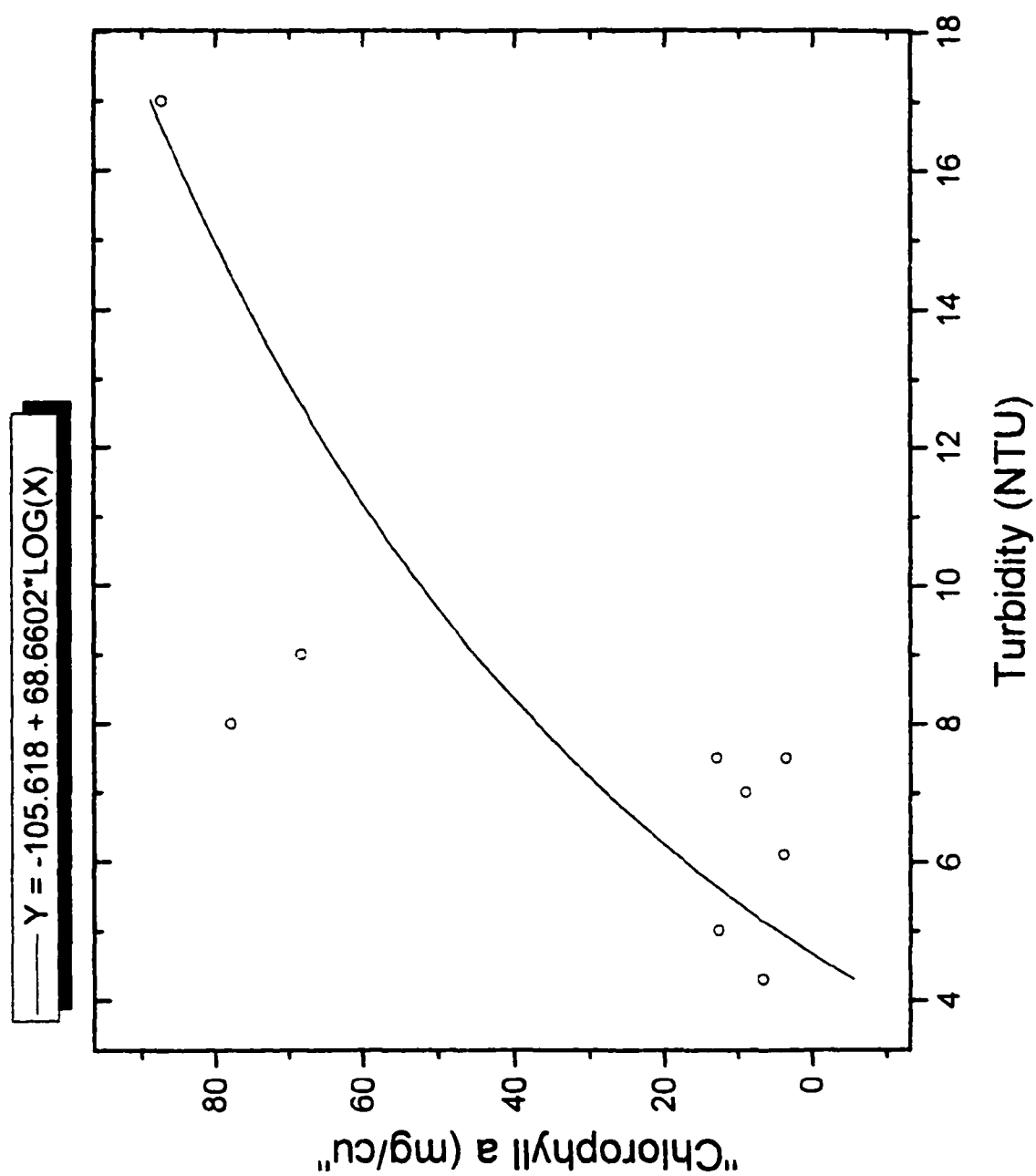
	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.70243	8.40724e-02	0.75151	0.56476
$Y = A \cdot X^B$	9	6.15885	0.20392	0.82288	0.67714
$Y = A \cdot \exp(B \cdot X)$	9	8.73375	6.83432e-03	0.76742	0.58894
$Y = A + B \cdot \log(X)$	9	4.82709	2.42700	0.77983	0.80783
$Y = A + B/X$	9	14.4899	-28.4523	-0.72676	0.52818
$Y = 1/(A + B \cdot X)$	9	0.11488	-5.92774e-04	-0.75426	0.56891
$Y = X/(A + B \cdot X)$	9	0.23840	7.00628e-02	0.86685	0.75143



4/8/01 08 46.48 FALL97.WST

Variable: Chlorophyll a (mg/cu)
 Independent variable: Turbidity (NTU)

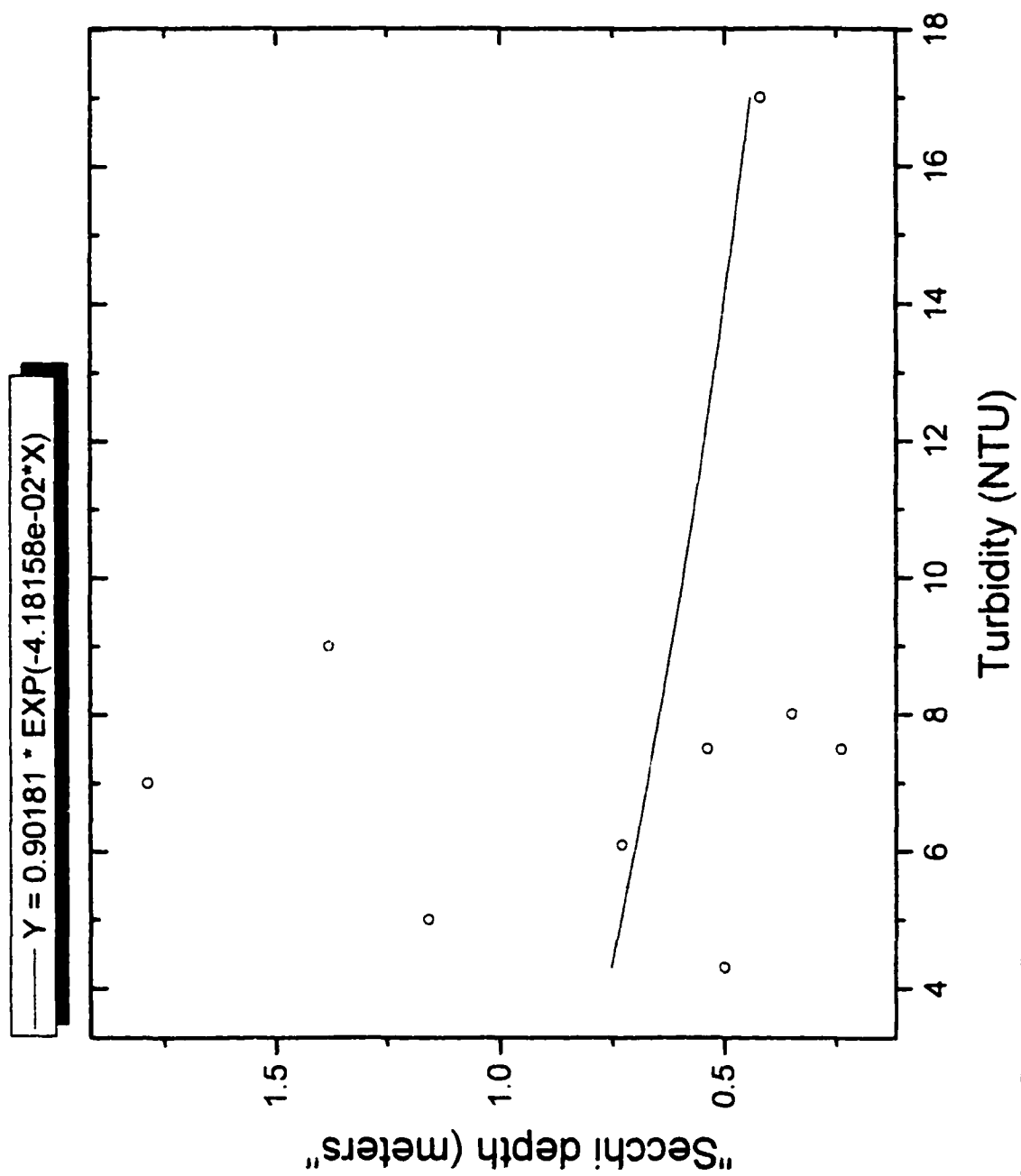
	N	A	B	R	R square
$Y = A + B \cdot X$	9	-25.4062	7.16198	0.75061	0.56342
$Y = A \cdot X^B$	9	0.20678	2.17629	0.67053	0.44961
$Y = A \cdot \text{EXP}(B \cdot X)$	9	2.65849	0.22552	0.65771	0.43259
$Y = A + B \cdot \text{LOG}(X)$	9	-105.618	68.8602	0.78022	0.57794
$Y = A + B/X$	9	103.578	-499.242	-0.71157	0.50633
$Y = 1/(A + B \cdot X)$	9	0.20983	-1.25989e-02	-0.46208	0.21352
$Y = X/(A + B \cdot X)$	9	0.82122	-8.81997e-03	-0.40961	0.16778



4/8/01 08:58:25 FALL97 WST

Variable: Secchi depth (meters)
Independent variable: Turbidity (NTU)

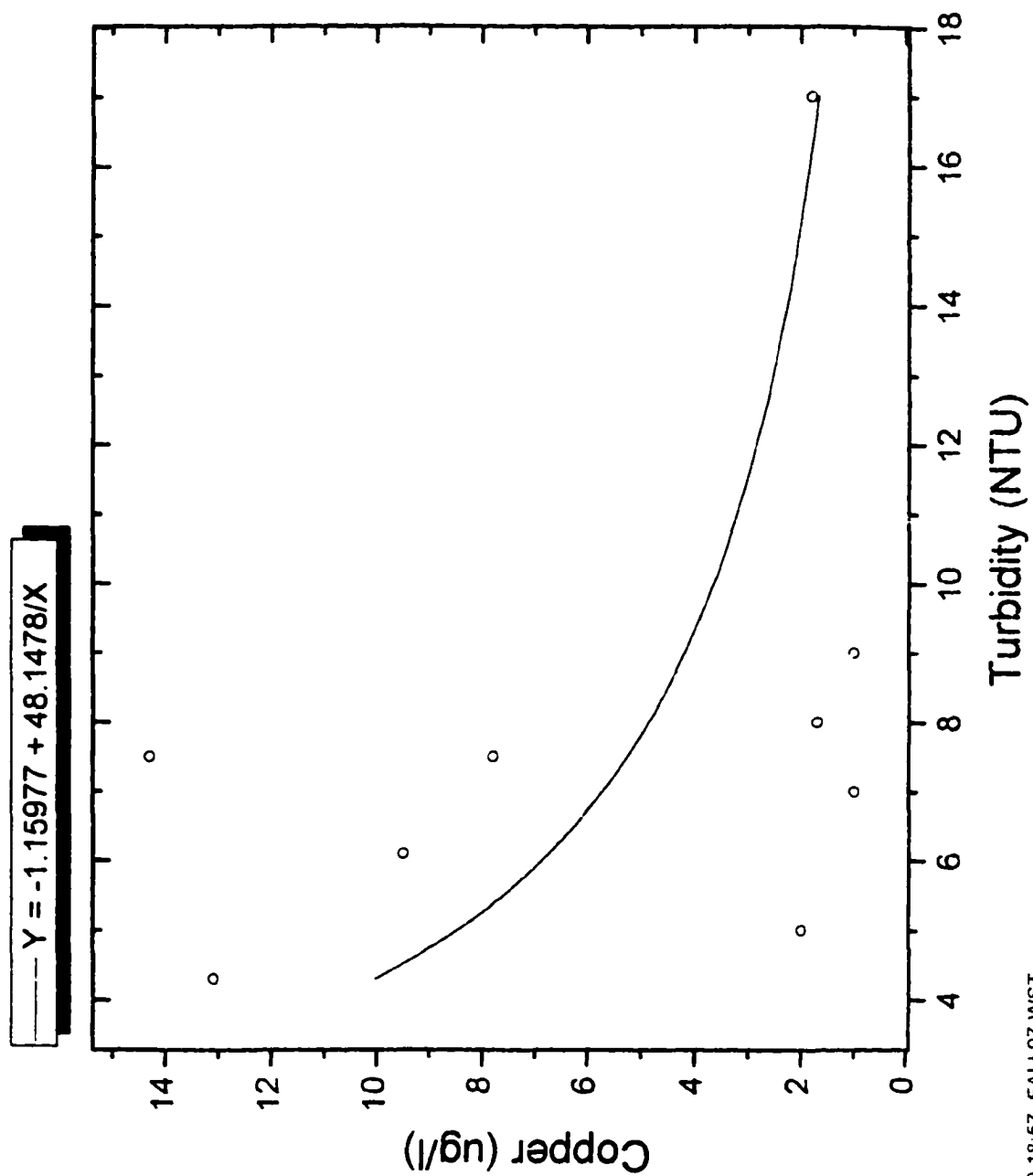
	N	A	B	R	R square
$Y = A + B \cdot X$	9	1.02585	-2.97285e-02	-0.2068	0.04276
$Y = A \cdot X^B$	9	1.33315	-0.36208	-0.21088	0.04447
$Y = A \cdot \exp(B \cdot X)$	9	0.90181	-4.18158e-02	-0.23052	0.05314
$Y = A + B \cdot \log(X)$	9	1.22807	-0.21949	-0.16131	0.02602
$Y = A + B/X$	9	0.63545	1.06915	0.10114	0.01023
$Y = 1/(A + B \cdot X)$	9	1.34931	6.48184e-02	0.2064	0.0426
$Y = X/(A + B \cdot X)$	9	-5.03859	2.59187	0.21819	0.0476



4/8/01 09:11 07 FALL97.WST

Variable: Copper (ug/l)
Independent variable: Turbidity (NTU)

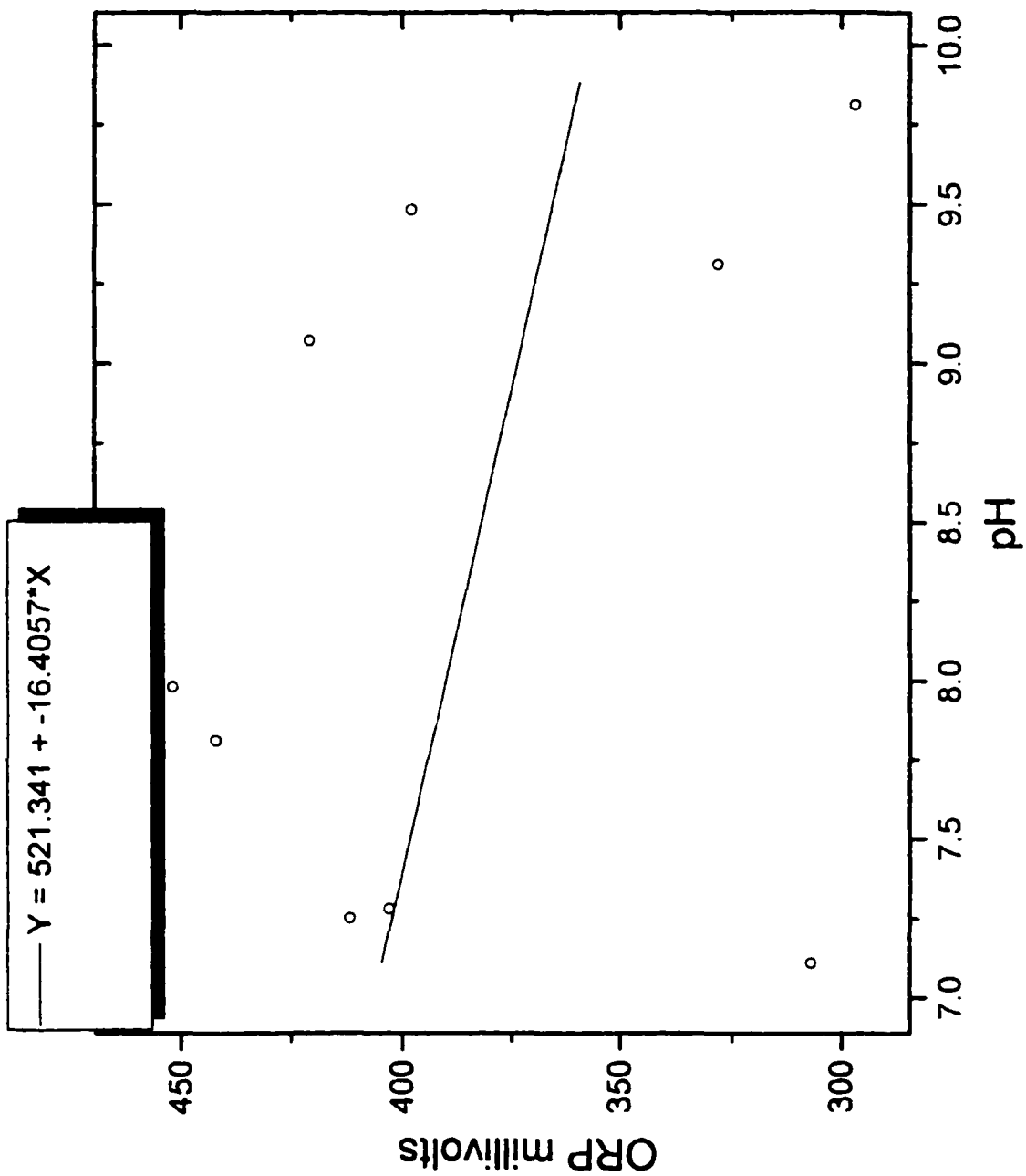
	N	A	B	R	R square
$Y = A + B \cdot X$	9	10.4179	-0.58208	-0.39649	0.15721
$Y = A \cdot X^B$	9	37.1538	-1.17948	-0.4175	0.1743
$Y = A \cdot \exp(B \cdot X)$	9	8.51549	-0.11102	-0.37198	0.13837
$Y = A + B \cdot \log(X)$	9	17.8009	-8.01316	-0.43272	0.18724
$Y = A + B/X$	9	-1.15977	48.1478	0.44801	0.19893
$Y = 1/(A + B \cdot X)$	9	0.21672	2.90336e-02	0.28436	0.08086
$Y = X/(A + B \cdot X)$	9	-2.95554	0.87428	0.39367	0.15498



4/8/01 09:18:57 FALL97 WST

Variable: ORP millivolts
Independent variable: pH

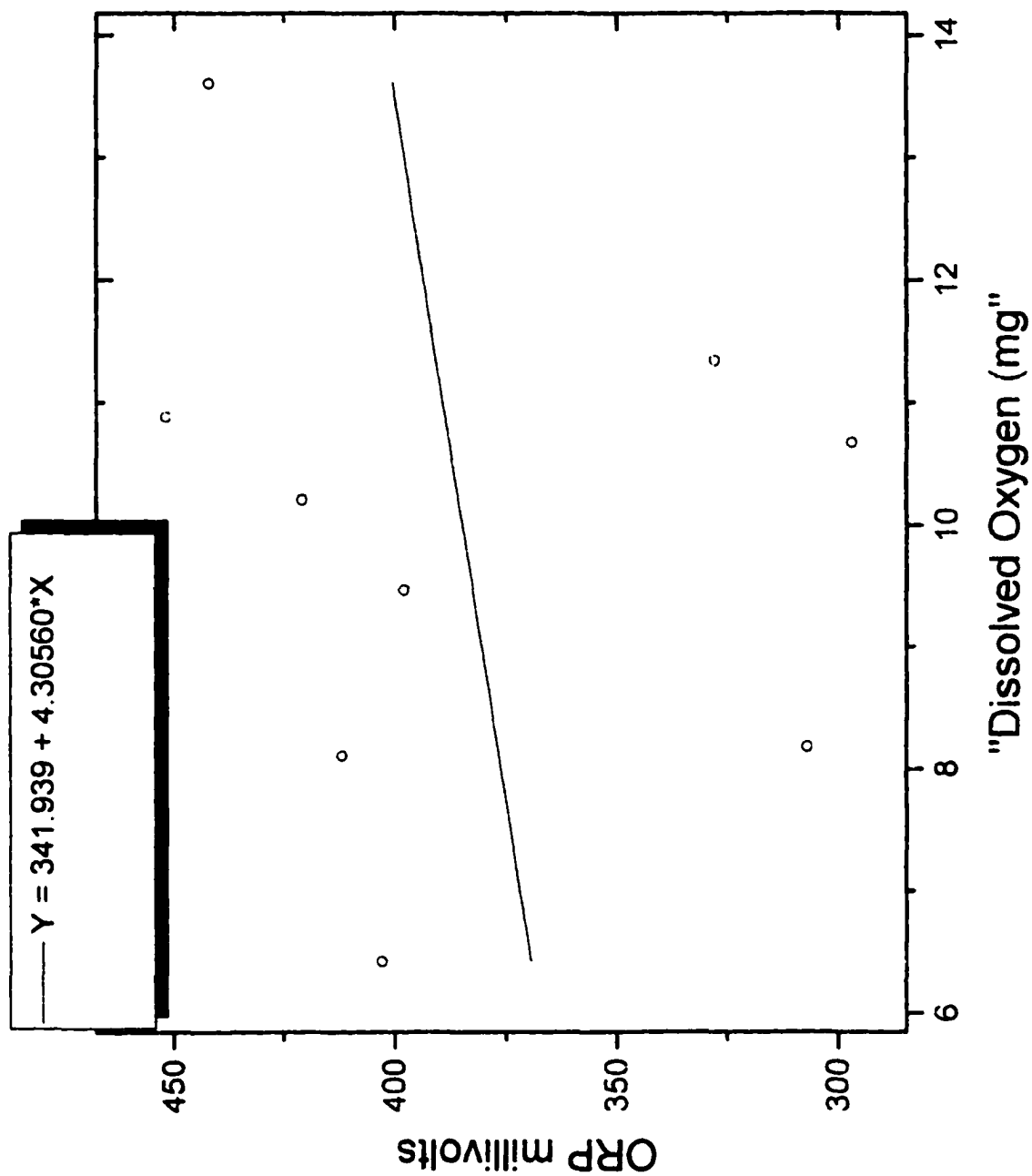
	N	A	B	R	R square
$Y = A + B \cdot X$	9	521.341	-16.4057	-0.30049	0.09029
$Y = A \cdot X^B$	9	778.268	-0.33875	-0.27213	0.07405
$Y = A \cdot \exp(B \cdot X)$	9	551.267	-4.45052e-02	-0.29876	0.08925
$Y = A + B \cdot \log(X)$	9	648.281	-124.787	-0.27353	0.07481
$Y = A + B/X$	9	271.350	930.068	0.24584	0.06044
$Y = 1/(A + B \cdot X)$	9	1.64059e-03	1.22225e-04	0.29678	0.08808
$Y = X/(A + B \cdot X)$	9	-6.95161e-03	3.50579e-03	0.2436	0.05934



4/8/01 09:31:08 SPRING98.WST

Variable: ORP millivolts
 Independent variable: Dissolved Oxygen (mg)

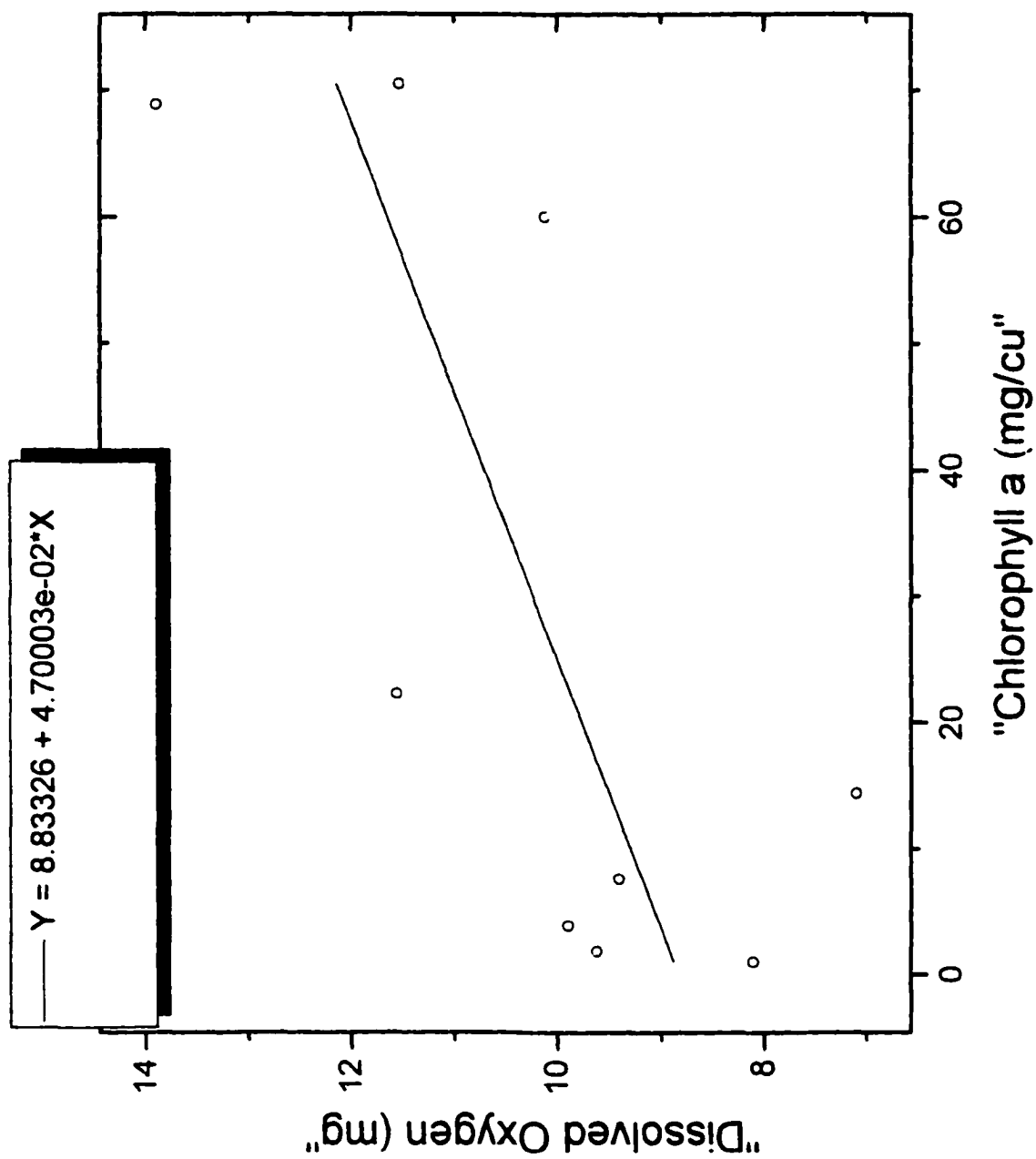
	N	A	B	R	R square
$Y = A + B \cdot X$	9	341.939	4.30560	0.15605	0.02435
$Y = A \cdot X^B$	9	327.493	6.58551e-02	0.09184	0.00843
$Y = A \cdot \exp(B \cdot X)$	9	344.891	9.88828e-03	0.13135	0.01725
$Y = A + B \cdot \log(X)$	9	314.944	30.6393	0.11659	0.01359
$Y = A + B/X$	9	403.953	-184.323	-0.07748	0.006
$Y = 1/(A + B \cdot X)$	9	2.88392e-03	-2.26328e-05	-0.10874	0.01182
$Y = X/(A + B \cdot X)$	9	5.52999e-04	2.60196e-03	0.03081	9.49691e-04



4/8/01 10:00:00 SPRING98 WST

Variable: Dissolved Oxygen (mg
Independent variable: Chlorophyll a (mg/cu)

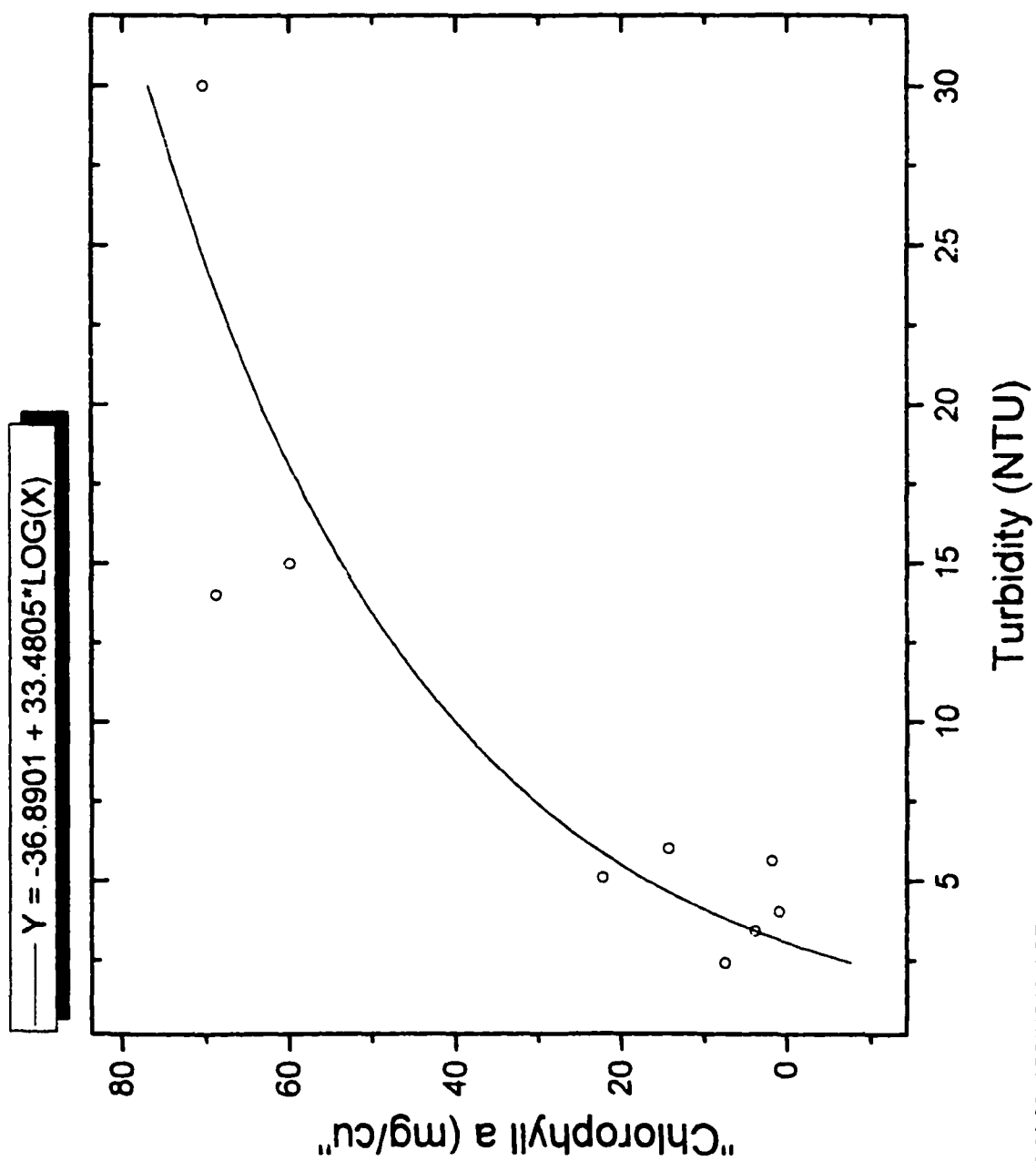
	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.83326	4.70003e-02	0.69715	0.48602
$Y = A \cdot X^B$	9	8.29467	7.39321e-02	0.59397	0.3528
$Y = A \cdot \exp(B \cdot X)$	9	8.79728	4.47974e-03	0.67153	0.45096
$Y = A + B \cdot \log(X)$	9	8.19911	0.78251	0.62206	0.38696
$Y = A + B/X$	9	10.7984	-2.82290	-0.4723	0.22307
$Y = 1/(A + B \cdot X)$	9	0.11430	-4.37094e-04	-0.63438	0.40244
$Y = X/(A + B \cdot X)$	9	2.62760e-02	9.60200e-02	0.43016	0.18504



4/8/01 10:11:01 SPRING98.WST

Variable: Chlorophyll a (mg/cu)
Independent variable: Turbidity (NTU)

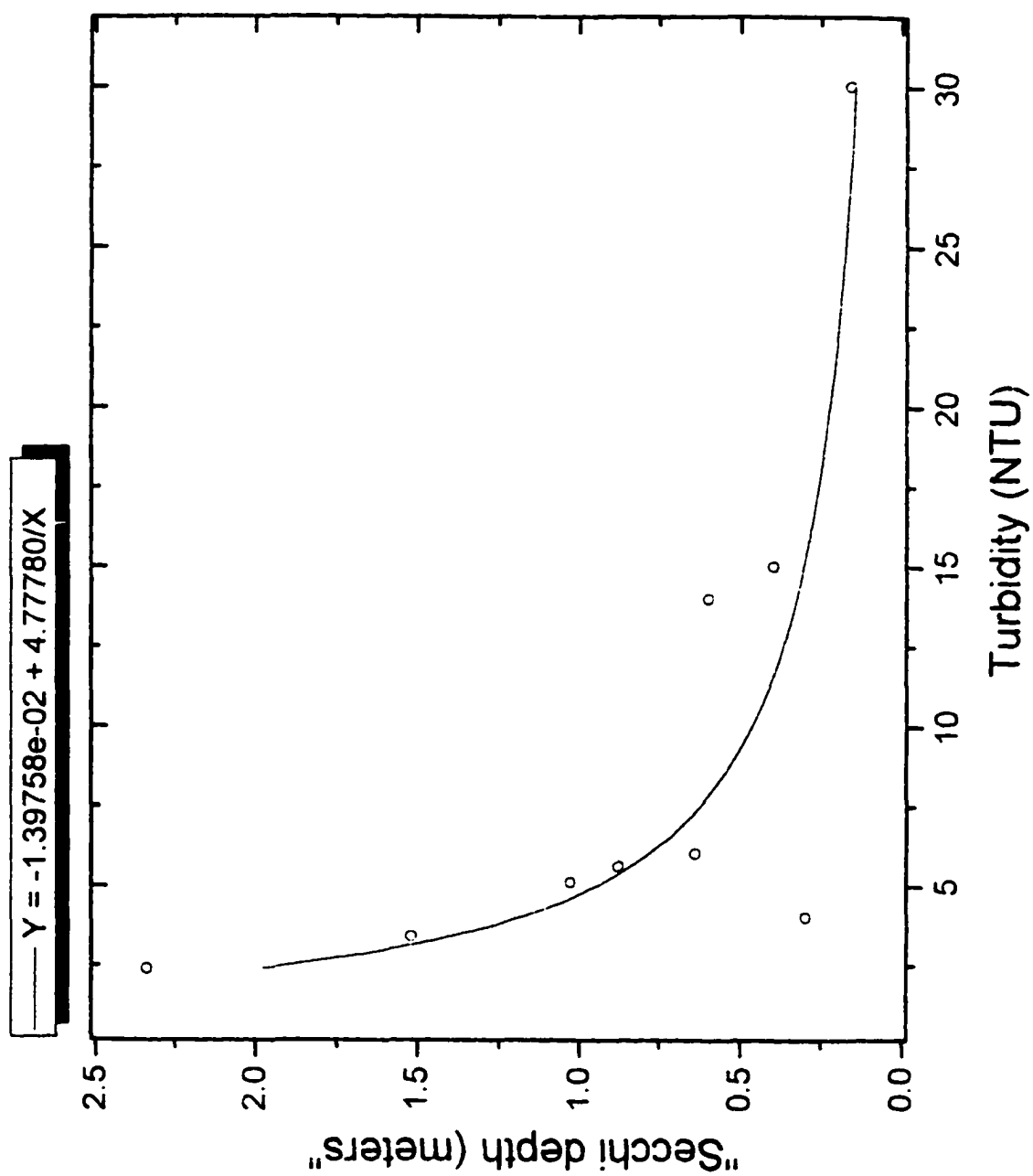
	N	A	B	R	R square
$Y = A + B \cdot X$	9	0.17347	2.90338	0.8675	0.75256
$Y = A \cdot X^B$	9	0.67656	1.48547	0.75858	0.57544
$Y = A \cdot \exp(B \cdot X)$	9	3.55159	0.12737	0.71015	0.50431
$Y = A + B \cdot \log(X)$	9	-36.8901	33.4805	0.91631	0.83963
$Y = A + B/X$	9	64.2800	-196.423	-0.80717	0.65153
$Y = 1/(A + B \cdot X)$	9	0.38623	-1.60221e-02	-0.42441	0.18012
$Y = X/(A + B \cdot X)$	9	0.93198	6.07284e-02	0.33954	0.11528



4/8/01 10:20:39 SPRING98.WST

Variable: Secchi depth (meters)
 Independent variable: Turbidity (NTU)

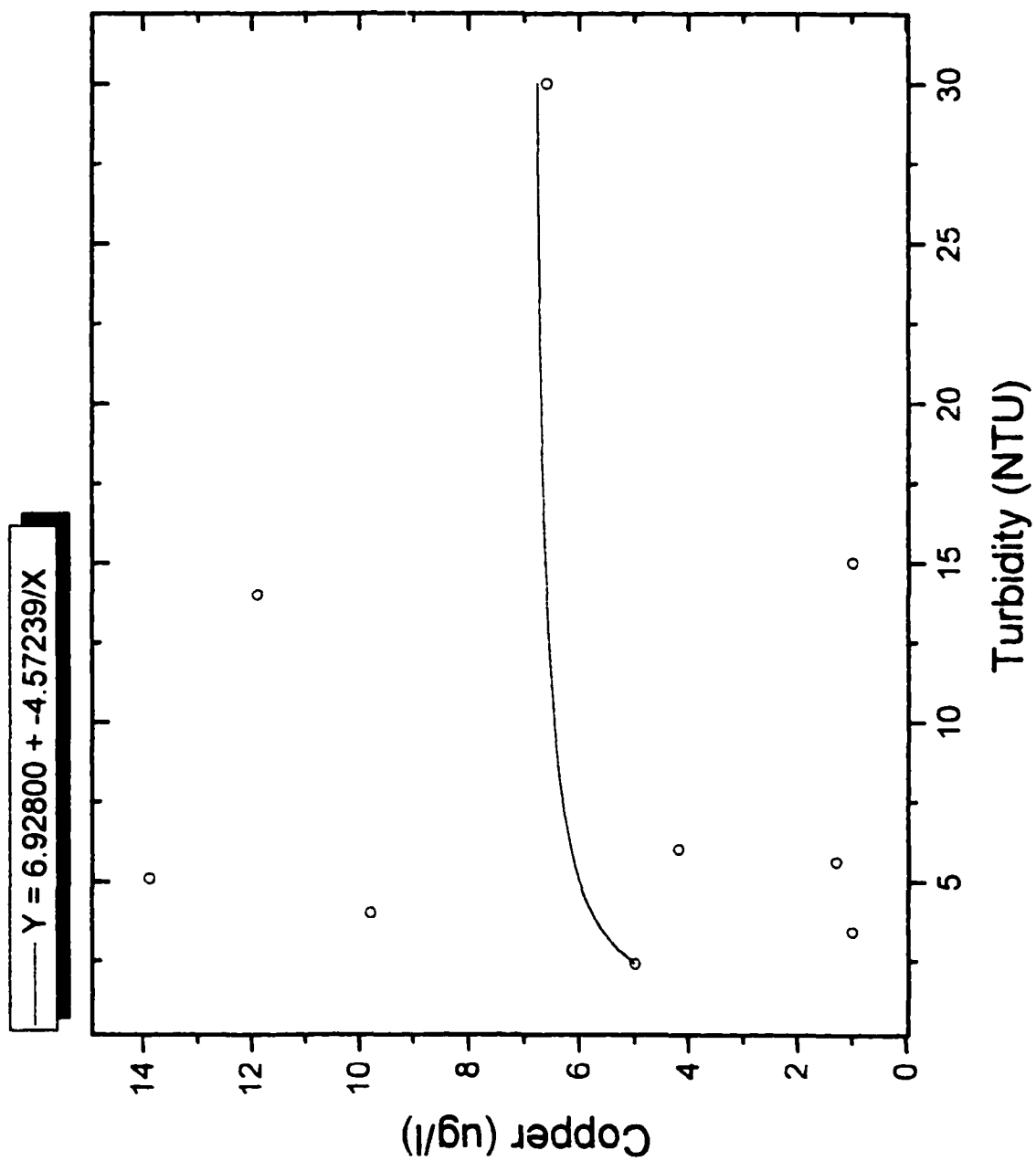
	N	A	B	R	R square
$Y = A + B \cdot X$	9	1.31637	-4.65189e-02	-0.60277	0.36333
$Y = A \cdot X^B$	9	3.04999	-0.79272	-0.78267	0.61257
$Y = A \cdot \exp(B \cdot X)$	9	1.29232	-7.07291e-02	-0.76238	0.58122
$Y = A + B \cdot \log(X)$	9	2.07880	-0.82280	-0.73898	0.54607
$Y = A + B/X$	9	-1.39758e-02	4.77780	0.85145	0.72498
$Y = 1/(A + B \cdot X)$	9	0.41424	0.17282	0.8472	0.71775
$Y = X/(A + B \cdot X)$	9	-9.05438	3.73975	0.61044	0.37263



4/8/01 10:50:13 SPRING98 WST

Variable: Copper (ug/l)
Independent variable: Turbidity (NTU)

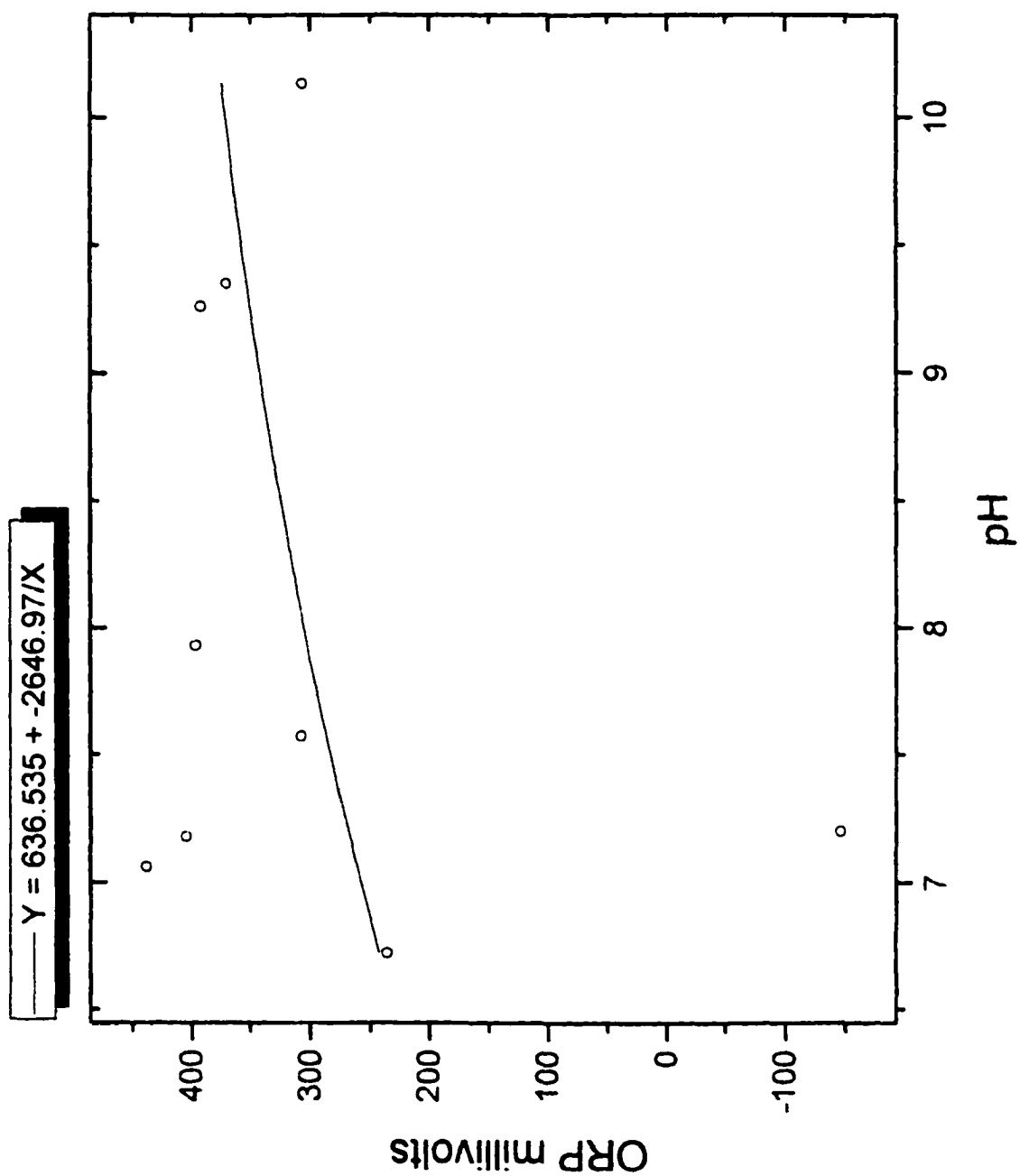
	N	A	B	R	R square
$Y = A + B \cdot X$	9	5.80987	2.82009e-02	0.0518	0.00268
$Y = A \cdot X^B$	9	3.33025	0.10112	0.07804	0.00609
$Y = A \cdot \exp(B \cdot X)$	9	3.58004	1.29405e-02	0.10902	0.01188
$Y = A + B \cdot \log(X)$	9	5.15727	0.47673	0.08022	0.00643
$Y = A + B/X$	9	6.92800	-4.57239	-0.11552	0.01334
$Y = 1/(A + B \cdot X)$	9	0.45041	-5.10988e-03	-0.11382	0.01295
$Y = X/(A + B \cdot X)$	9	-5.94182e-03	0.40297	0.00182	3.31403e-06



4/8/01 10:57:57 SPRING98.WST

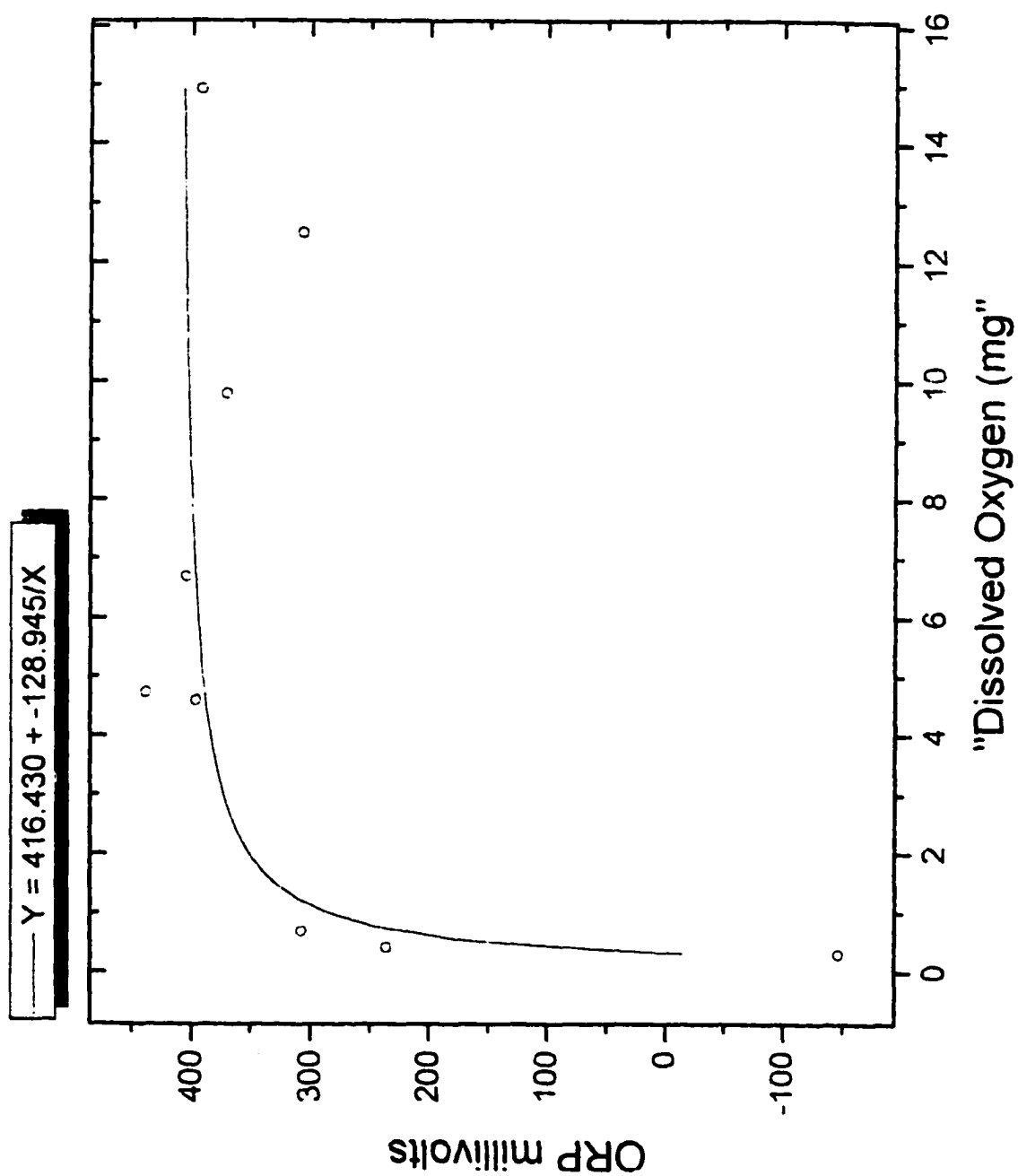
Variable: ORP millivolts
Independent variable: pH

	N	A	B	R	R square
$Y = A + B \cdot X$	9	5.51997	36.7448	0.25081	0.0629
$Y = A + B \cdot \text{LOG}(X)$	9	-351.744	314.606	0.2585	0.06682
$\cdot Y = A + B/X$	9	636.535	-2646.97	-0.26499	0.07022
$Y = 1/(A + B \cdot X)$	9	-3.13897e-03	6.16695e-04	0.22791	0.05194
$Y = X/(A + B \cdot X)$	9	-3.92757e-02	6.79902e-03	0.2129	0.04532



Variable: ORP millivolts
 Independent variable: Dissolved Oxygen (mg)

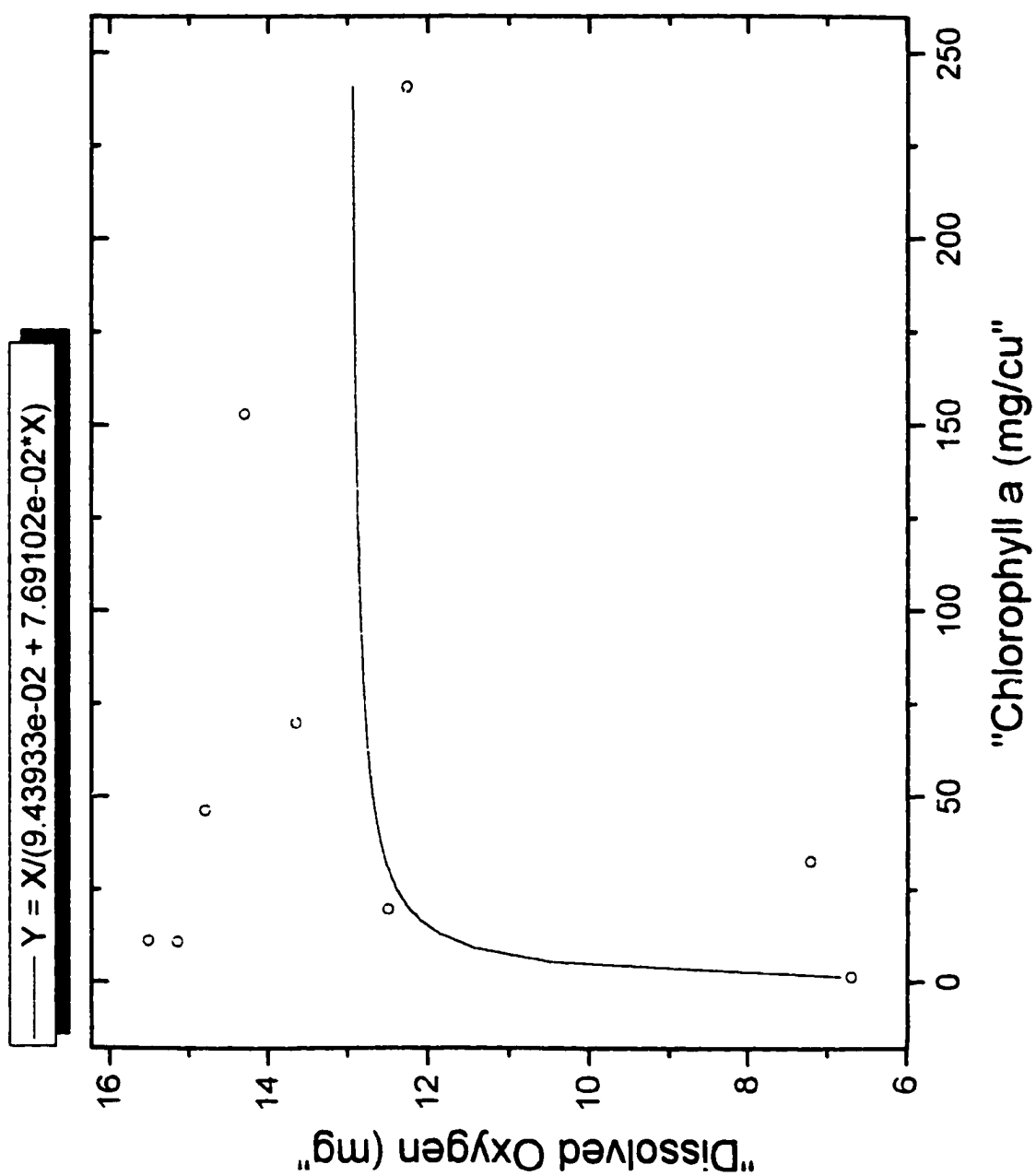
	N	A	B	R	R square
$Y = A + B \cdot X$	9	202.754	16.2009	0.48738	0.23754
$Y = A + B \cdot \text{LOG}(X)$	9	206.127	85.2746	0.72343	0.52336
$Y = A + B/X$	9	416.430	-128.945	-0.88543	0.78399
$Y = 1/(A + B \cdot X)$	9	6.10222e-04	1.99598e-04	0.32511	0.1057
$Y = X/(A + B \cdot X)$	9	-1.68229e-03	3.32652e-03	0.62548	0.39122



4/8/01 11:49:31 SUMMER98.WST

Variable: Dissolved Oxygen (mg)
Independent variable: Chlorophyll a (mg/cu)

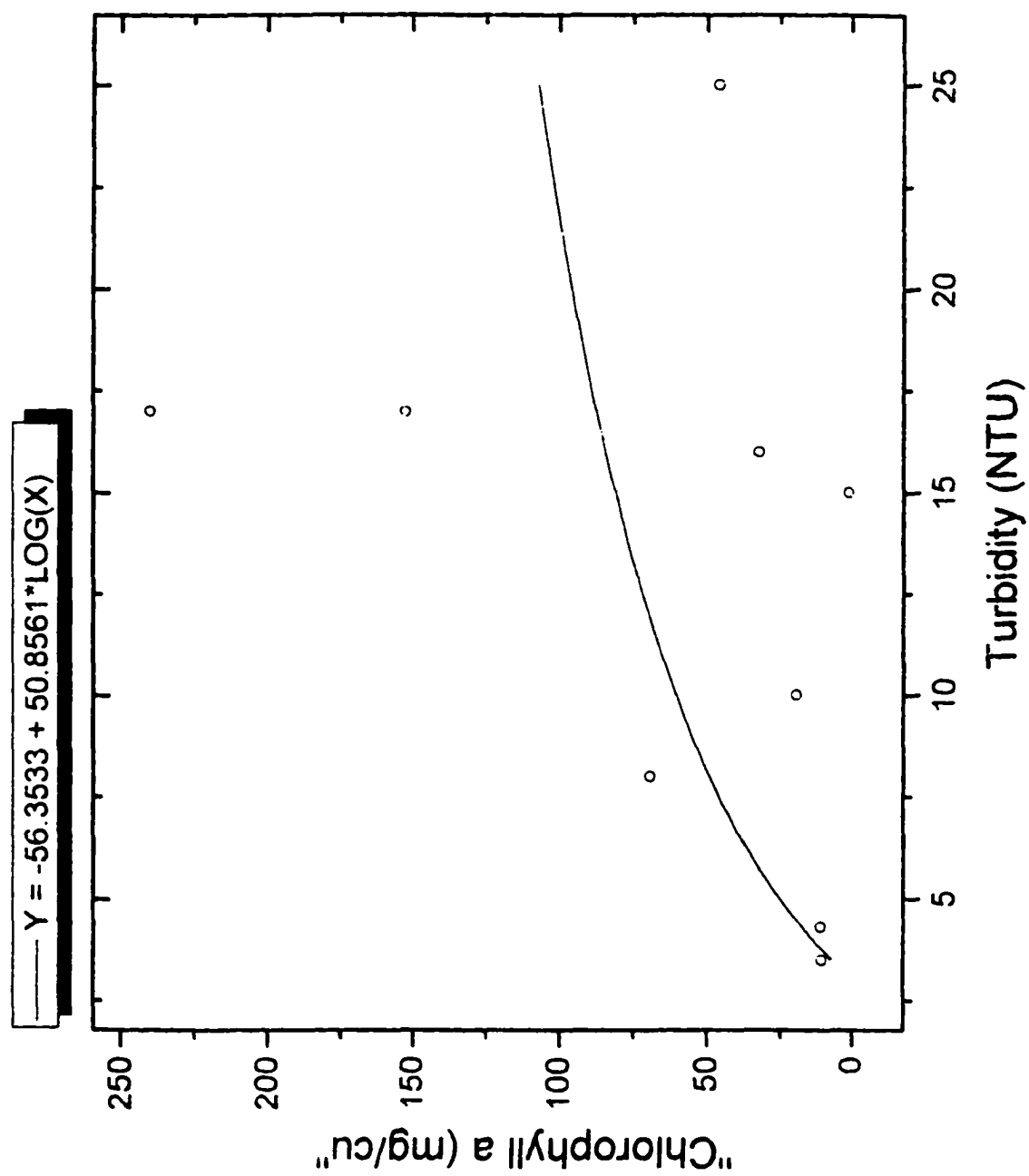
	N	A	B	R	R square
$Y = A + B \cdot X$	9	12.0590	6.05874e-03	0.14734	0.02171
$Y = A \cdot X^B$	9	8.82265	9.09470e-02	0.44654	0.1994
$Y = A \cdot \exp(B \cdot X)$	9	11.3604	7.95877e-04	0.20089	0.04035
$Y = A + B \cdot \log(X)$	9	9.68353	0.82703	0.39122	0.15305
$Y = A + B/X$	9	13.4547	-8.61951	-0.61021	0.37236
$Y = 1/(A + B \cdot X)$	9	9.43222e-02	-9.91149e-05	-0.2456	0.06032
$Y = X/(A + B \cdot X)$	9	9.43933e-02	7.69102e-02	0.6809	0.46363



4/5/01 11:56 45 SUMMER98.WST

Variable: Chlorophyll a (mg/cu
Independent variable: Turbidity (NTU)

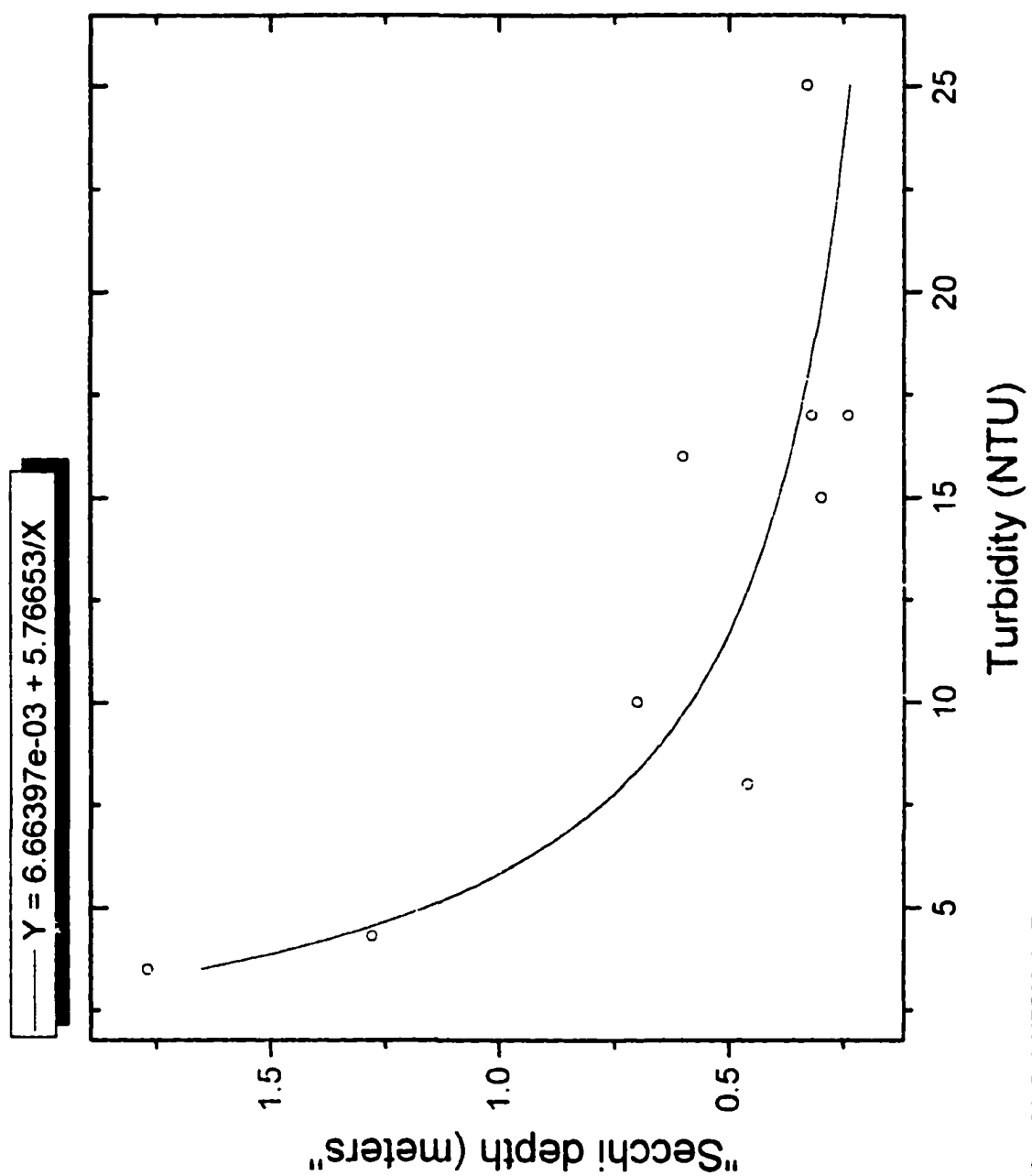
	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.71079	4.36756	0.37797	0.14286
$Y = A \cdot X^B$	9	4.12717	0.80949	0.34617	0.11984
$Y = A \cdot \exp(B \cdot X)$	9	10.7489	7.56172e-02	0.33642	0.11318
$Y = A + B \cdot \log(X)$	9	-56.3533	50.8561	0.42304	0.17898
$Y = A + B/X$	9	109.404	-388.778	-0.41908	0.17561
$Y = 1/(A + B \cdot X)$	9	0.11245	2.99952e-04	0.00891	7.95136e-05
$Y = X/(A + B \cdot X)$	9	-0.21540	0.14098	0.07975	0.00636



4/8/01 12:05:36 SUMMER98.WST

Variable: Secchi depth (meters)
Independent variable: Turbidity (NTU)

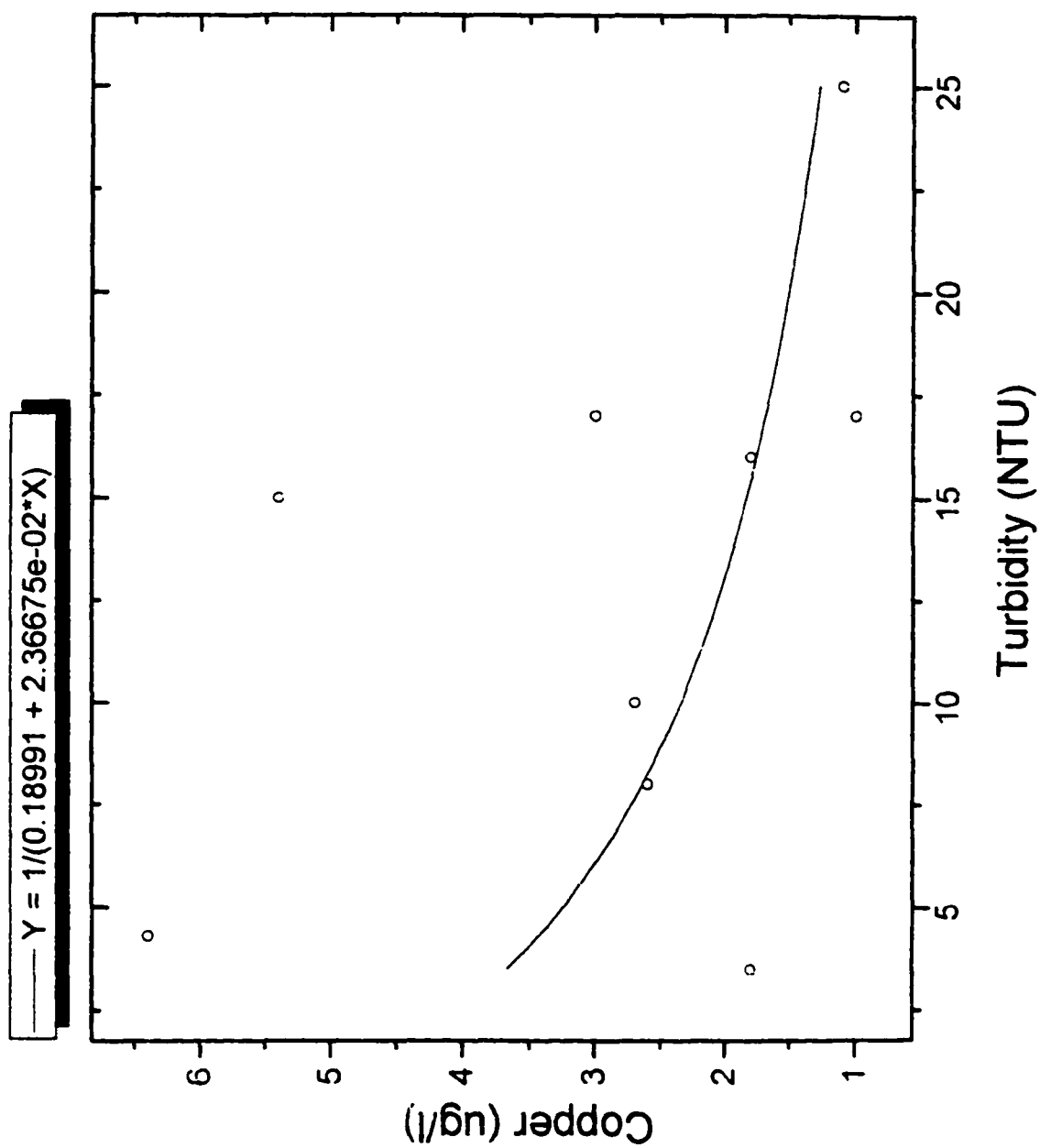
	N	A	B	R	R square
$Y = A + B \cdot X$	9	1.42623	-5.90334e-02	-0.78622	0.61815
$Y = A \cdot X^B$	9	4.66108	-0.91142	-0.88906	0.79044
$Y = A \cdot \exp(B \cdot X)$	9	1.47461	-7.94552e-02	-0.80634	0.65018
$Y = A + B \cdot \log(X)$	9	2.34518	-0.70396	-0.90119	0.81215
$Y = A + B/X$	9	6.66397e-03	5.76653	0.95658	0.91506
$Y = 1/(A + B \cdot X)$	9	0.51215	0.13524	0.76225	0.58102
$Y = X/(A + B \cdot X)$	9	-11.3710	3.55375	0.79824	0.63719



4/8/01 12.11.39 SUMMER98.WST

Variable: Copper (ug/l)
Independent variable: Turbidity (NTU)

	N	A	B	R	R square
$Y = A + B \cdot X$	9	4.35726	-0.11585	-0.43245	0.18702
$Y = A \cdot X^B$	9	6.10488	-0.39240	-0.41379	0.17122
$Y = A \cdot \exp(B \cdot X)$	9	4.31239	-4.57035e-02	-0.50139	0.25139
$Y = A + B \cdot \log(X)$	9	5.39931	-1.06219	-0.38112	0.14525
$Y = A + B/X$	9	2.11419	6.57450	0.30568	0.09344
$Y = 1/(A + B \cdot X)$	9	0.18991	2.36675e-02	0.5584	0.31181
$Y = X/(A + B \cdot X)$	9	-1.11534	0.62209	0.32776	0.10742

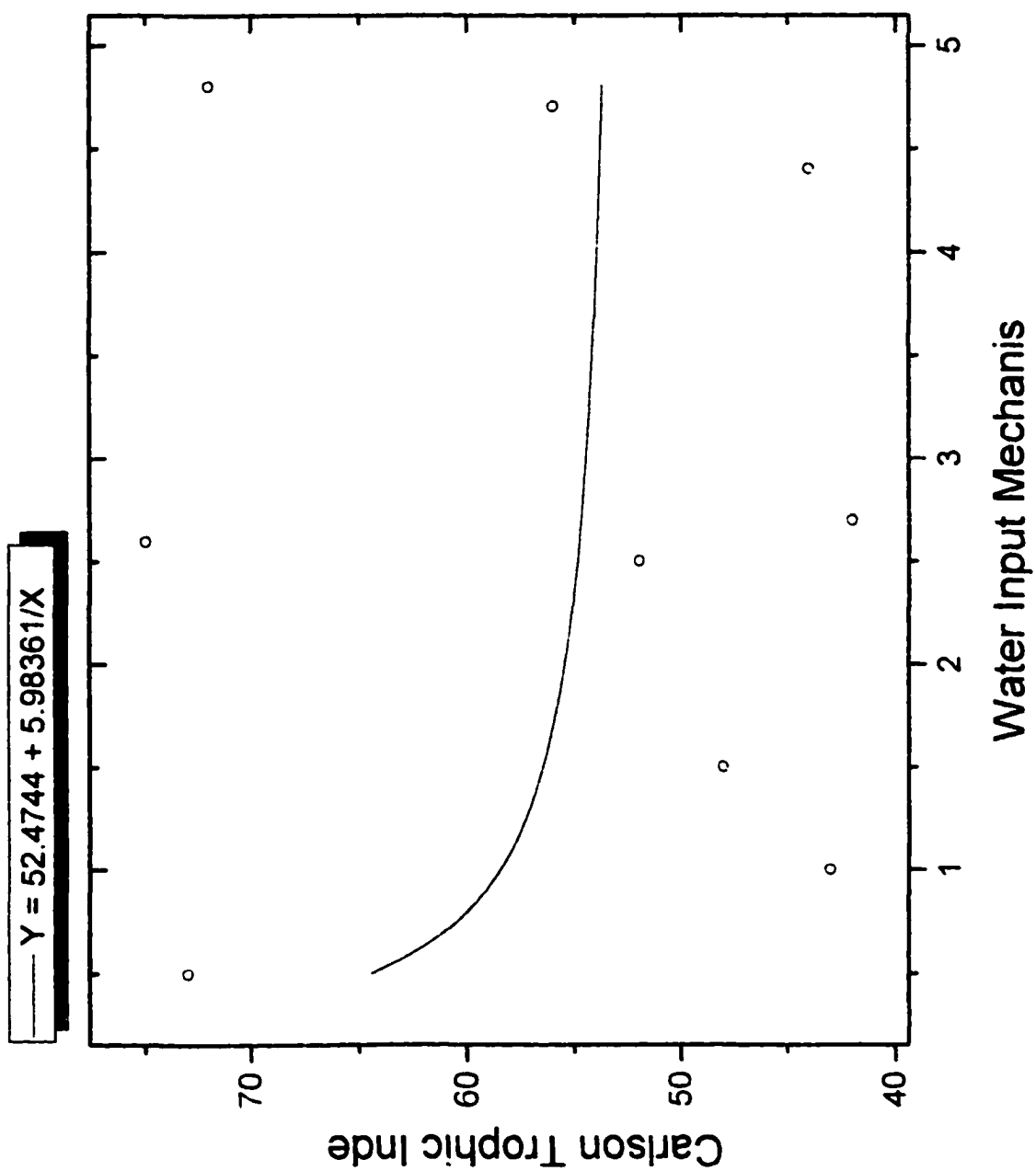


4/8/01 12:18:33 SUMMER98 WST

**E2 - BETWEEN CLASSIFICATION SCORES
AND SELECTED WATER QUALITY PARAMETERS**

Variable: Carlson Trophic Inde
Independent variable: Water Input Mechanis

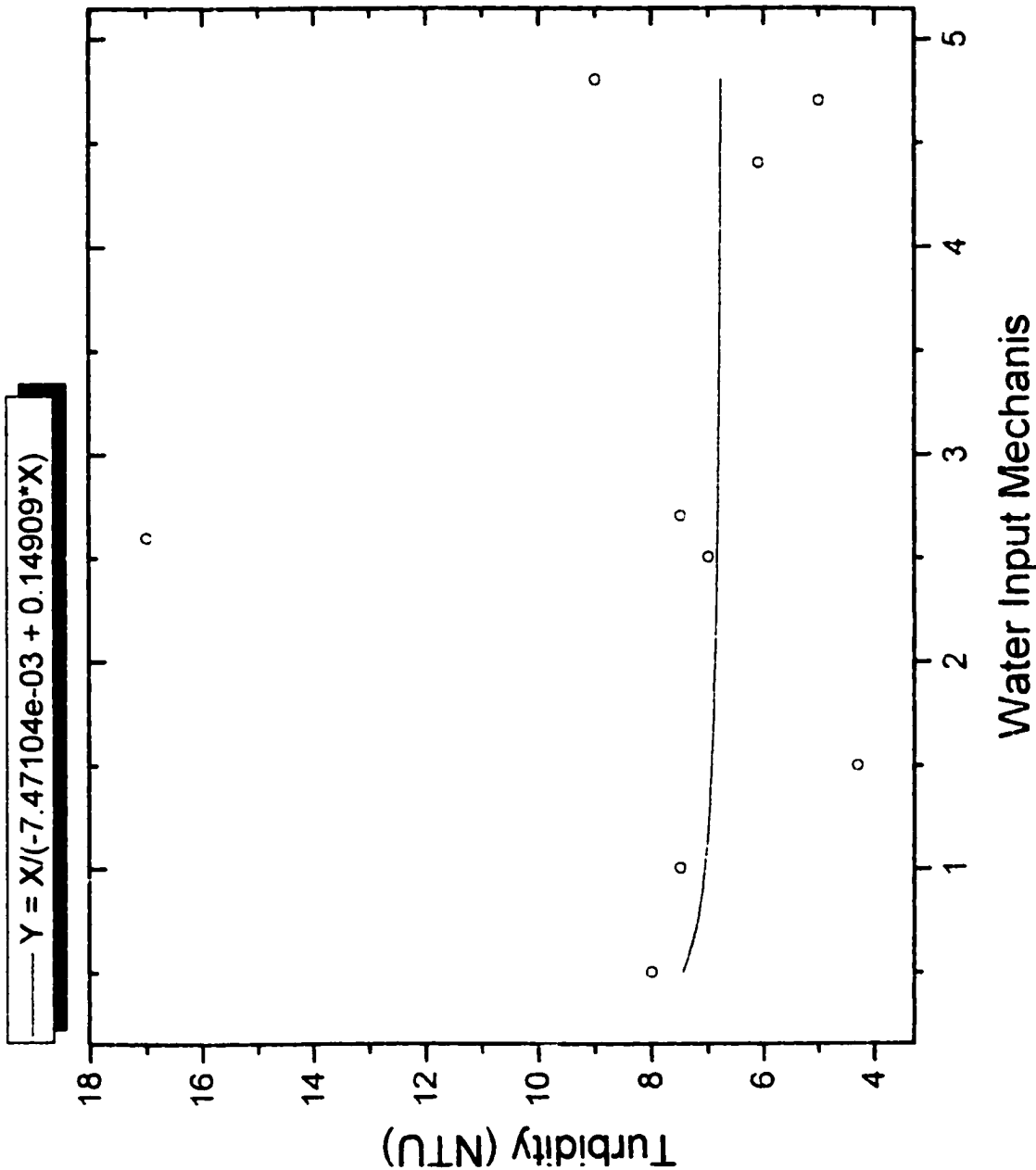
	N	A	B	R	R square
$Y = A + B \cdot X$	9	55.2604	0.30999	0.0363	0.00131
$Y = A \cdot X^B$	9	55.7594	-2.42428e-02	-0.07814	0.0061
$Y = A \cdot \exp(B \cdot X)$	9	53.5070	7.98190e-03	0.05365	0.00287
$Y = A + B \cdot \log(X)$	9	57.4508	-1.68037	-0.09436	0.0089
$Y = A + B/X$	9	52.4744	5.98361	0.25454	0.06479
$Y = 1/(A + B \cdot X)$	9	1.92497e-02	-1.86756e-04	-0.07008	0.00491
$Y = X/(A + B \cdot X)$	9	-1.64635e-03	1.97378e-02	0.22443	0.05037



4/8/01 12:56:26 FALL97.WST

Variable: Turbidity (NTU)
Independent variable: Water Input Mechanis

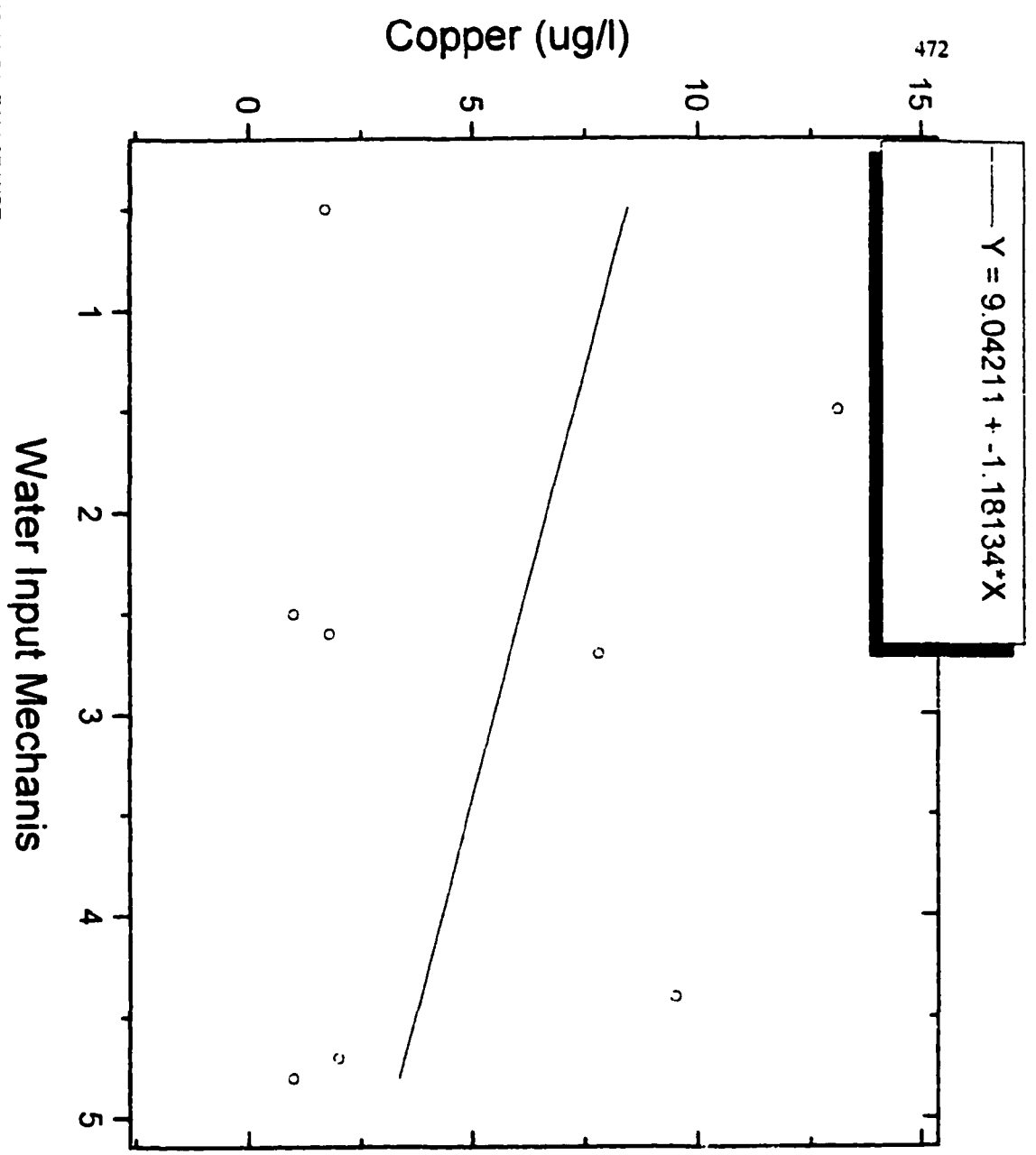
	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.26977	-0.12258	-0.05298	0.0028
$Y = A \cdot X^B$	9	7.43534	-1.31380e-02	-0.02577	6.64239e-04
$Y = A \cdot \exp(B \cdot X)$	9	7.67385	-1.53212e-02	-0.06267	0.00392
$Y = A + B \cdot \log(X)$	9	7.88671	5.84787e-02	0.01211	1.46883e-04
$Y = A + B/X$	9	8.08531	-0.21714	-0.03408	0.00116
$Y = 1/(A + B \cdot X)$	9	0.13932	1.90280e-03	0.06047	0.00365
$Y = X/(A + B \cdot X)$	9	-7.47104e-03	0.14909	0.08624	0.00743



Variable: Copper (ug/l)
Independent variable: Water Input Mechanis

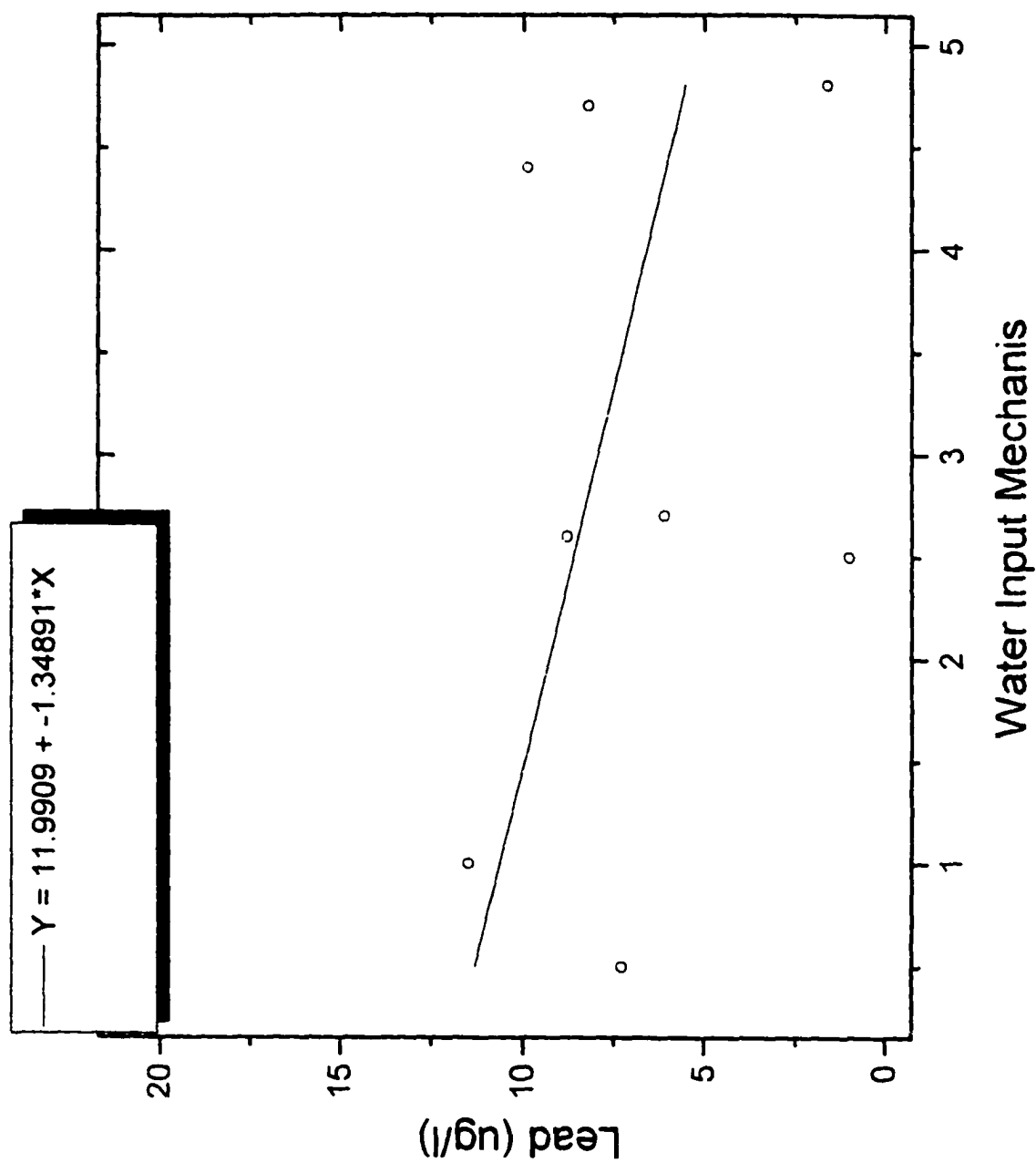
	N	A	B	R	R square
* $Y = A + B \cdot X$	9	9.04211	-1.18134	-0.34777	0.12095
$Y = A \cdot X^B$	9	4.44426	-0.28914	-0.20077	0.04031
$Y = A \cdot \exp(B \cdot X)$	9	6.13184	-0.20128	-0.29146	0.08495
$Y = A + B \cdot \log(X)$	9	7.21377	-1.77333	-0.25034	0.06267
$Y = A + B/X$	9	5.46720	0.54757	0.05855	0.00342
$Y = 1/(A + B \cdot X)$	9	0.26768	6.53571e-02	0.27666	0.07654
$Y = X/(A + B \cdot X)$	9	-5.48296e-02	0.48038	0.08431	0.0071

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Variable: Lead (ug/l)
Independent variable: Water Input Mechanis

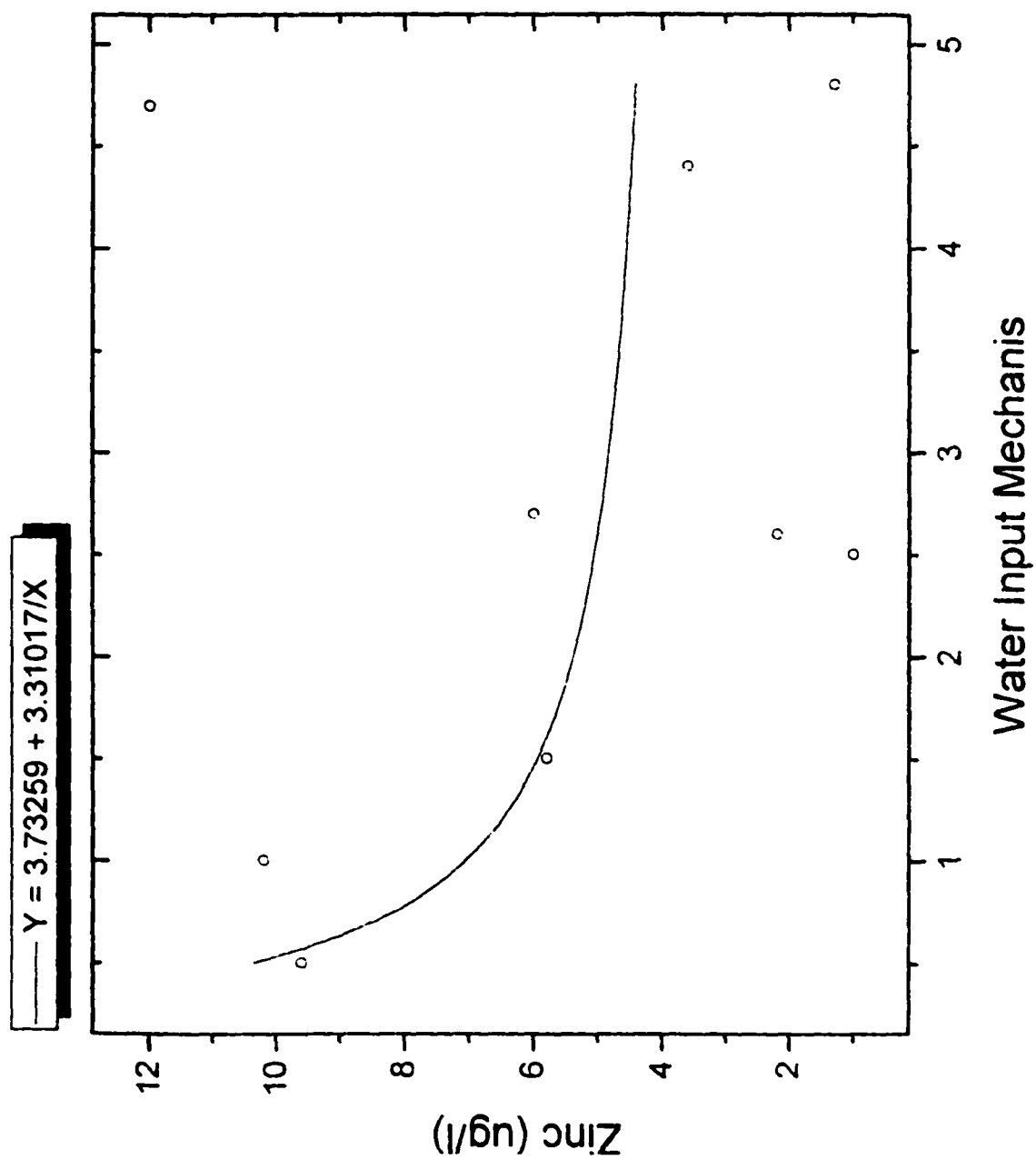
	N	A	B	R	R square
* $Y = A + B \cdot X$	9	11.9909	-1.34891	-0.37974	0.1442
$Y = A \cdot X^B$	9	8.39118	-0.39846	-0.31835	0.10135
$Y = A \cdot \exp(B \cdot X)$	9	10.4061	-0.19416	-0.32351	0.10466
$Y = A + B \cdot \log(X)$	9	10.1647	-2.35289	-0.31783	0.10089
$Y = A + B/X$	9	7.25586	1.69968	0.17381	0.03021
$Y = 1/(A + B \cdot X)$	9	0.14587	4.39724e-02	0.21662	0.04692
$Y = X/(A + B \cdot X)$	9	-0.14068	0.35205	0.25174	0.06337



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Variable: Zinc (ug/l)
 independent variable: Water Input Mechanis

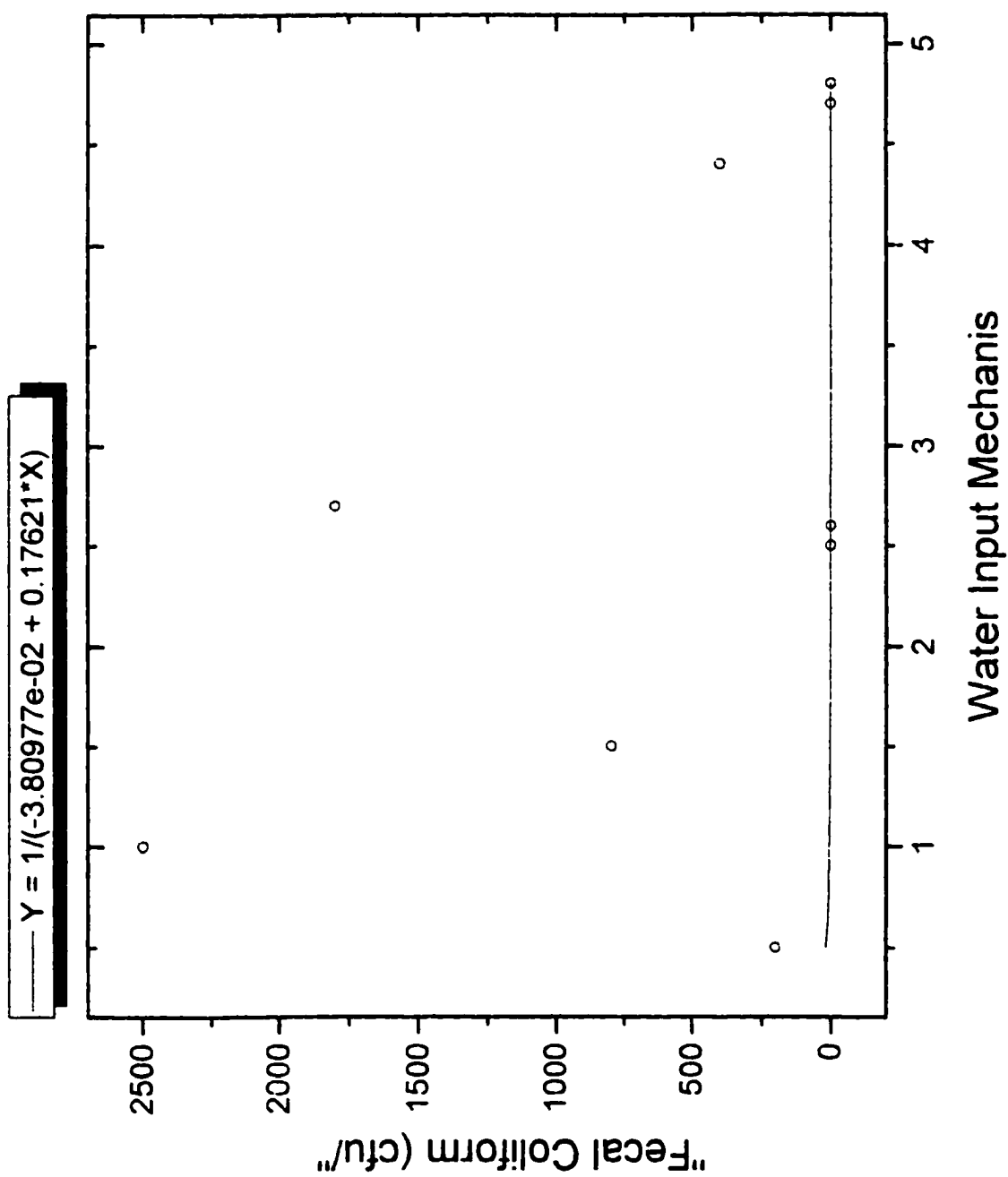
	N	A	B	R	R square
$Y = A + B \cdot X$	9	7.79068	-0.74566	-0.29238	0.08549
$Y = A \cdot X^B$	9	6.42560	-0.52851	-0.44387	0.19711
$Y = A \cdot \exp(B \cdot X)$	9	7.19196	-0.19458	-0.34087	0.11619
$Y = A + B \cdot \log(X)$	9	7.53669	-2.24807	-0.4227	0.17867
$Y = A + B/X$	9	3.73259	3.31017	0.47149	0.2223
$Y = 1/(A + B \cdot X)$	9	0.17773	6.18054e-02	0.29825	0.08955
$Y = X/(A + B \cdot X)$	9	-0.22217	0.46238	0.39076	0.15269



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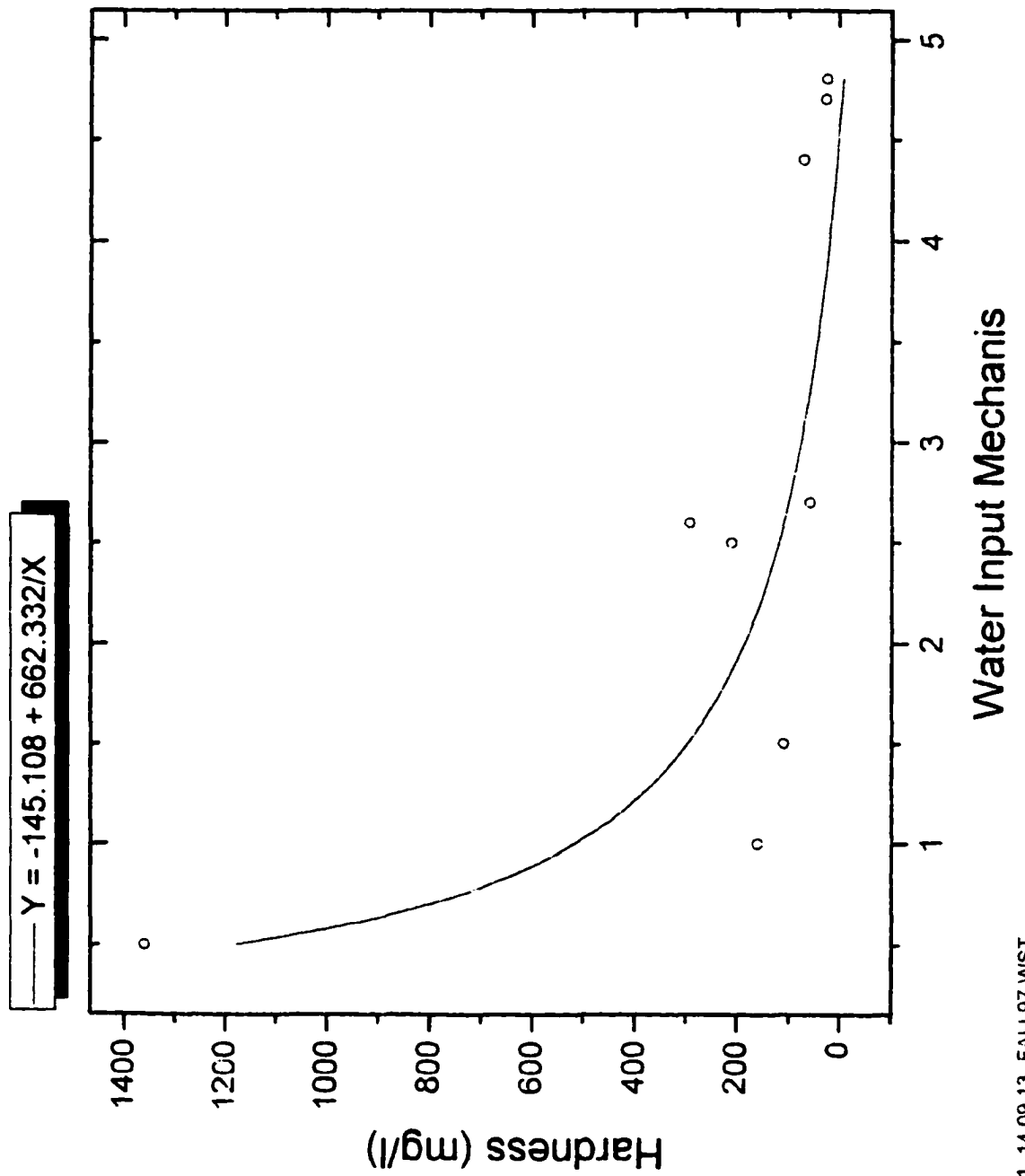
Variable: Faecal Coliform (cfu/
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	1332.49	-254.592	-0.44486	0.1979
$Y = A \cdot X^B$	9	267.886	-2.37223	-0.50779	0.25785
$Y = A \cdot \exp(B \cdot X)$	9	1041.62	-1.18392	-0.52849	0.2793
$Y = A + B \cdot \log(X)$	9	987.977	-419.195	-0.35124	0.12337
$Y = A + B/X$	9	470.822	268.116	0.17018	0.02896
$Y = 1/(A + B \cdot X)$	9	-3.80977e-02	0.17621	0.53629	0.2876
$Y = X/(A + B \cdot X)$	9	-0.45070	0.71945	0.49825	0.24825



Variable: Hardness (mg/l)
Independent variable: Water Input Mechanis

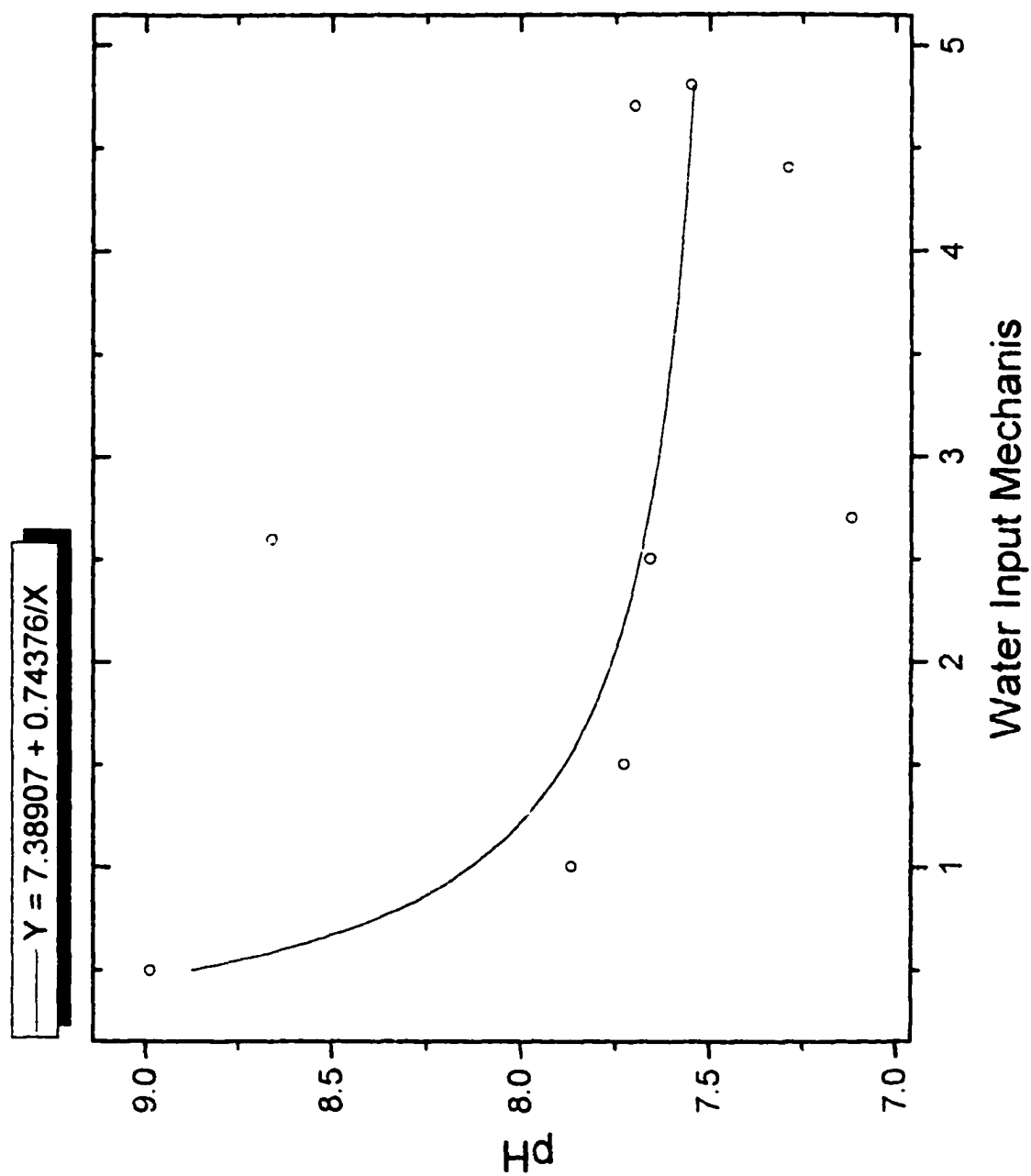
	N	A	B	R	R square
$Y = A + B \cdot X$	9	704.644	-162.947	-0.61682	0.38047
$Y = A \cdot X^B$	9	347.443	-1.35415	-0.83645	0.69966
$Y = A \cdot \exp(B \cdot X)$	9	667.792	-0.63144	-0.81339	0.6616
$Y = A + B \cdot \log(X)$	9	600.063	-429.757	-0.78009	0.60854
$Y = A + B/X$	9	-145.108	662.332	0.91074	0.82946
$Y = 1/(A + B \cdot X)$	9	-5.13233e-03	7.12122e-03	0.82241	0.67637
$Y = X/(A + B \cdot X)$	9	-1.35576e-02	2.26515e-02	0.56875	0.32348



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Variable: pH
Independent variable: Water Input Mechanis

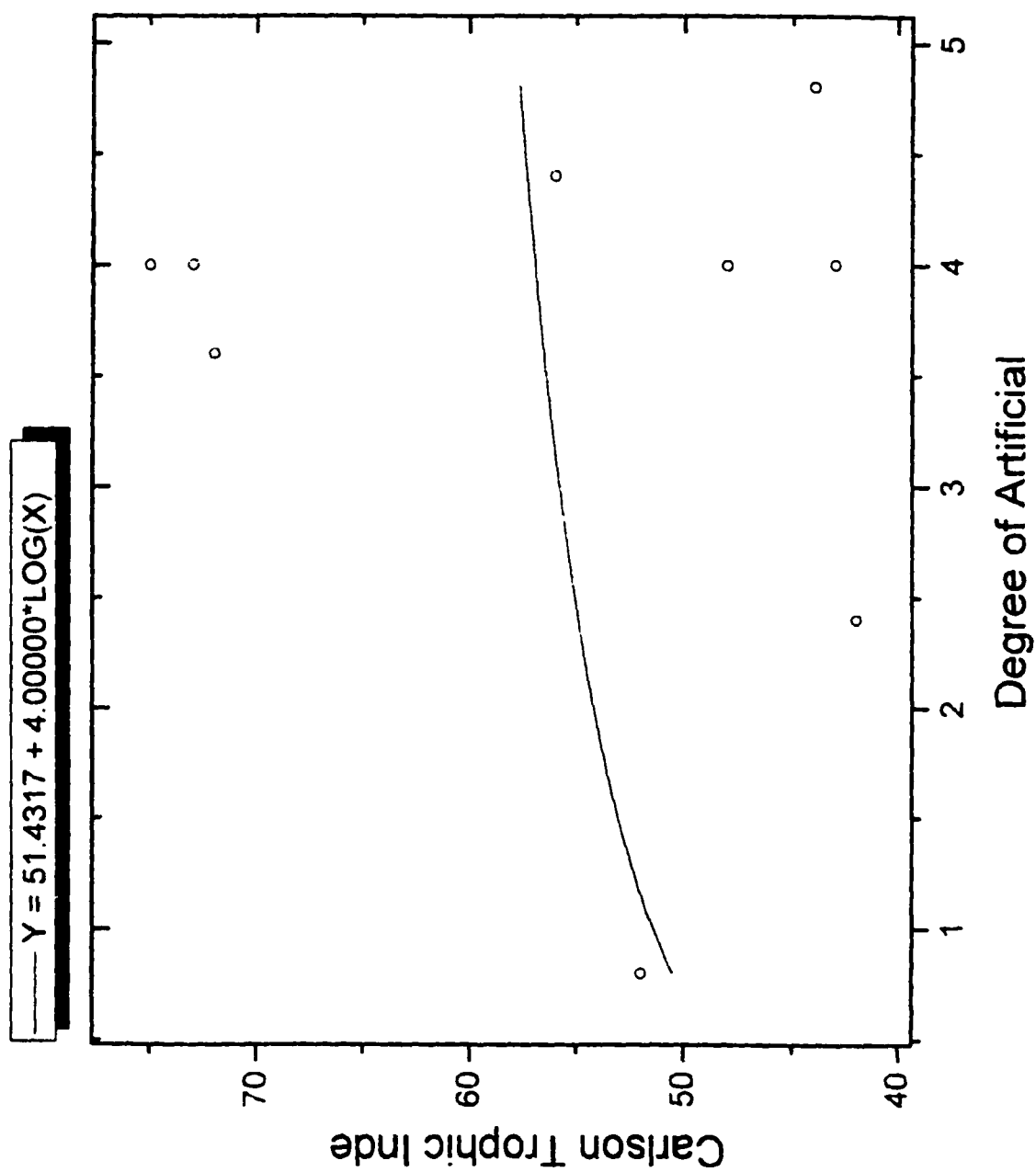
	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.41932	-0.21068	-0.55401	0.30693
$Y = A \cdot X^B$	9	8.22760	-6.35888e-02	-0.64623	0.41762
$Y = A \cdot \exp(B \cdot X)$	9	8.40021	-2.60374e-02	-0.55182	0.3045
$Y = A + B \cdot \log(X)$	9	8.25250	-0.51601	-0.65068	0.42339
$Y = A + B/X$	9	7.38907	0.74376	0.71045	0.50475
$Y = 1/(A + B \cdot X)$	9	0.11932	3.22827e-03	0.54881	0.3012
$Y = X/(A + B \cdot X)$	9	-1.12092e-02	0.13499	0.69221	0.47916



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Variable: Carlson Trophic Inde
Independent variable: Degree of Artificial

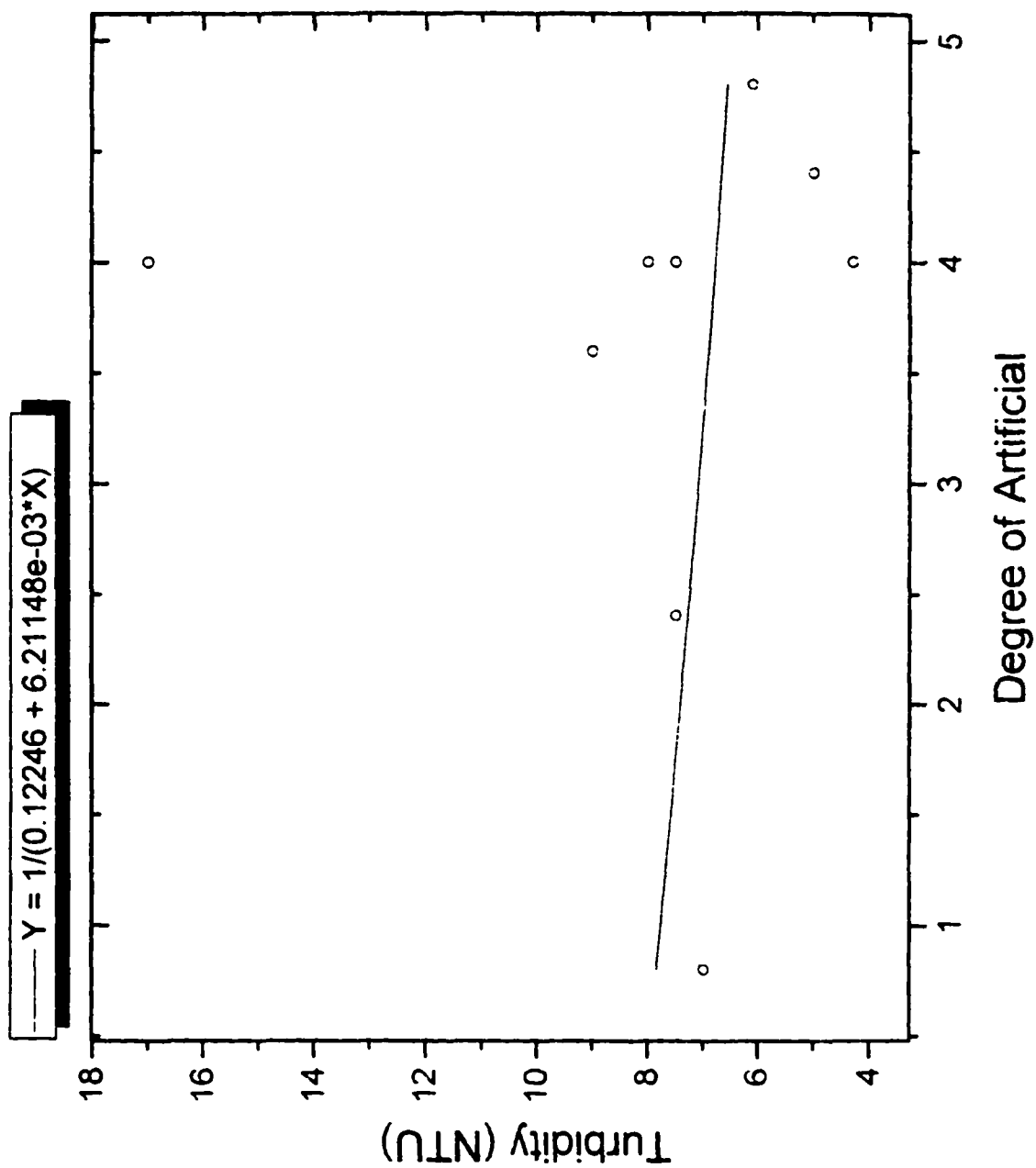
	N	A	B	R	R square
$Y = A + B \cdot X$	9	50.2819	1.63947	0.14678	0.02154
$Y = A \cdot X^B$	9	50.9665	6.03068e-02	0.14108	0.0199
$Y = A \cdot \exp(B \cdot X)$	9	49.8937	2.58258e-02	0.13271	0.01761
$Y = A + B \cdot \log(X)$	9	51.4317	4.00000	0.16302	0.02657
$Y = A + B/X$	9	58.4409	-8.20360	-0.15127	0.02288
$Y = 1/(A + B \cdot X)$	9	2.01959e-02	-4.10259e-04	-0.1177	0.01385
$Y = X/(A + B \cdot X)$	9	1.19027e-03	1.82902e-02	0.09301	0.00865



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Variable: Turbidity (NTU)
Independent variable: Degree of Artificial

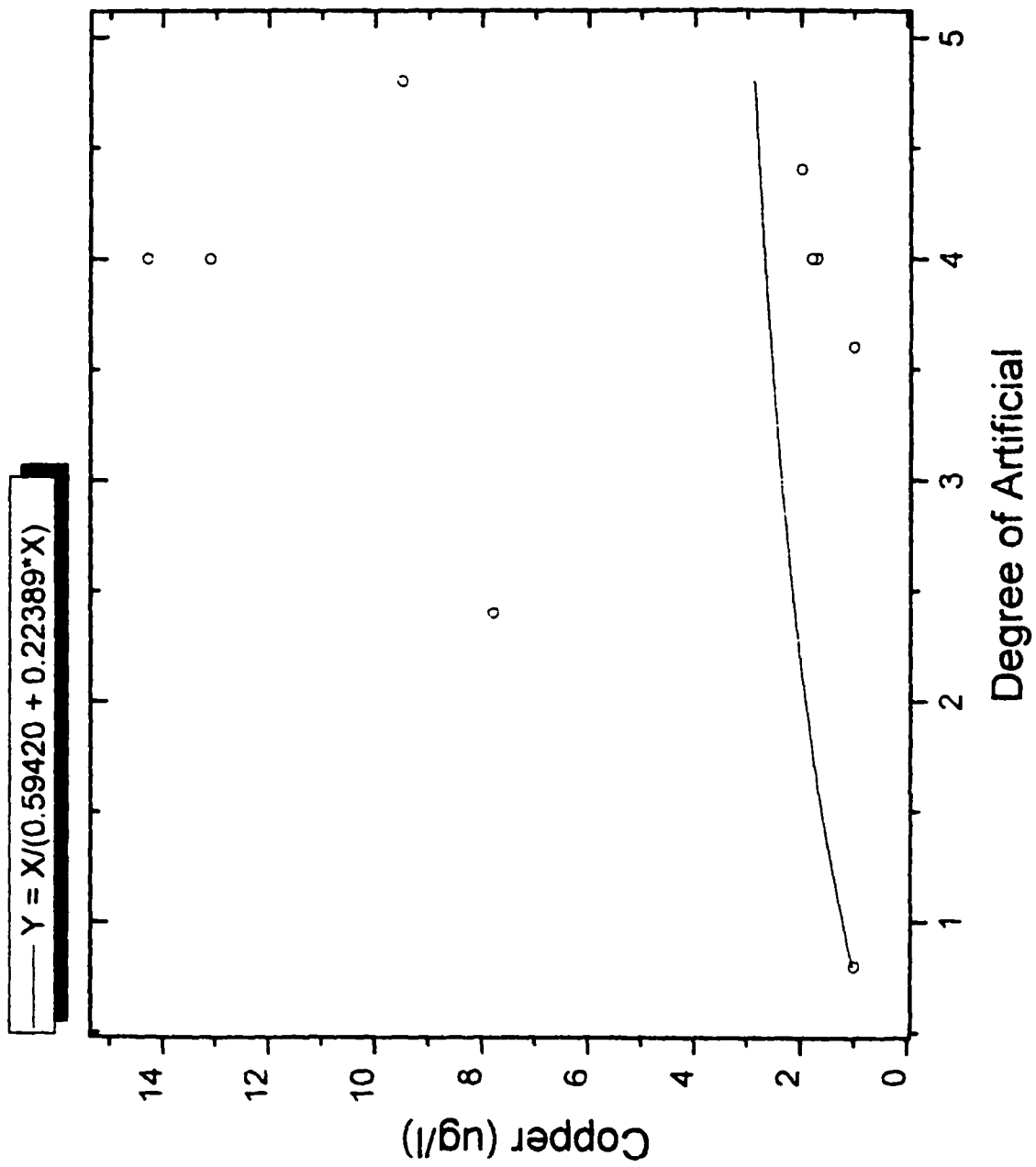
	N	A	B	R	R square
$Y = A + B \cdot X$	9	7.75134	5.11869e-02	0.01691	2.86029e-04
$Y = A \cdot X^B$	9	7.43367	-8.76116e-03	-0.01247	1.55579e-04
$Y = A \cdot \exp(B \cdot X)$	9	7.93896	-2.13781e-02	-0.06685	0.00447
$Y = A + B \cdot \log(X)$	9	7.46348	0.40164	0.0604	0.00364
$Y = A + B/X$	9	8.28522	-0.93695	-0.08431	0.0071
$Y = 1/(A + B \cdot X)$	9	0.12246	6.21148e-03	0.15091	0.02277
$Y = X/(A + B \cdot X)$	9	-7.37891e-03	0.14732	0.04882	0.00238



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Variable: Copper (ug/l)
Independent variable: Degree of Artificial

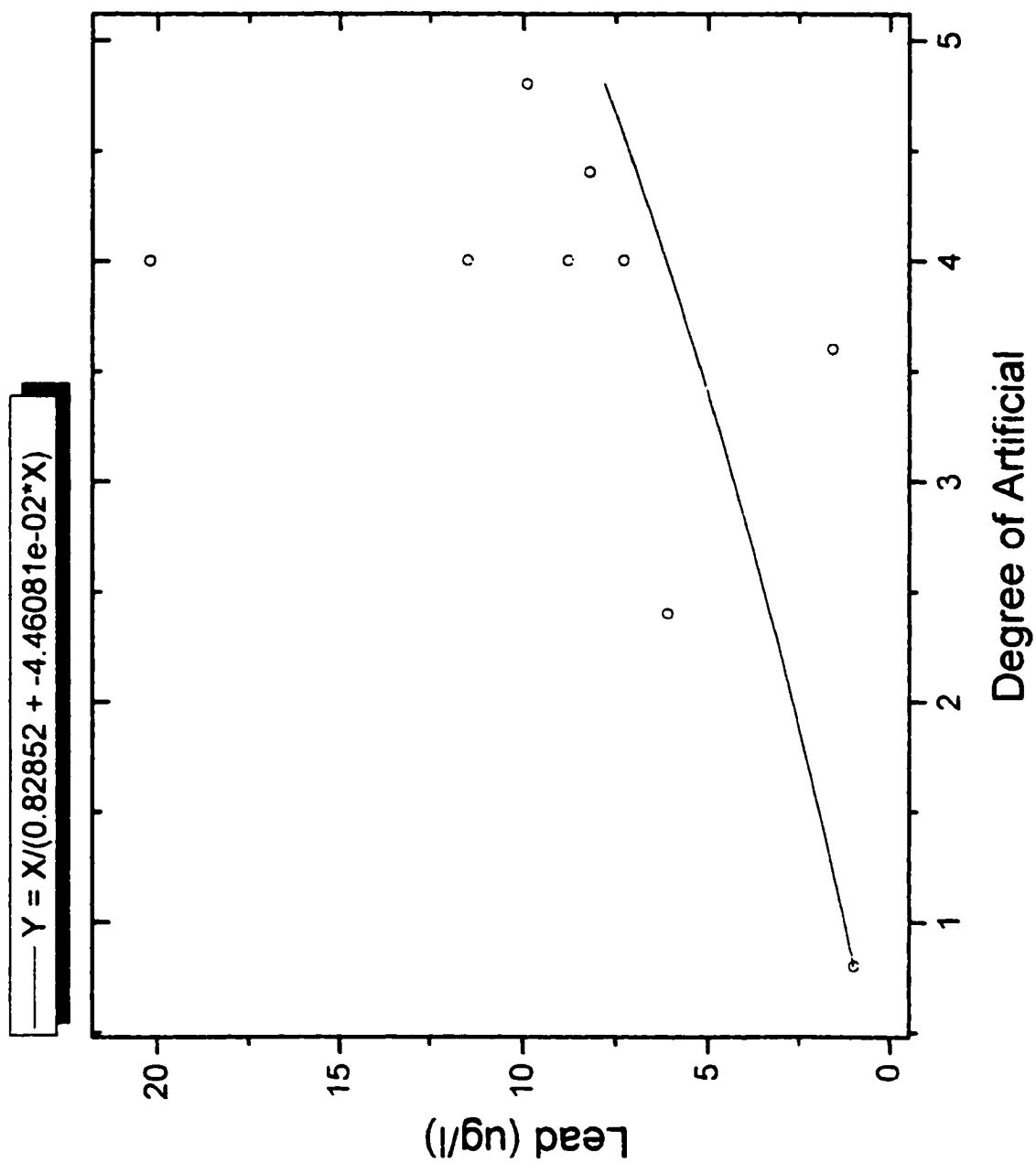
	N	A	B	R	R square
$Y = A + B \cdot X$	9	1.19466	1.29525	0.2915	0.08497
$Y = A \cdot X^B$	9	1.45288	0.75868	0.38233	0.14617
$Y = A \cdot \text{EXP}(B \cdot X)$	9	1.13065	0.32014	0.35441	0.1256
$Y = A + B \cdot \text{LOG}(X)$	9	2.25619	3.02928	0.31035	0.09632
$Y = A + B/X$	9	7.77213	-5.25114	-0.32189	0.10361
$Y = 1/(A + B \cdot X)$	9	0.96120	-0.14460	-0.46796	0.21898
$\cdot Y = X/(A + B \cdot X)$	9	0.59420	0.22389	0.52375	0.27431



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Variable: Lead (ug/l)
Independent variable: Degree of Artificial

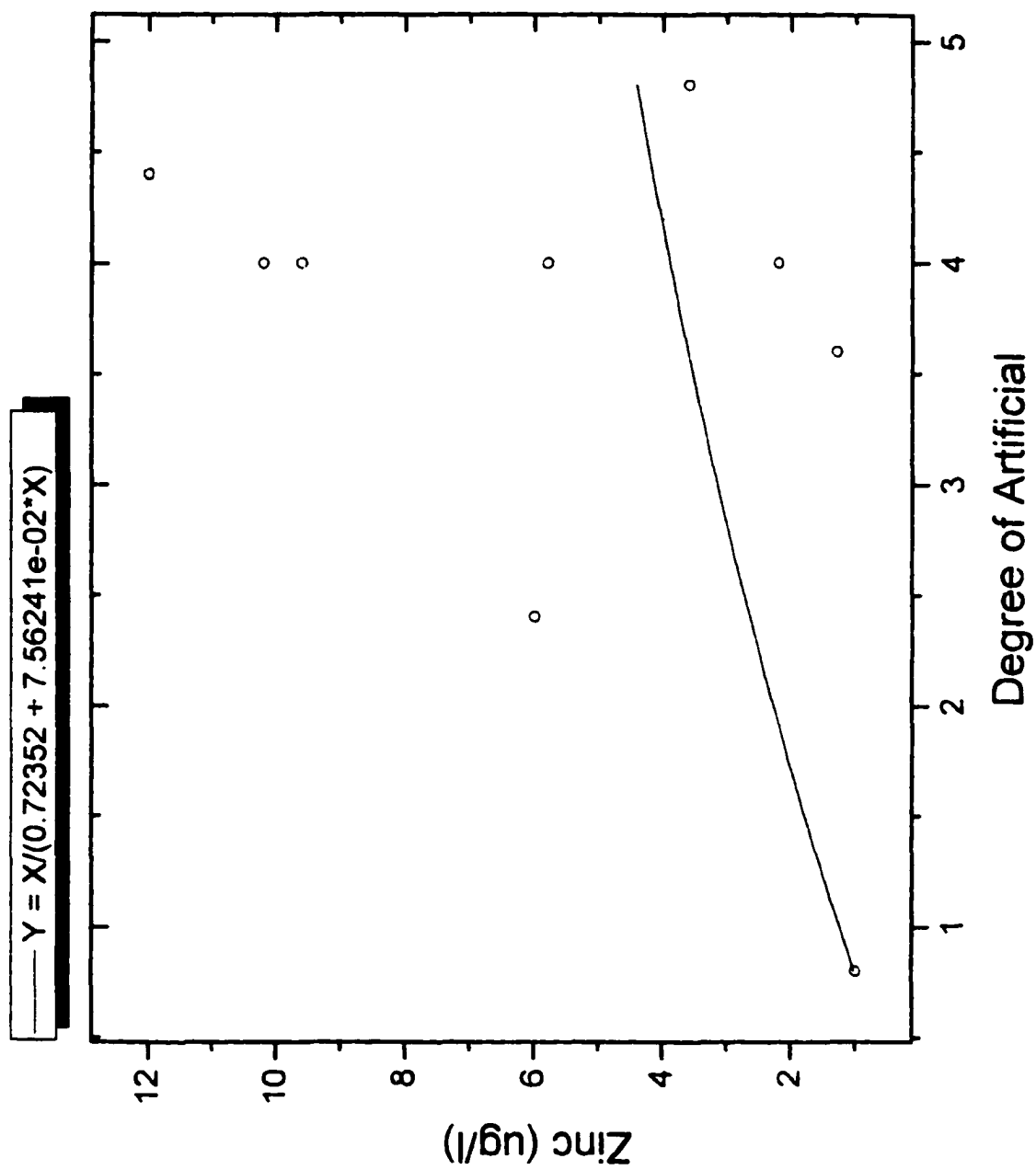
	N	A	B	R	R square
$Y = A + B \cdot X$	9	-0.83738	2.56677	0.55241	0.30516
$Y = A \cdot X^B$	9	1.37151	1.27675	0.74031	0.54805
$Y = A \cdot \exp(B \cdot X)$	9	0.80418	0.57021	0.72631	0.52753
$Y = A + B \cdot \log(X)$	9	1.76872	5.57350	0.54804	0.29816
$Y = A + B/X$	9	11.6286	-8.89247	-0.52127	0.27172
$Y = 1/(A + B \cdot X)$	9	1.01329	-0.21001	-0.79094	0.62559
$Y = X/(A + B \cdot X)$	9	0.82852	-4.46081e-02	-0.84987	0.72228



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Variable: Zinc (ug/l)
Independent variable: Degree of Artificial

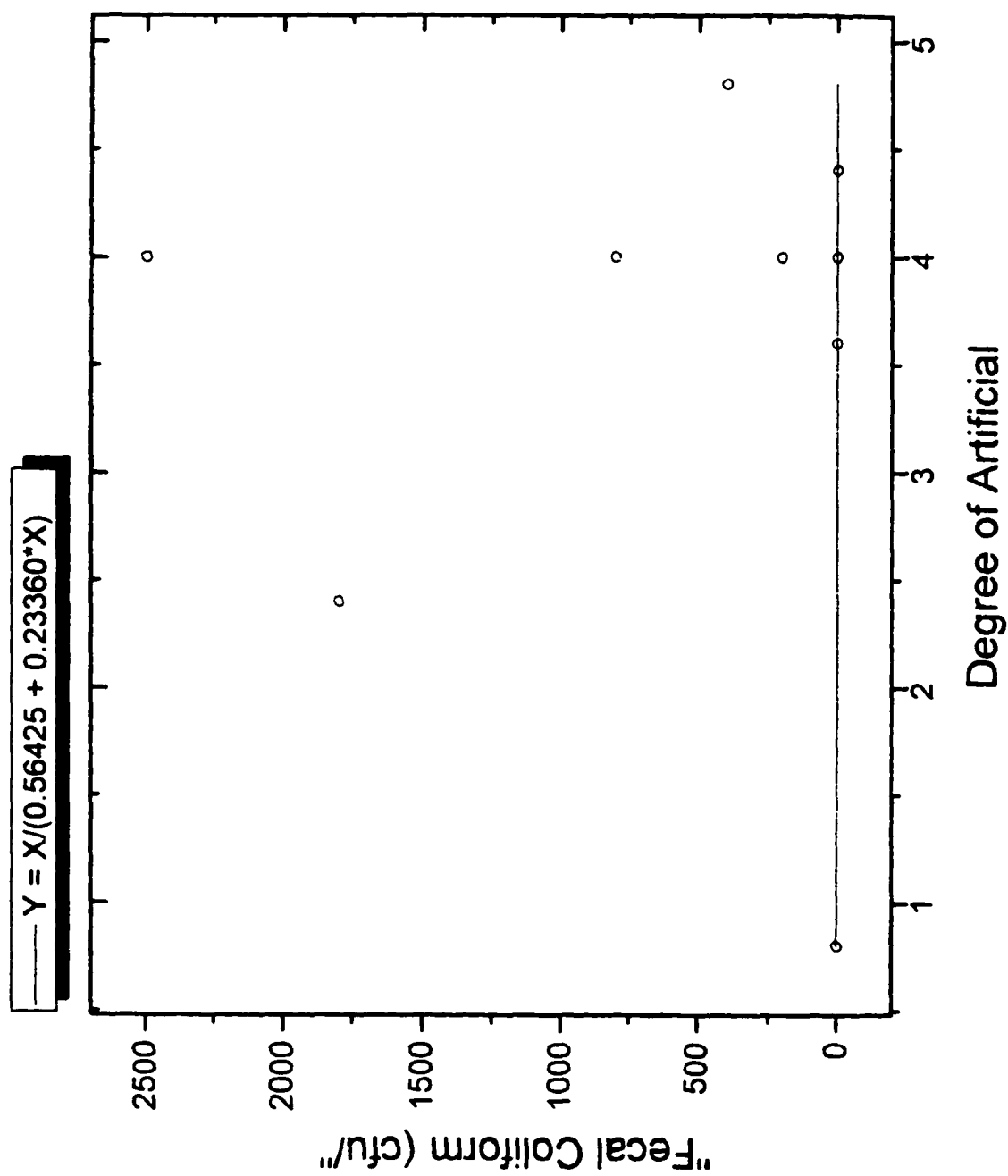
	N	A	B	R	R square
$Y = A + B \cdot X$	9	0.59970	1.44686	0.43375	0.18814
$Y = A \cdot X^B$	9	1.40628	0.93857	0.57219	0.32741
$Y = A \cdot \exp(B \cdot X)$	9	1.01390	0.40081	0.53679	0.28814
$Y = A + B \cdot \log(X)$	9	1.89107	3.29390	0.44948	0.20203
$Y = A + B/X$	9	7.80543	-5.48775	-0.44806	0.20076
$Y = 1/(A + B \cdot X)$	9	0.97922	-0.17771	-0.65781	0.43272
$Y = X/(A + B \cdot X)$	9	0.72352	7.56241e-02	0.72945	0.5321



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Variable: Fecal Coliform (cfu/
Independent variable: Degree of Artificial

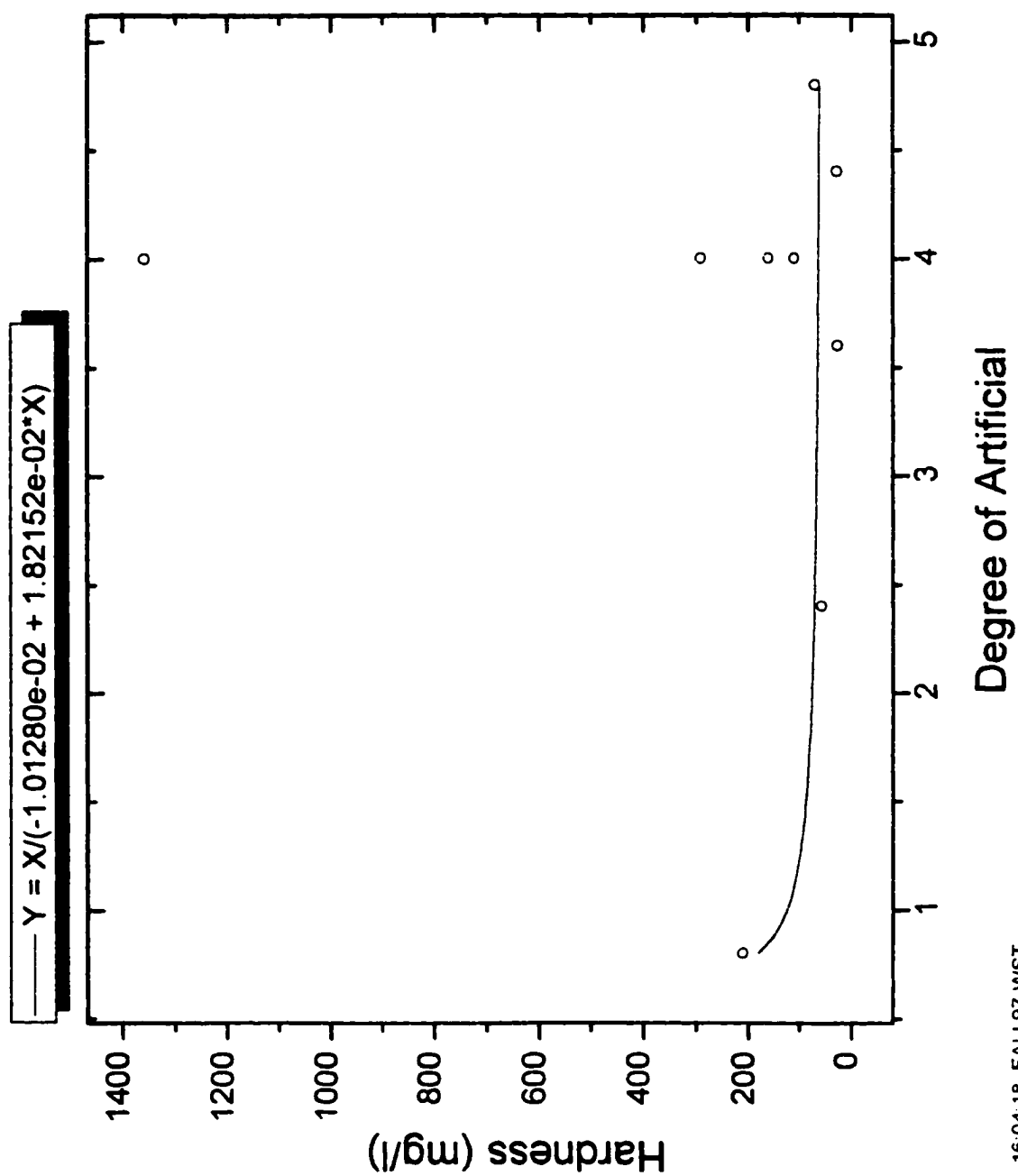
	N	A	B	R	R square
$Y = A + B \cdot X$	9	642.113	-2.34421	-0.00313	9.80591e-06
$Y = A \cdot X^B$	9	4.92079	1.80011	0.27964	0.0782
$Y = A \cdot \exp(B \cdot X)$	9	4.24118	0.63407	0.21638	0.04682
$Y = A + B \cdot \log(X)$	9	451.722	155.623	0.09463	0.00895
$Y = A + B/X$	9	816.238	-485.833	-0.17676	0.03124
$Y = 1/(A + B \cdot X)$	9	0.86593	-0.11824	-0.27509	0.07567
$Y = X/(A + B \cdot X)$	9	0.56425	0.23360	0.35756	0.12785



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Variable: Hardness (mg/l)
Independent variable: Degree of Artificial

	N	A	B	R	R square
$Y = A + B \cdot X$	9	162.674	26.6543	0.07713	0.00594
$Y = A \cdot X^B$	9	159.750	-0.25865	-0.11595	0.01344
$Y = A \cdot \exp(B \cdot X)$	9	163.542	-9.17022e-02	-0.0903	0.00815
$Y = A + B \cdot \log(X)$	9	189.056	58.4587	0.07701	0.00593
$Y = A + B/X$	9	288.342	-82.2703	-0.06484	0.0042
$Y = 1/(A + B \cdot X)$	9	6.97453e-03	2.09164e-03	0.18466	0.0341
$Y = X/(A + B \cdot X)$	9	-1.01280e-02	1.82152e-02	0.24355	0.05931

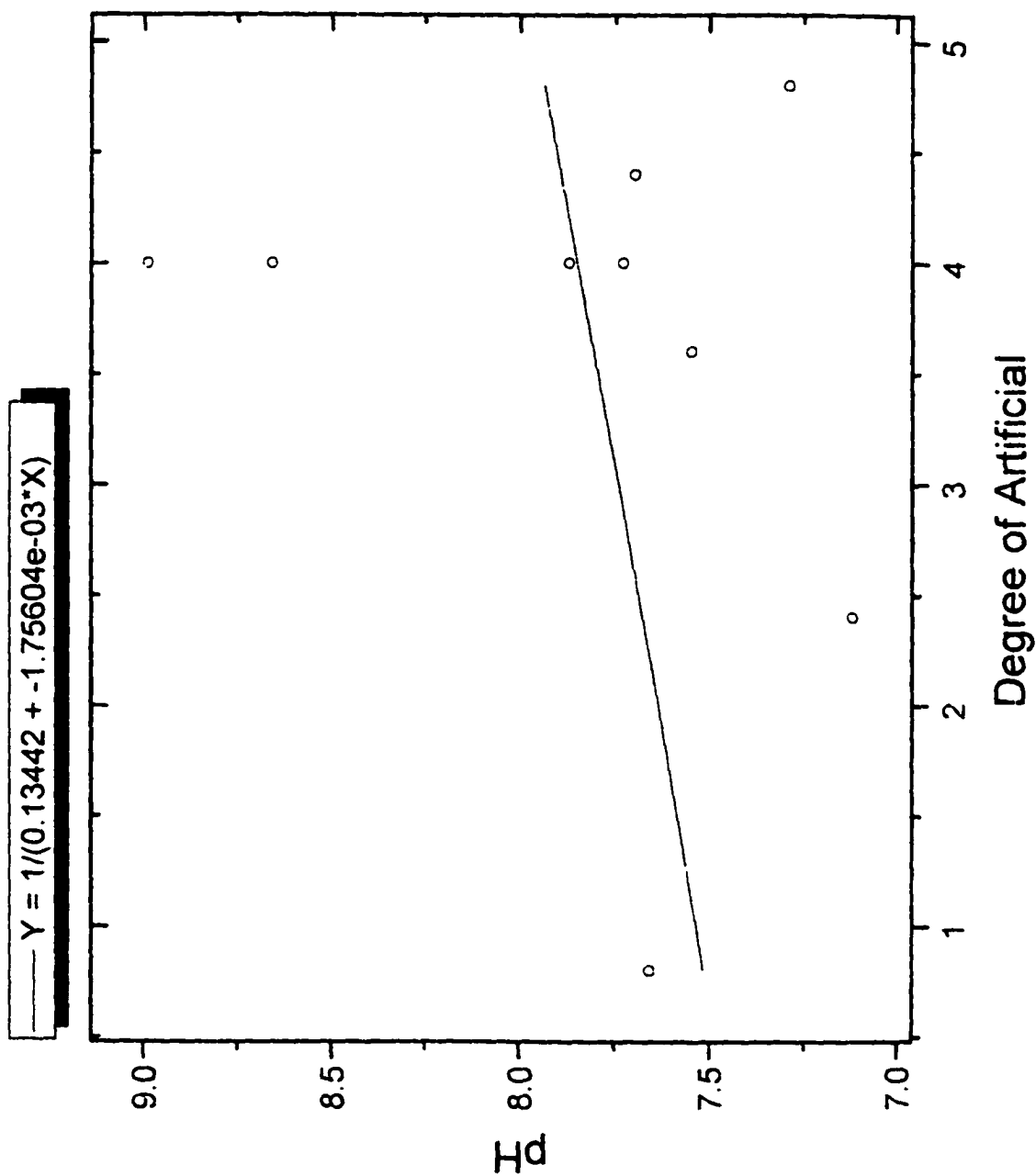


4/8/01 16:04:18 FALL97.WST

Variable: pH

Independent variable: Degree of Artificial

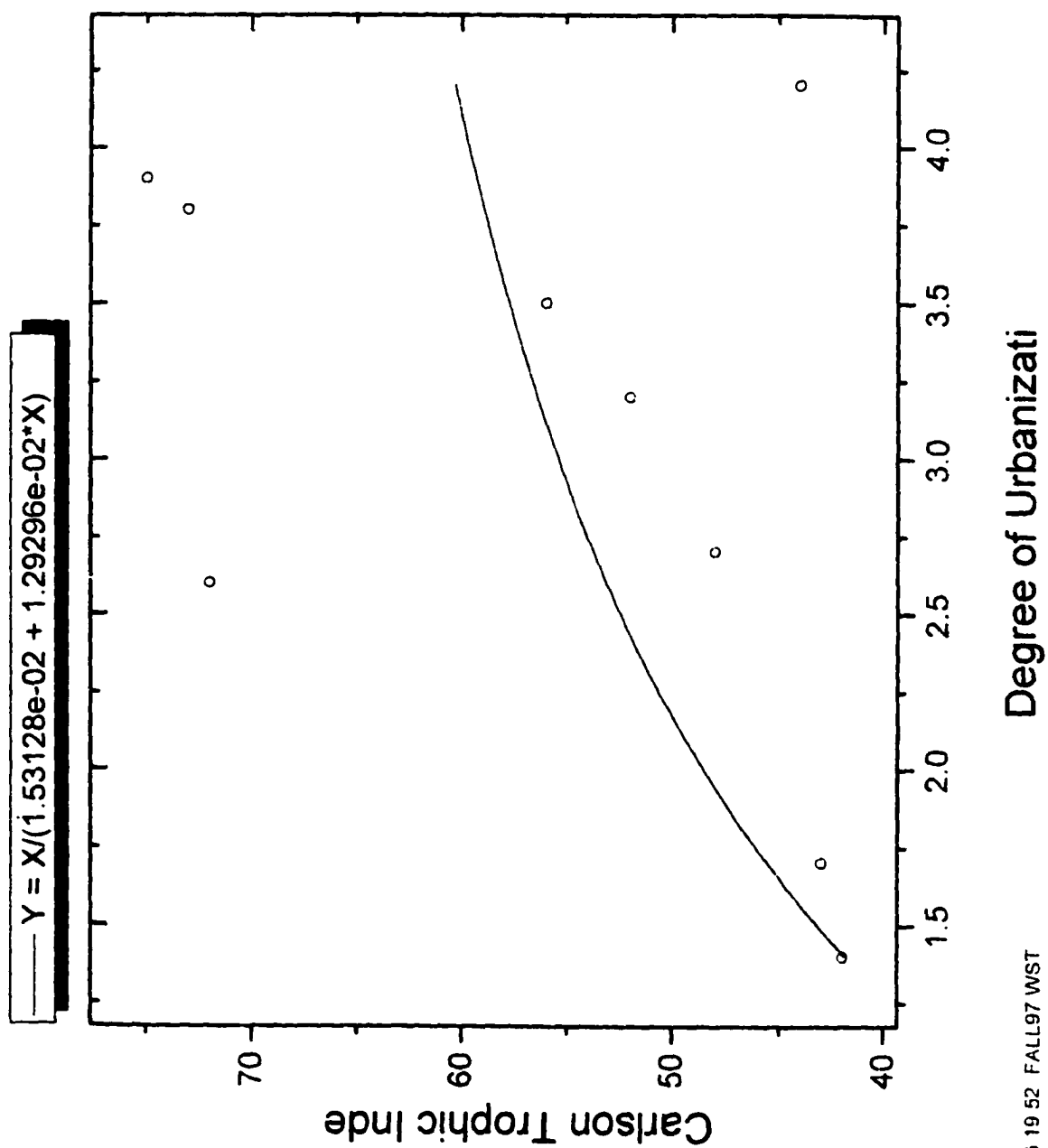
	N	A	B	R	R square
$Y = A + B \cdot X$	9	7.43979	0.11287	0.2269	0.05148
$Y = A \cdot X^B$	9	7.56421	2.85254e-02	0.21038	0.04426
$Y = A \cdot \text{EXP}(B \cdot X)$	9	7.43974	1.40521e-02	0.22767	0.05183
$Y = A + B \cdot \text{LOG}(X)$	9	7.58946	0.23221	0.2125	0.04515
$Y = A + B/X$	9	7.98077	-0.31860	-0.17445	0.03043
$Y = 1/(A + B \cdot X)$	9	0.13442	-1.75604e-03	-0.22822	0.05208
$Y = X/(A + B \cdot X)$	9	4.63175e-03	0.12644	0.18395	0.02688



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Variable: Carlson Trophic Inde
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
$Y = A + B \cdot X$	9	36.2674	6.61458	0.47411	0.22478
$Y = A \cdot X^B$	9	38.6500	0.33371	0.53597	0.28726
$Y = A \cdot \text{EXP}(B \cdot X)$	9	38.1782	0.11981	0.49296	0.24301
$Y = A + B \cdot \text{LOG}(X)$	9	37.1122	18.2627	0.51098	0.2611
$Y = A + B/X$	9	72.8285	-44.0785	-0.53196	0.26298
$Y = 1/(A + B \cdot X)$	9	2.54274e-02	-2.23008e-03	-0.51222	0.26237
$Y = X/(A + B \cdot X)$	9	1.53128e-02	1.29296e-02	0.5922	0.3507

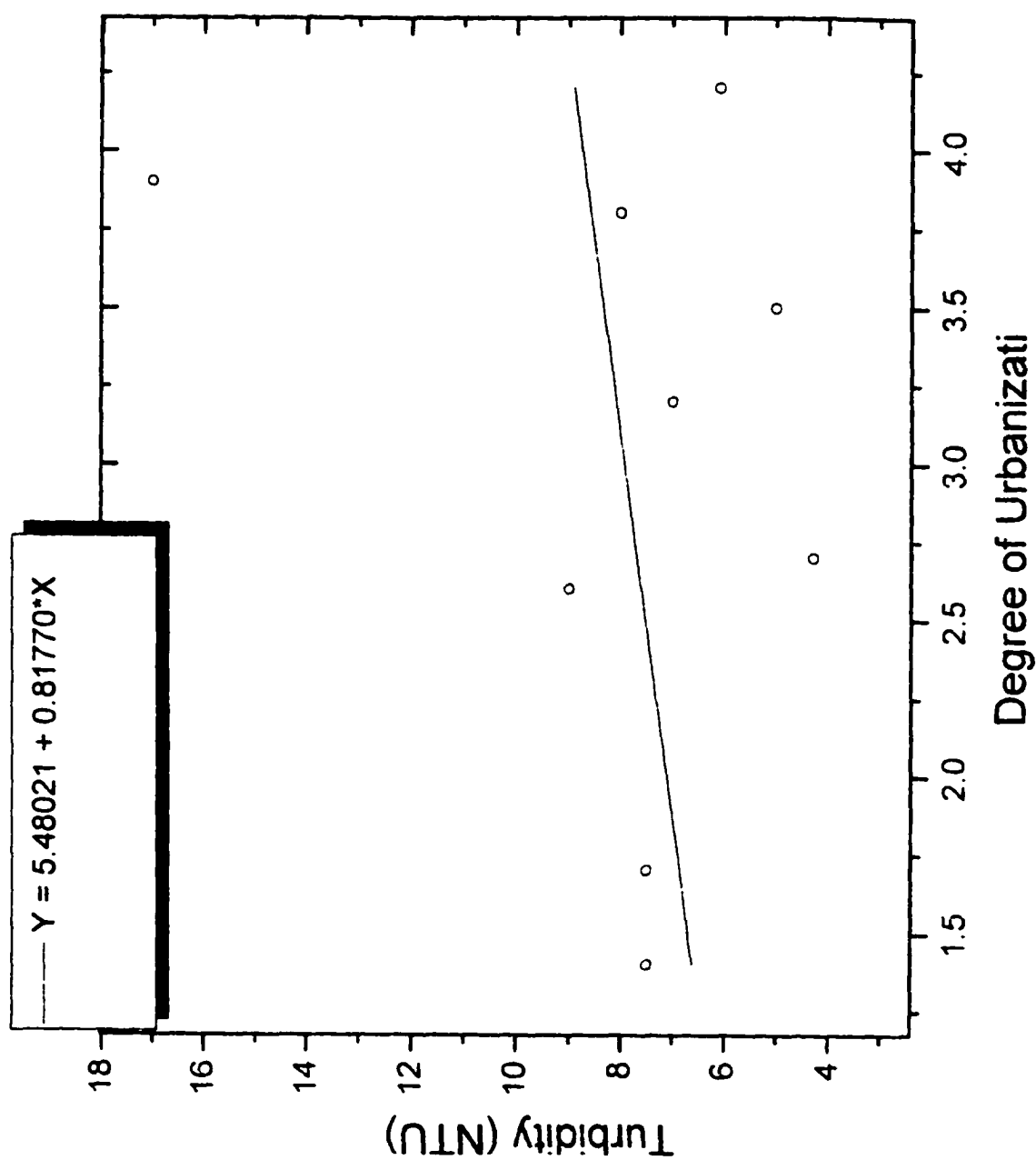


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Variable: Turbidity (NTU)

Independent variable: Degree of Urbanizati

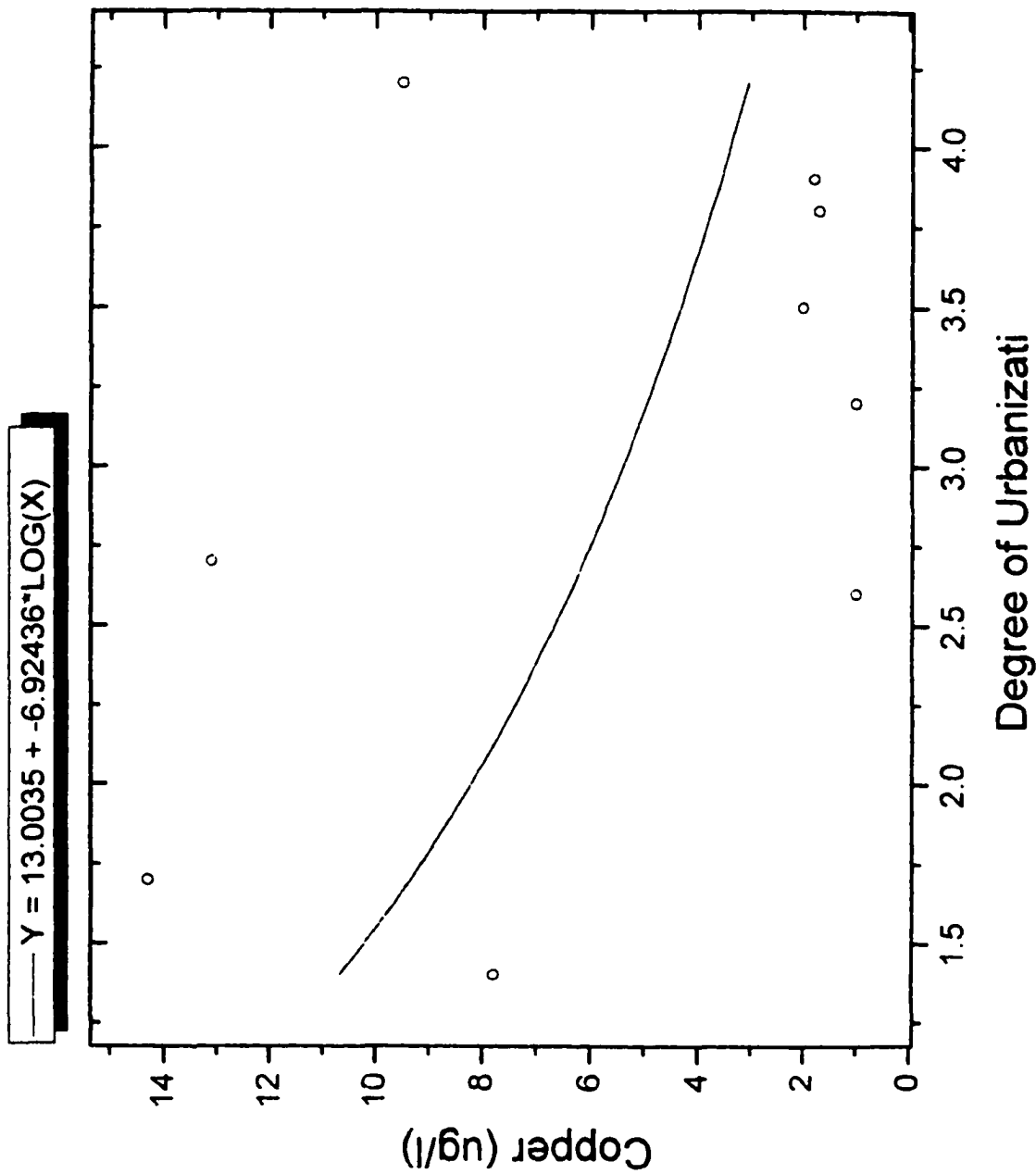
	N	A	B	R	R square
$Y = A + B \cdot X$	9	5.48021	0.81770	0.2163	0.04678
$Y = A \cdot X^B$	9	6.63722	9.90835e-02	0.09684	0.00937
$Y = A \cdot \exp(B \cdot X)$	9	6.25040	5.43750e-02	0.13614	0.01853
$Y = A + B \cdot \log(X)$	9	6.09166	1.77031	0.1828	0.03341
$Y = A + B/X$	9	9.19412	-3.32428	-0.14805	0.02192
$Y = 1/(A + B \cdot X)$	9	0.15339	-2.94852e-03	-0.05735	0.00328
$Y = X/(A + B \cdot X)$	9	-9.51893e-03	0.14816	0.03117	9.71848e-04



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Variable: Copper (ug/l)
Independent variable: Degree of Urbanizati

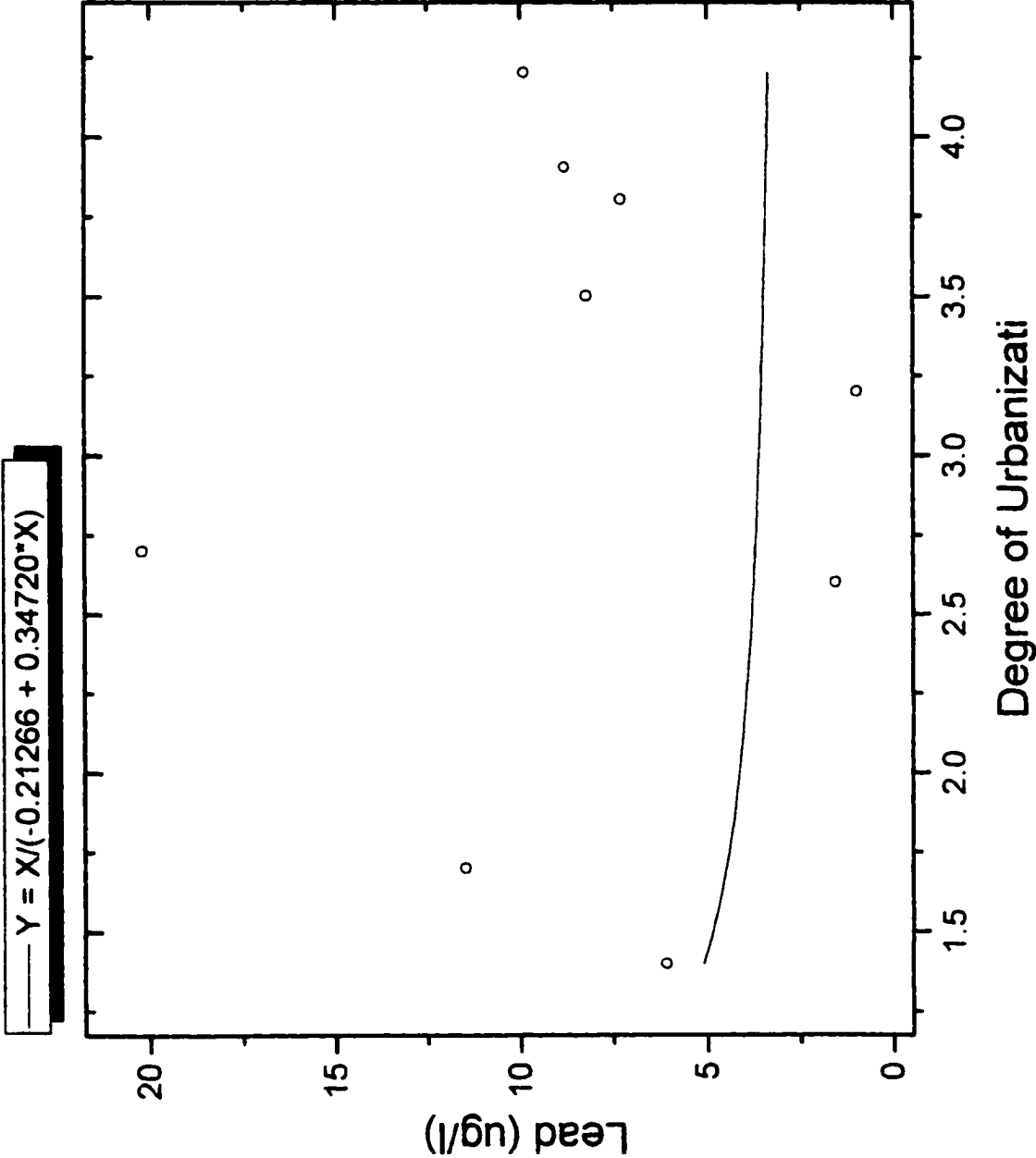
	N	A	B	R	R square
$Y = A + B \cdot X$	9	13.5422	-2.58073	-0.46499	0.21622
$Y = A \cdot X^B$	9	13.8978	-1.31752	-0.45582	0.20777
$Y = A \cdot \exp(B \cdot X)$	9	13.9318	-0.45769	-0.40564	0.16454
$Y = A + B \cdot \log(X)$	9	13.0035	-8.92436	-0.48703	0.2372
$Y = A + B/X$	9	-0.25627	15.9684	0.48445	0.23489
$Y = 1/(A + B \cdot X)$	9	0.12363	0.10780	0.27931	0.07801
$Y = X/(A + B \cdot X)$	9	-0.93104	0.80017	0.40615	0.16495



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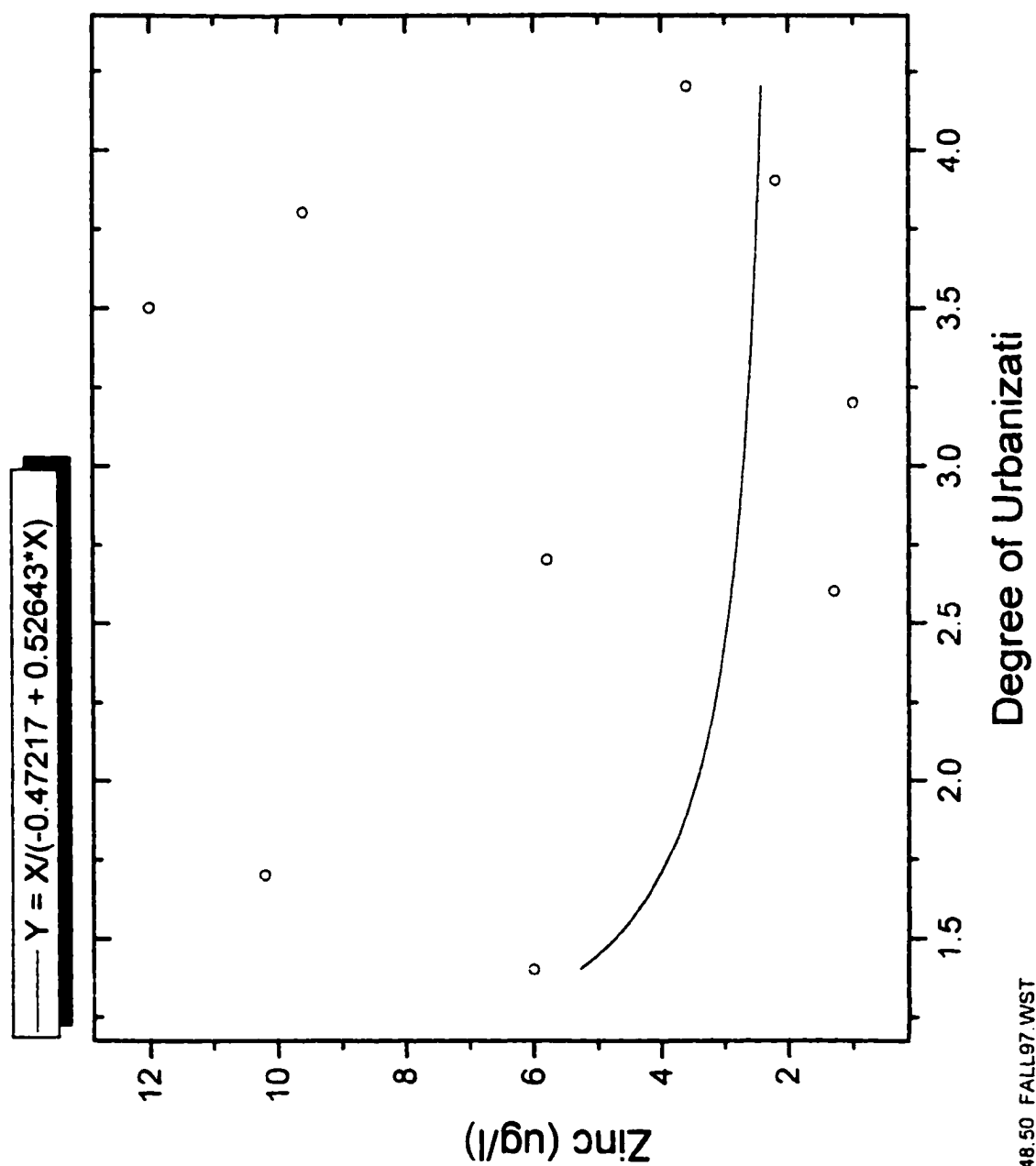
Variable: Lead (ug/l)
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.86311	-0.19140	-0.03297	0.00108
$Y = A \cdot X^B$	9	6.46332	-5.44353e-02	-0.02166	4.69567e-04
$Y = A \cdot \exp(B \cdot X)$	9	5.66469	2.50866e-02	0.02558	6.54457e-04
$Y = A + B \cdot \log(X)$	9	8.72898	-0.42303	-0.02845	8.09607e-04
$Y = A + B/X$	9	8.08767	0.53053	0.01539	2.36903e-04
$Y = 1/(A + B \cdot X)$	9	0.28457	-6.00788e-03	-0.01811	3.28130e-04
$Y = X/(A + B \cdot X)$	9	-0.21266	0.34720	0.10796	0.01165



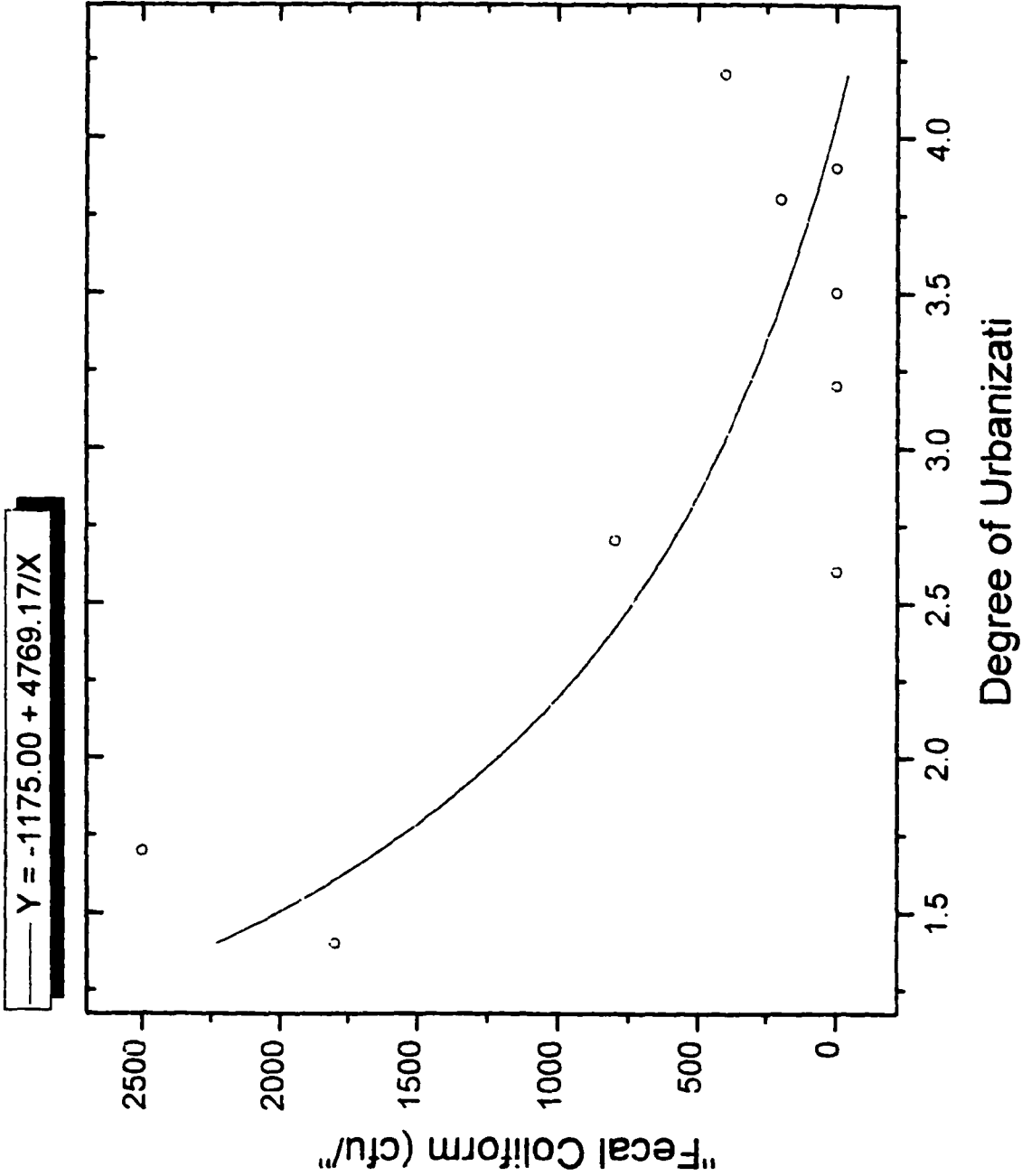
Variable: Zinc (ug/l)
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
$Y = A + B \cdot X$	9	7.67413	-0.64322	-0.15437	0.02383
$Y = A \cdot X^B$	9	7.16714	-0.51000	-0.21346	0.04556
$Y = A \cdot \exp(B \cdot X)$	9	6.78934	-0.15880	-0.17026	0.02899
$Y = A + B \cdot \log(X)$	9	7.67987	-1.86042	-0.17429	0.03037
$Y = A + B/X$	9	3.97727	4.65948	0.18828	0.03545
$Y = 1/(A + B \cdot X)$	9	0.22473	4.08711e-02	0.12111	0.01466
$Y = X/(A + B \cdot X)$	9	-0.47217	0.52643	0.2356	0.0555



Variable: Fecal Coliform (cfu/
Independent variable: Degree of Urbanizati

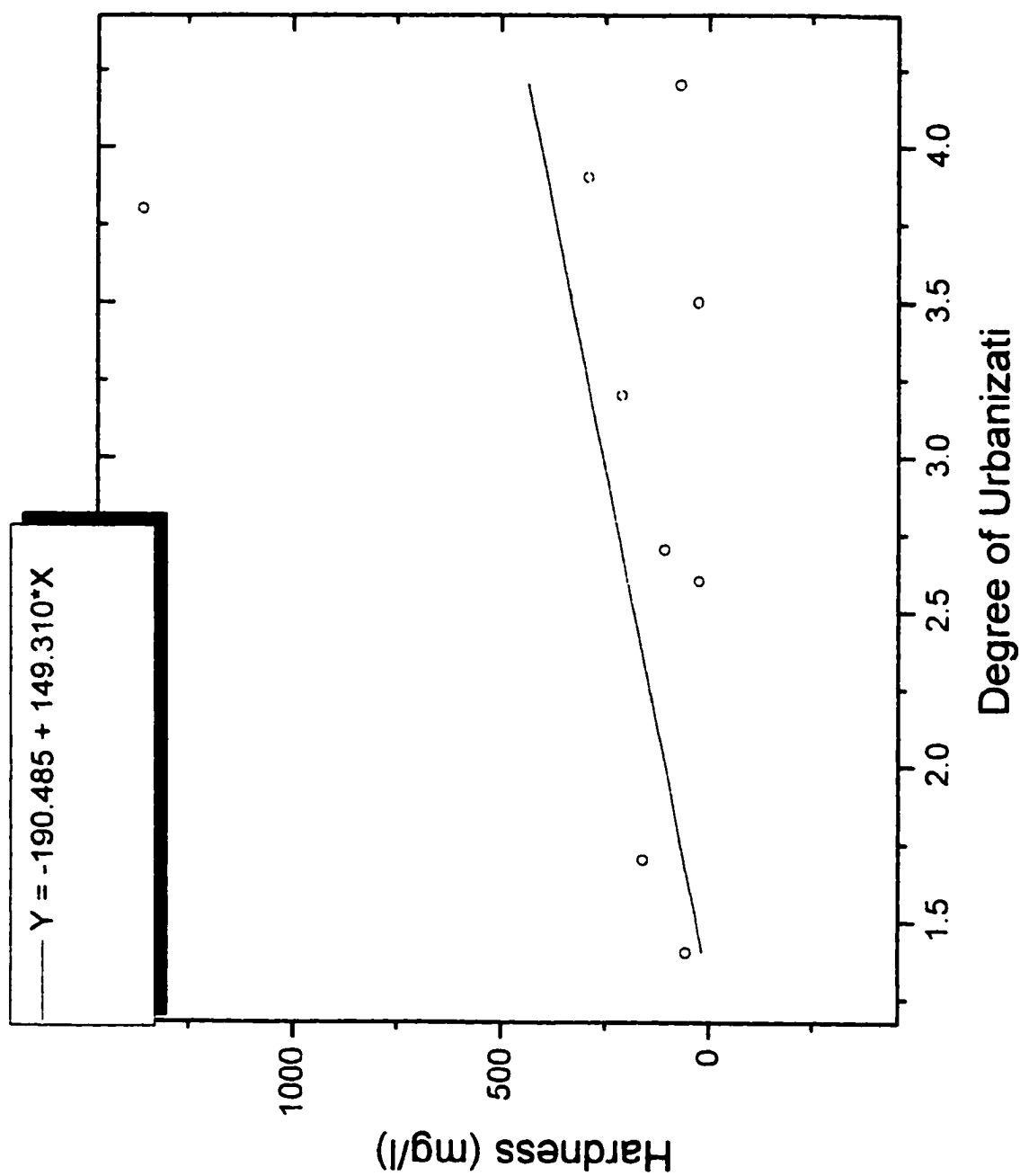
	N	A	B	R	R square
$Y = A + B \cdot X$	9	2871.59	-745.938	-0.79774	0.63639
$Y = A \cdot X^B$	9	6143.17	-4.82908	-0.51503	0.26525
$Y = A \cdot \text{EXP}(B \cdot X)$	9	5862.46	-1.65900	-0.45325	0.20544
$Y = A + B \cdot \text{LOG}(X)$	9	2732.85	-2017.73	-0.84235	0.70955
$Y = A + B/X$	9	-1175.00	4769.17	0.85877	0.73749
$Y = 1/(A + B \cdot X)$	9	-2.52647e-02	0.15692	0.2923	0.08544
$Y = X/(A + B \cdot X)$	9	-1.27910	0.93064	0.40115	0.16092



4/8/01 16:55:02 FALL97.WST

Variable: Hardness (mg/l)
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
$Y = A + B \cdot X$	9	-190.485	149.310	0.34592	0.11966
$Y = A \cdot X^B$	9	46.4465	0.89657	0.27593	0.07613
$Y = A \cdot \exp(B \cdot X)$	9	37.7712	0.37982	0.29945	0.08967
$Y = A + B \cdot \log(X)$	9	-119.491	362.328	0.32789	0.10738
$Y = A + B/X$	9	550.563	-772.860	-0.30148	0.09089
$Y = 1/(A + B \cdot X)$	9	2.00348e-02	-1.87445e-03	-0.13249	0.01755
$Y = X/(A + B \cdot X)$	9	4.80954e-03	1.25874e-02	0.05723	0.00327

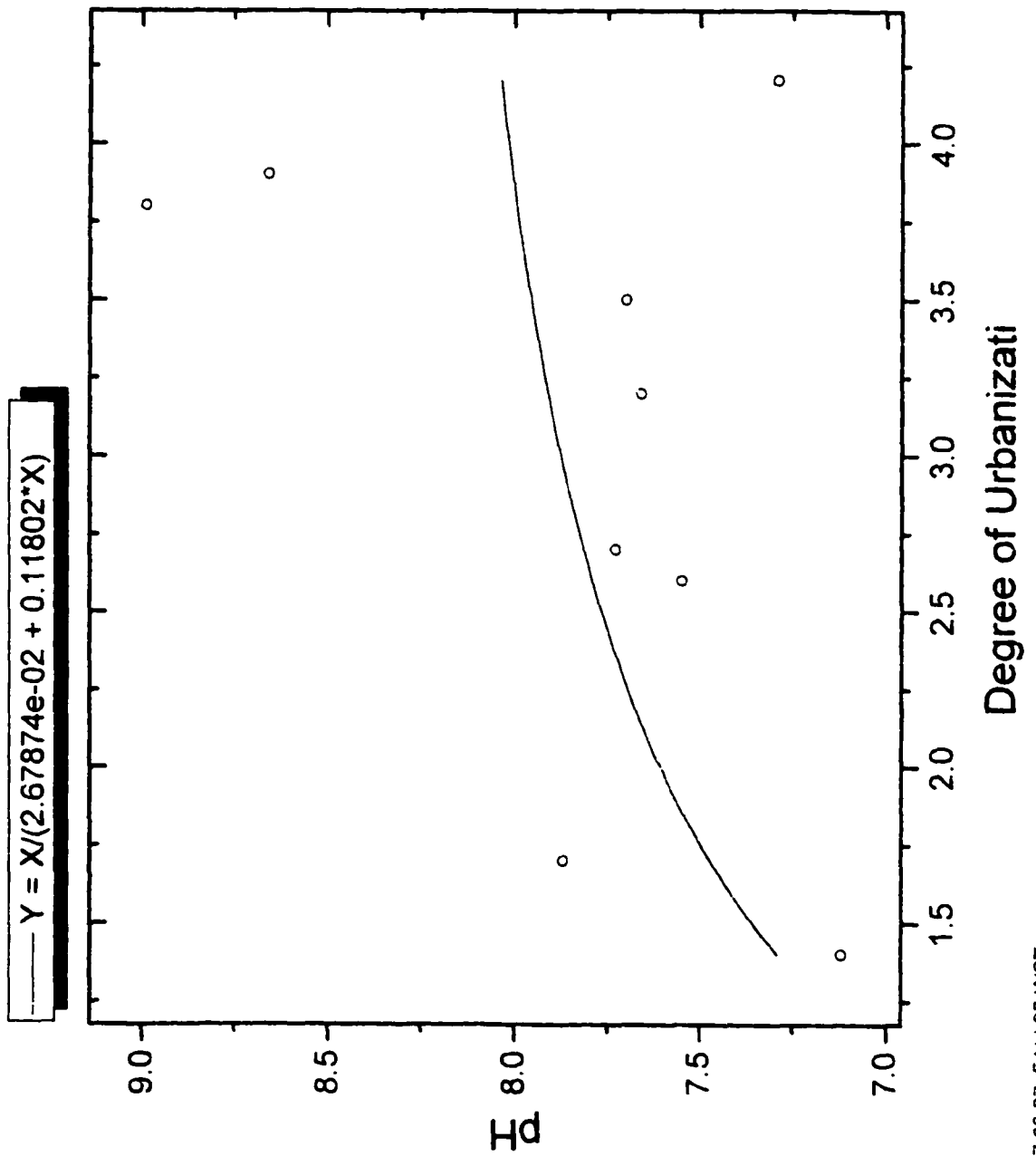


4/8/01 17:00:32 FALL97 WST

Variable: pH

Independent variable: Degree of Urbanizati

	N	A	B	R	R square
$Y = A + B \cdot X$	9	6.99970	0.28046	0.45139	0.20376
$Y = A \cdot X^B$	9	7.11410	9.10483e-02	0.46102	0.21254
$Y = A \cdot \exp(B \cdot X)$	9	7.04747	3.47097e-02	0.45022	0.2027
$Y = A + B \cdot \log(X)$	9	7.08188	0.72980	0.45851	0.21023
$Y = A + B/X$	9	8.48044	-1.68571	-0.4568	0.20867
$Y = 1/(A + B \cdot X)$	9	0.14112	-4.31324e-03	-0.44878	0.20141
$Y = X/(A + B \cdot X)$	9	2.67874e-02	0.11802	0.46929	0.22023

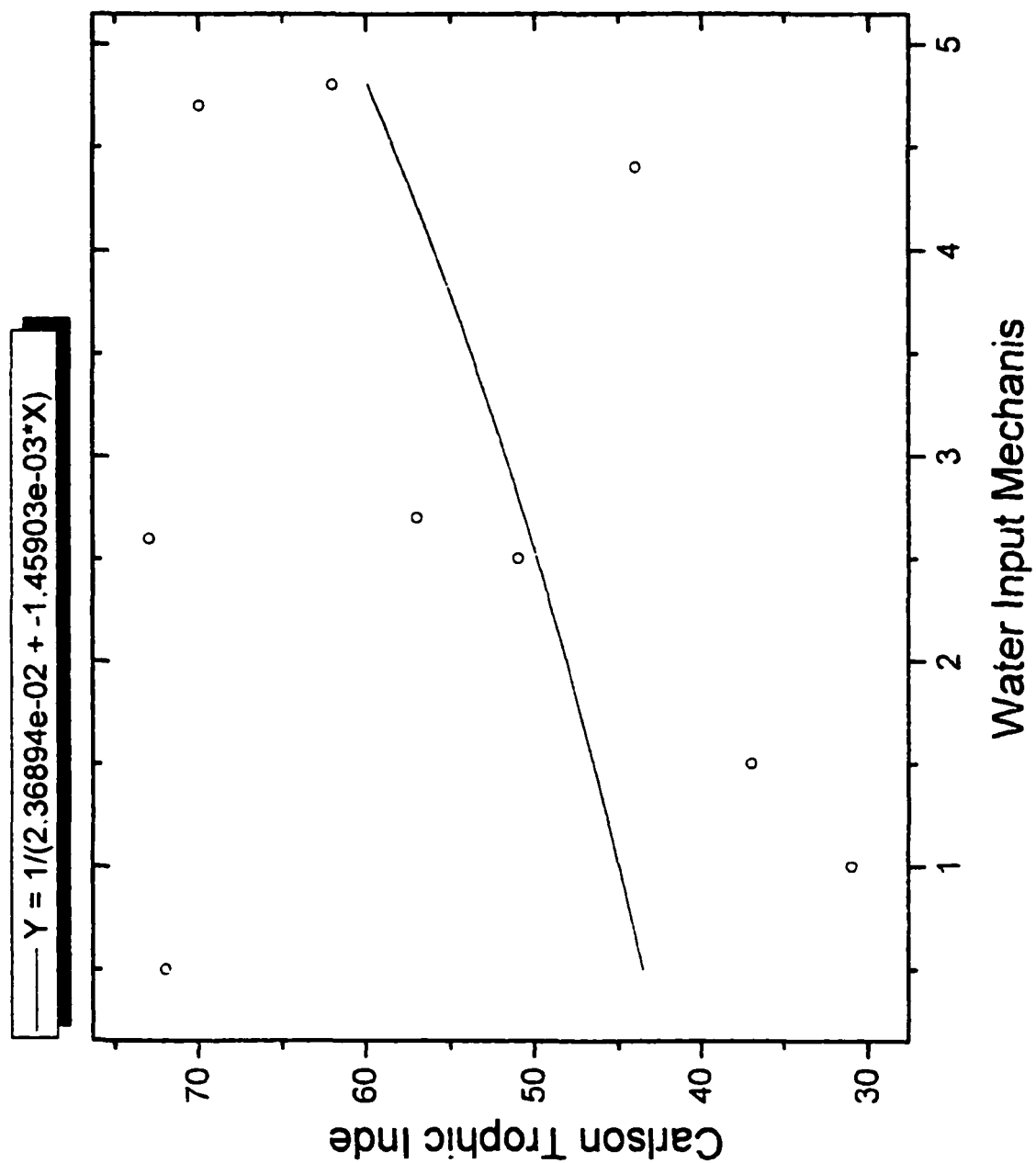


4/8/01 17:06:27 FALL97.WST

SPRING98.WST:Simple regression

Variable: Carlson Trophic Inde
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	48.5411	2.43442	0.25106	0.06303
$Y = A \cdot X^B$	9	49.8258	7.94304e-02	0.19828	0.03931
$Y = A \cdot \exp(B \cdot X)$	9	45.1248	5.91836e-02	0.30809	0.09492
$Y = A + B \cdot \log(X)$	9	53.0677	2.70246	0.13364	0.01786
$Y = A + B/X$	9	54.0993	1.84751	0.06921	0.00479
$Y = 1/(A + B \cdot X)$	9	2.36894e-02	-1.45903e-03	-0.35984	0.12948
$Y = X/(A + B \cdot X)$	9	5.73025e-04	1.93369e-02	0.05133	0.00263

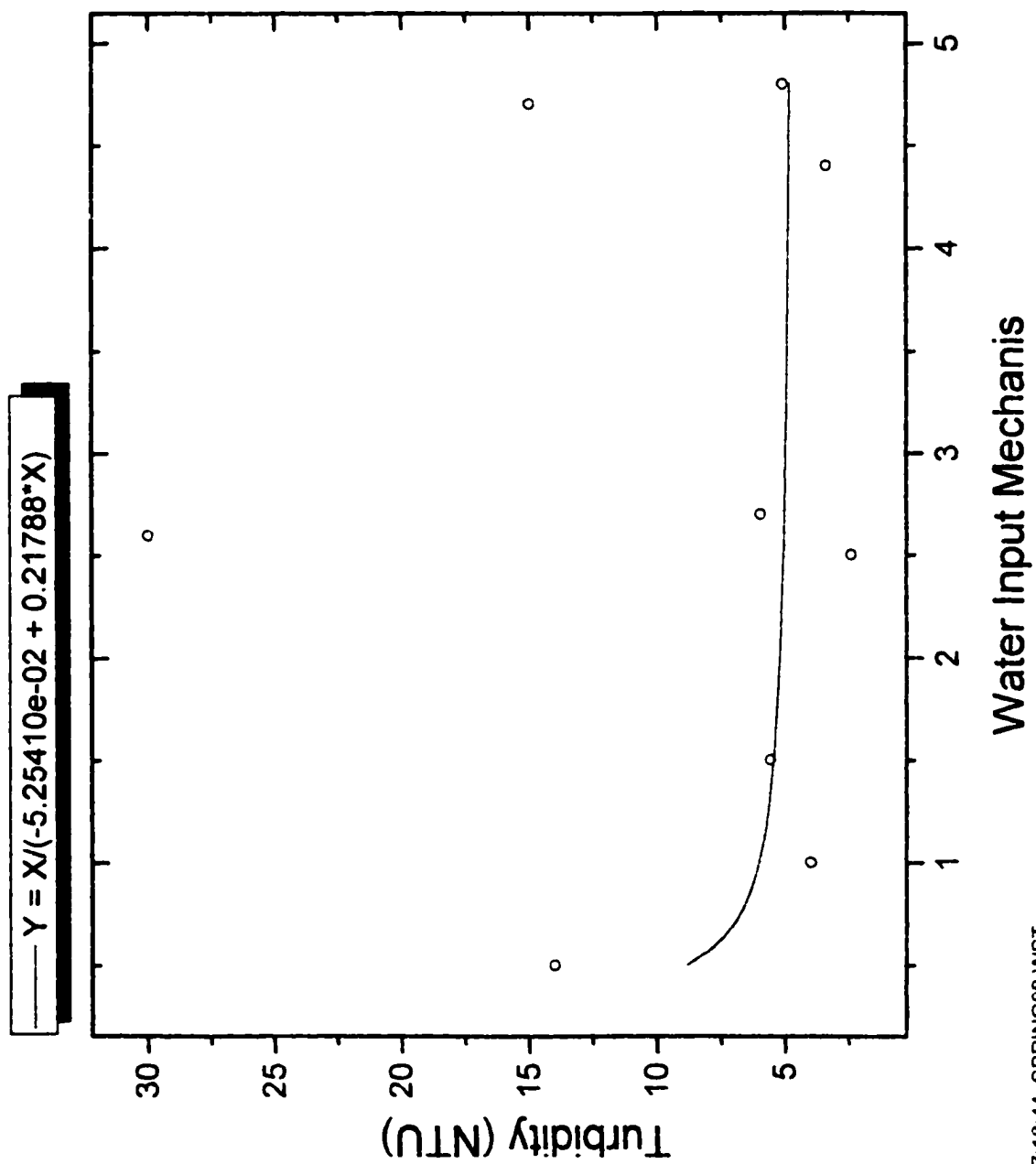


4/8/01 17:13:30 SPRING98.WST

Variable: Turbidity (NTU)

Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	10.1840	-0.24924	-0.04476	0.002
$Y = A \cdot X^B$	9	7.62324	-0.12587	-0.11836	0.01401
$Y = A \cdot \exp(B \cdot X)$	9	7.47157	-2.92444e-02	-0.05734	0.00328
$Y = A + B \cdot \log(X)$	9	9.92660	-0.53510	-0.04609	0.00212
$Y = A + B/X$	9	8.71020	1.29949	0.08478	0.00718
$Y = 1/(A + B \cdot X)$	9	0.17421	4.27387e-03	0.05581	0.00311
$Y = X/(A + B \cdot X)$	9	-5.25410e-02	0.21788	0.24926	0.06213

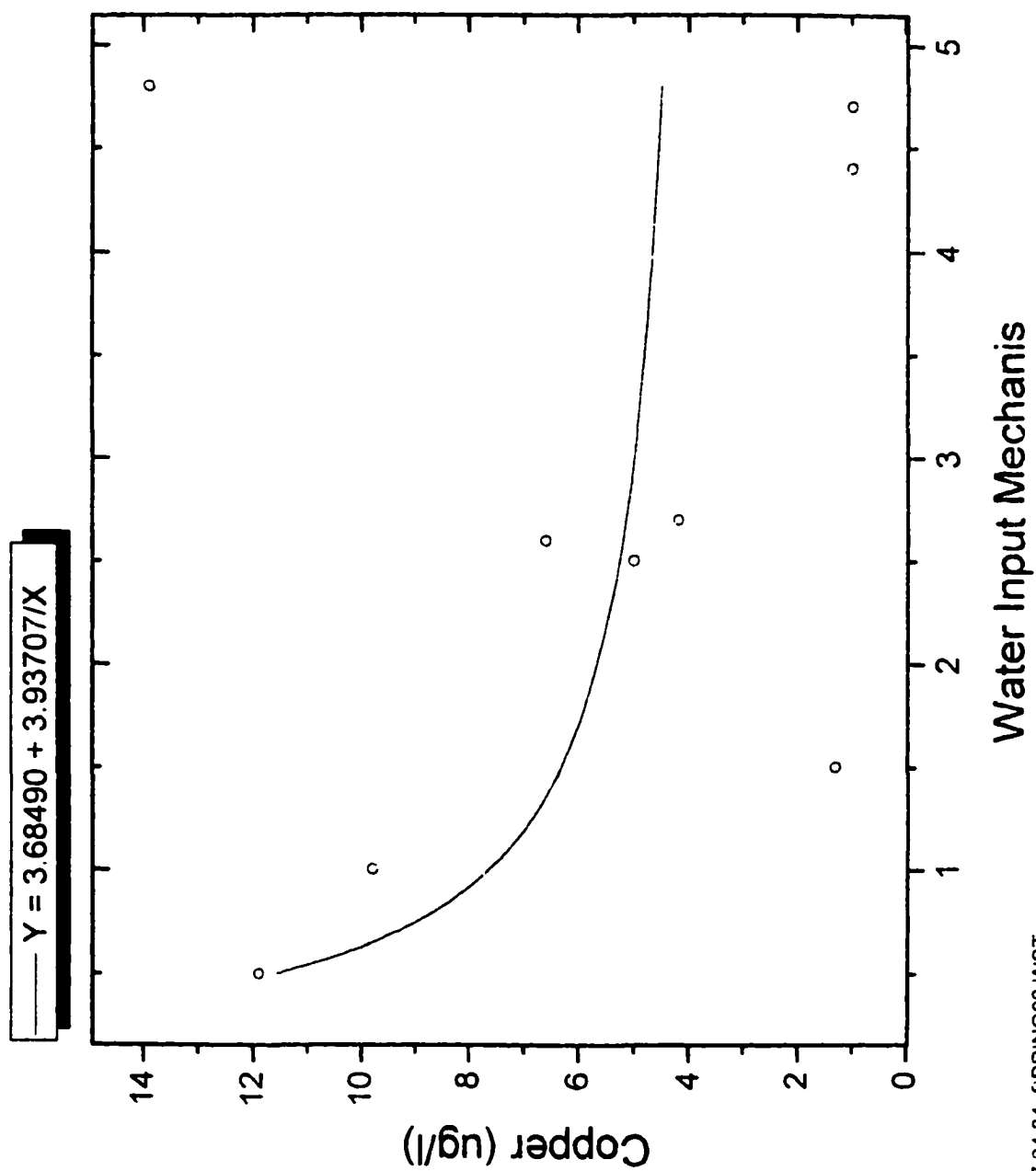


4/8/01 17:18:44 SPRING98.WST

Variable: Copper (ug/l)

Independent variable: Water Input Mechanis

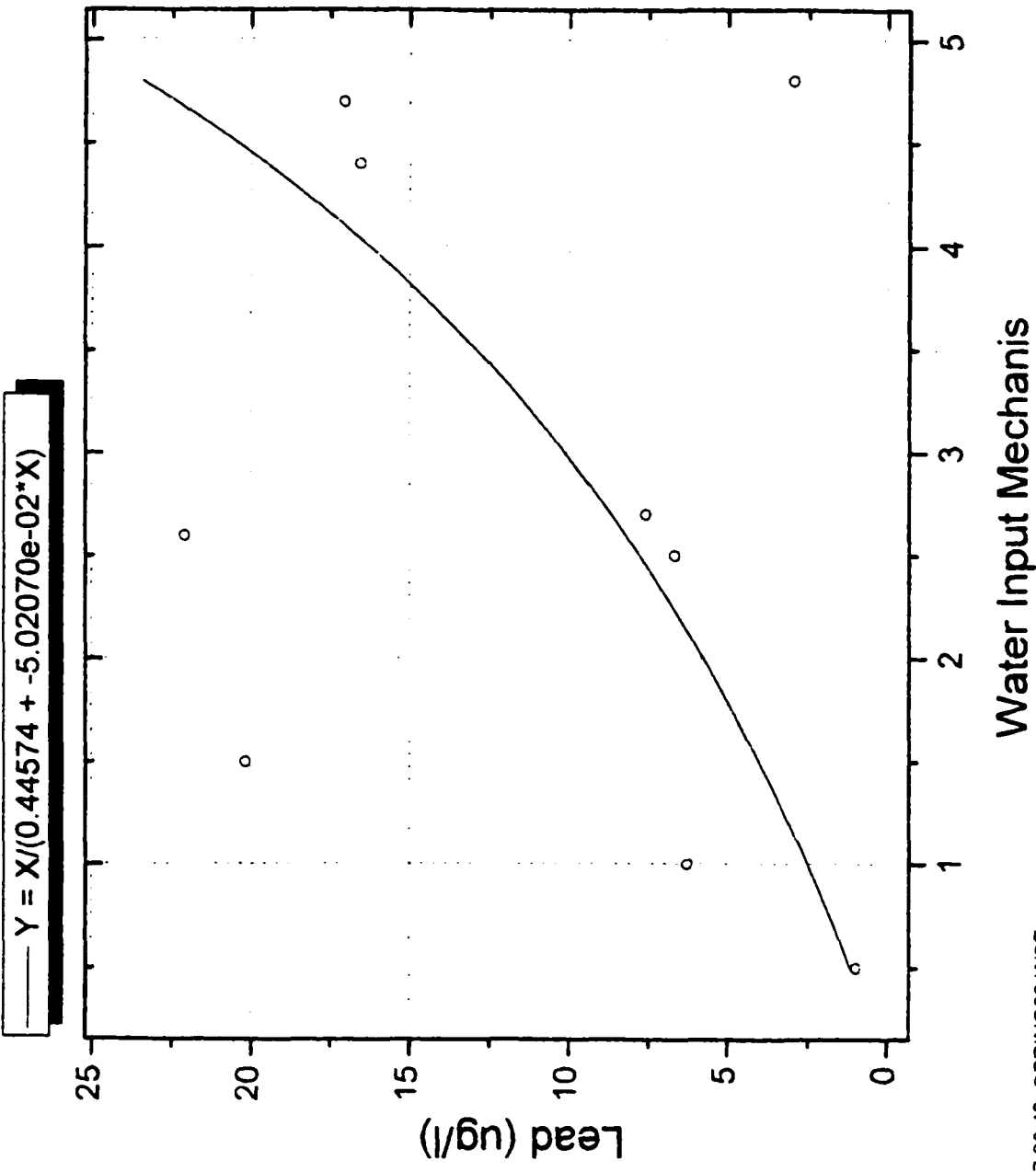
	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.16615	-0.76094	-0.25109	0.06304
$Y = A \cdot X^B$	9	6.51289	-0.59640	-0.43281	0.18732
$Y = A \cdot \exp(B \cdot X)$	9	8.10547	-0.25295	-0.38282	0.14655
$Y = A + B \cdot \log(X)$	9	8.01204	-2.42620	-0.38389	0.14737
$Y = A + B/X$	9	3.68490	3.93707	0.47191	0.2227
$Y = 1/(A + B \cdot X)$	9	8.67971e-02	0.11480	0.45938	0.21103
$Y = X/(A + B \cdot X)$	9	-0.27126	0.56674	0.39428	0.15545



4/8/01 17:24:34 SPRINC98.WST

Variable: Lead (ug/l)
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.02550	1.14860	0.2344	0.05494
$Y = A \cdot X^B$	9	4.47723	0.71470	0.53617	0.28747
$Y = A \cdot \exp(B \cdot X)$	9	4.32908	0.21987	0.34399	0.11833
$Y = A + B \cdot \log(X)$	9	8.15690	3.78917	0.3708	0.13749
$Y = A + B/X$	9	15.0746	-6.41157	-0.4753	0.22591
$Y = 1/(A + B \cdot X)$	9	0.45262	-8.45049e-02	-0.44211	0.19546
$Y = X/(A + B \cdot X)$	9	0.44574	-5.02070e-02	-0.84711	0.7176

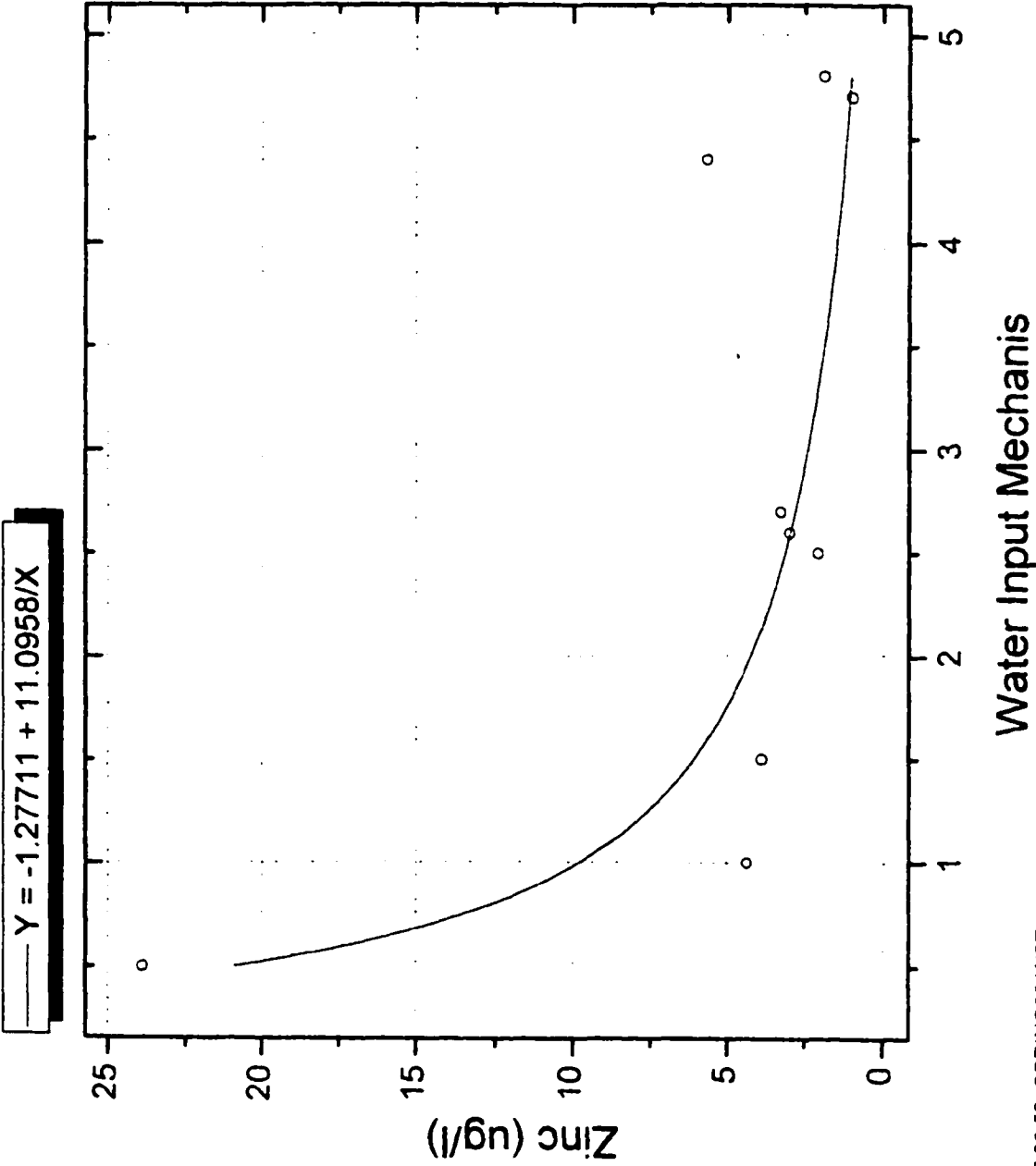


4/8/01 17:30 12 SPRING98.WST

Variable: Zinc (ug/l)

Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	12.4230	-2.53468	-0.57512	0.33077
$Y = A \cdot X^B$	9	7.32393	-0.90410	-0.78706	0.61947
$Y = A \cdot \exp(B \cdot X)$	9	9.84456	-0.37040	-0.67245	0.45219
$Y = A + B \cdot \log(X)$	9	11.0756	-7.03548	-0.78549	0.58598
$Y = A + B/X$	9	-1.27711	11.0958	0.91454	0.83638
$Y = 1/(A + B \cdot X)$	9	5.78054e-02	0.11415	0.65789	0.43283
$Y = X/(A + B \cdot X)$	9	-0.27900	0.54066	0.5841	0.34117

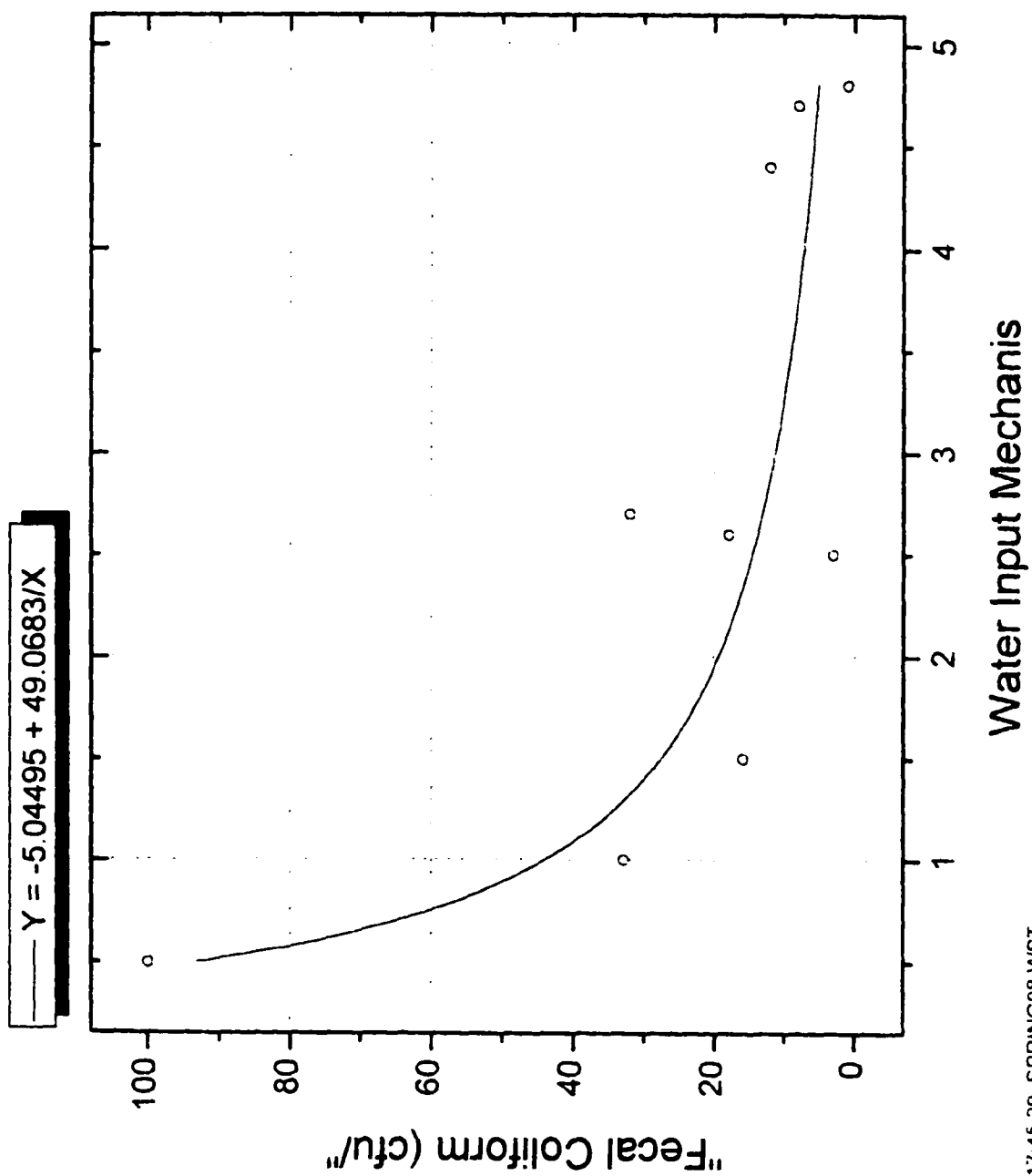


4/8/01 17 39 50 SPRING98.WST

SPRING98.WST:Simple regression

Variable: Fecal Coliform (cfu/
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	60.8012	-13.1259	-0.69157	0.47827
$Y = A \cdot X^B$	9	36.3676	-1.31701	-0.73937	0.54867
$Y = A \cdot \exp(B \cdot X)$	9	68.2422	-0.61191	-0.71639	0.51322
$Y = A + B \cdot \log(X)$	9	51.3535	-33.3347	-0.8422	0.7093
$Y = A + B/X$	9	-5.04495	49.0683	0.93911	0.88192
$Y = 1/(A + B \cdot X)$	9	-0.10132	0.10701	0.5385	0.28998
$Y = X/(A + B \cdot X)$	9	-0.19965	0.31370	0.36495	0.13319

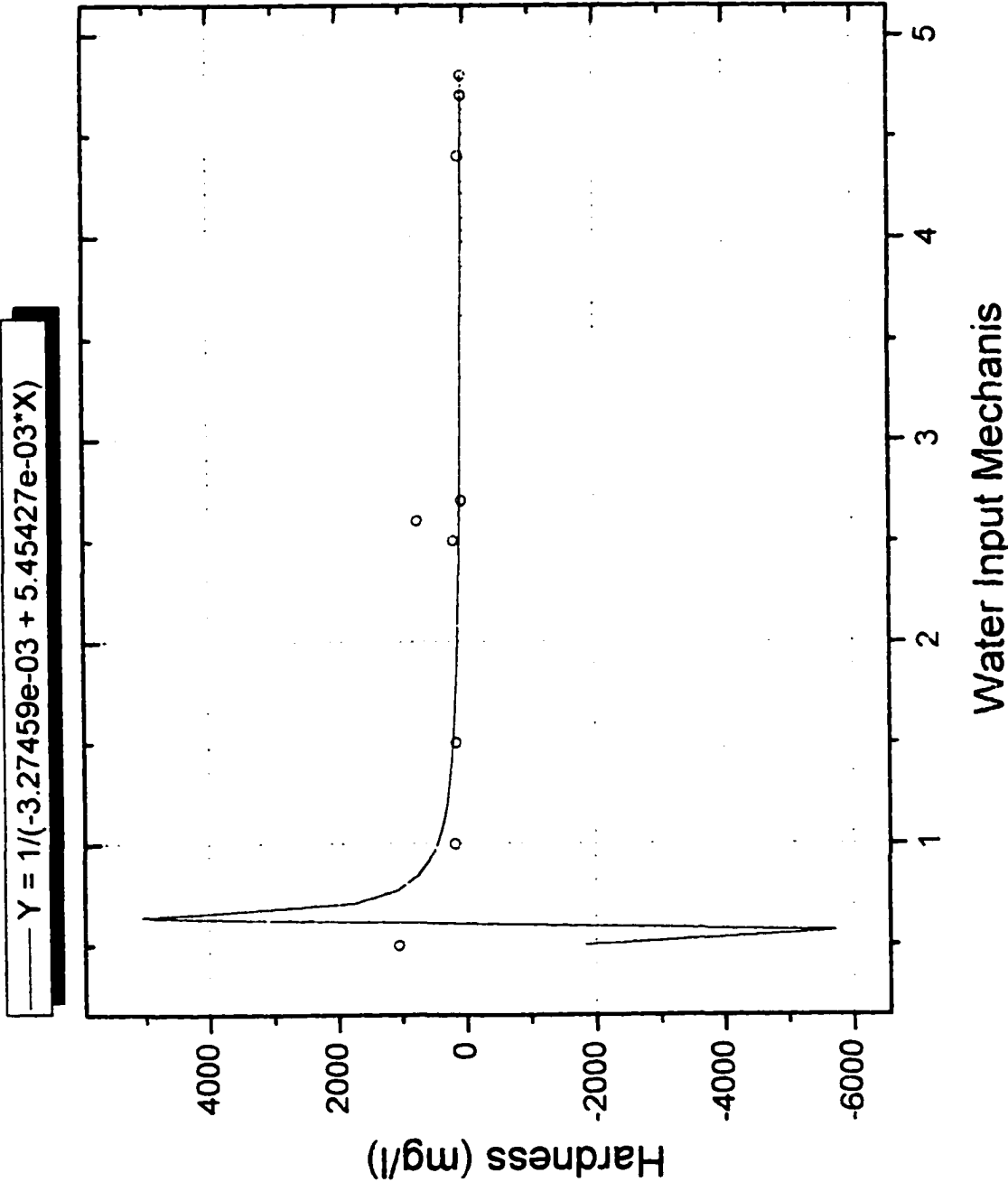


4/8/01 17:45:29 SPRING98.WST

Variable: Hardness (mg/l)

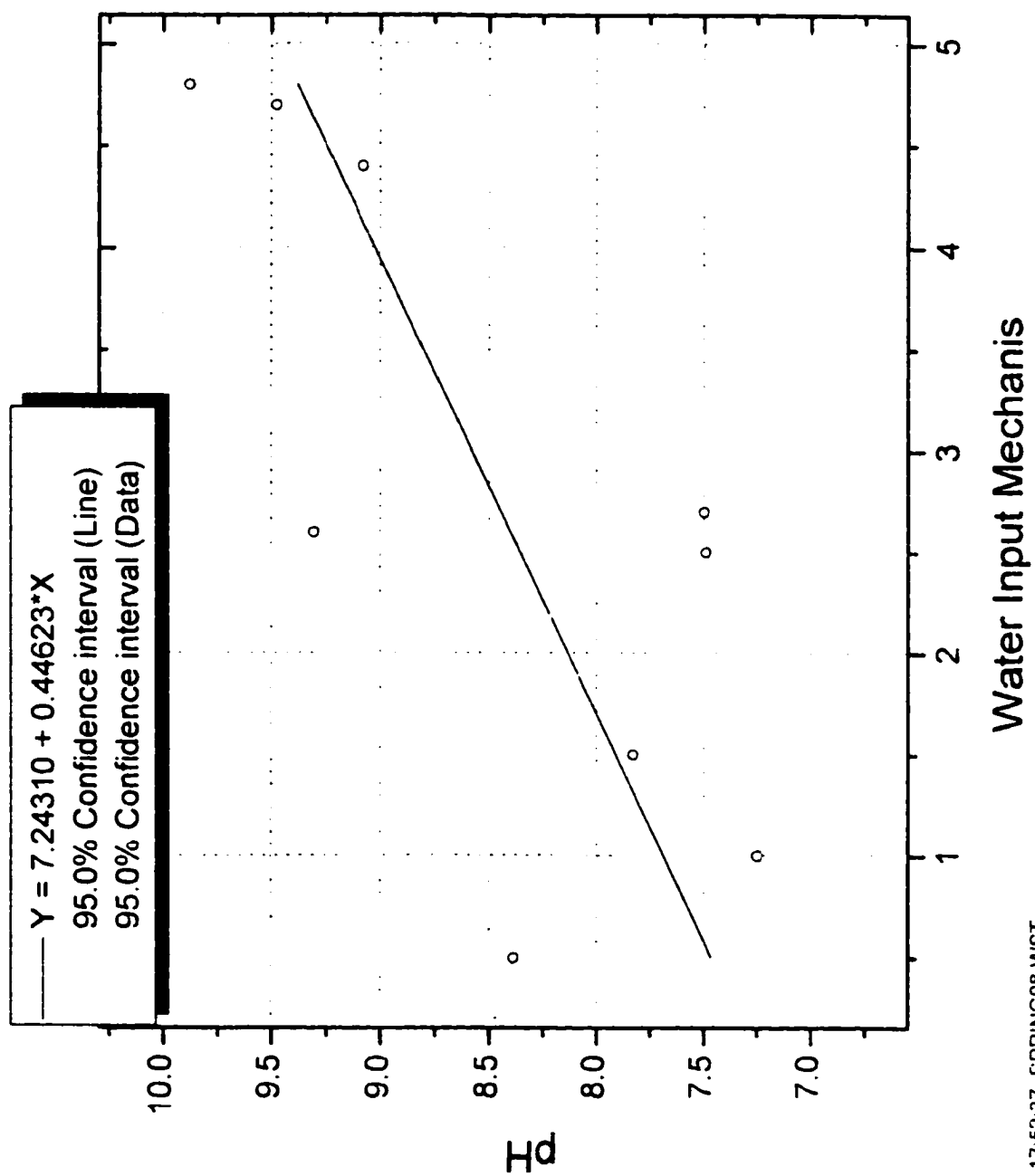
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	651.773	-134.209	-0.59049	0.34867
$Y = A \cdot X^B$	9	369.080	-1.17531	-0.73995	0.54752
$Y = A \cdot \exp(B \cdot X)$	9	690.072	-0.56943	-0.74762	0.55894
$Y = A + B \cdot \log(X)$	9	540.088	-321.916	-0.67917	0.46128
$Y = A + B/X$	9	-2.88236	471.102	0.75292	0.5669
$Y = 1/(A + B \cdot X)$	9	-3.27459e-03	5.45427e-03	0.79674	0.63479
$Y = X/(A + B \cdot X)$	9	-1.06076e-02	1.81414e-02	0.56286	0.31681



Variable: pH
Independent variable: Water Input Mechanis

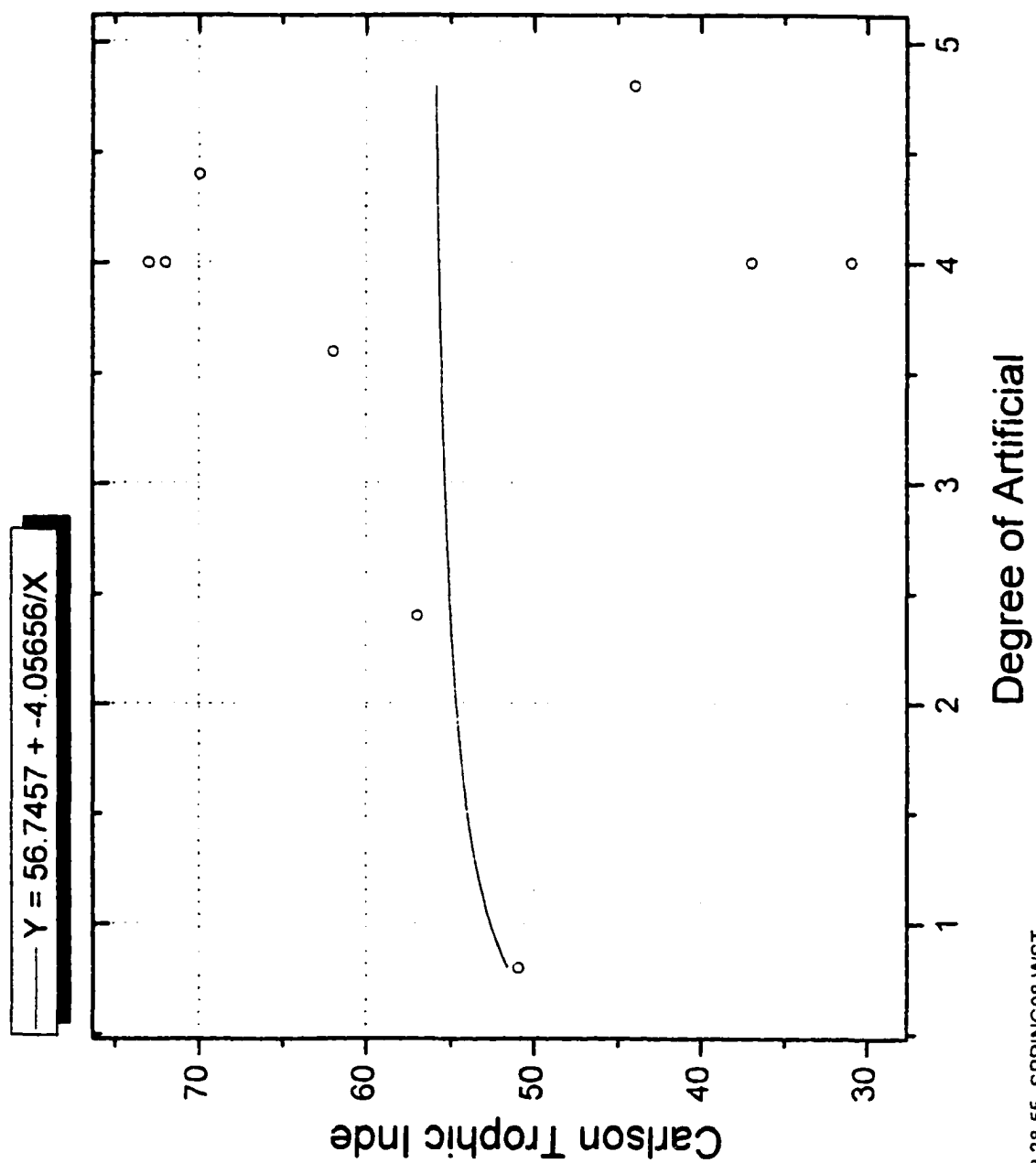
	N	A	B	R	R square
* Y = A + B*X	9	7.24310	0.44623	0.71926	0.51733
Y = A * X^B	9	7.87057	8.40635e-02	0.54988	0.30237
Y = A * EXP(B*X)	9	7.29874	5.19038e-02	0.70803	0.5013
Y = A + B*LOG(X)	9	7.88745	0.72792	0.56261	0.31654
Y = A + B/X	9	8.82171	-0.58234	-0.34096	0.11625
Y = 1/(A + B*X)	9	0.13620	-6.07119e-03	-0.69609	0.48454
Y = X/(A + B*X)	9	7.46216e-03	0.11501	0.31079	0.09659



4/8/01 17:52:37 SPRING98 WST

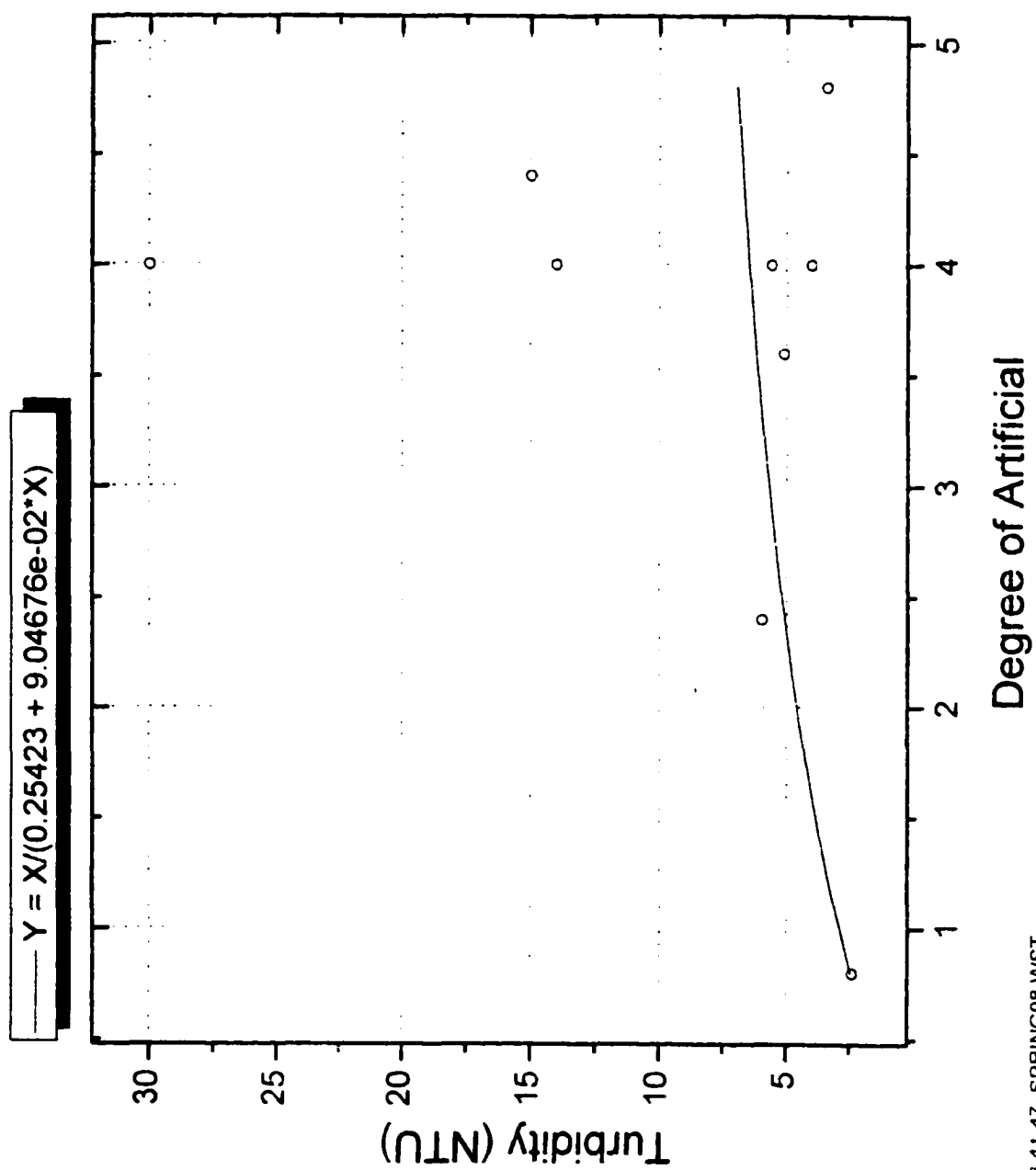
Variable: Carlson Trophic Inde
Independent variable: Degree of Artificial

	N	A	B	R	R square
$Y = A + B \cdot X$	9	53.7715	0.40801	0.03216	0.00103
$Y = A \cdot X^B$	9	52.9868	1.55201e-03	0.00281	7.90576e-06
$Y = A \cdot \exp(B \cdot X)$	9	54.4777	-7.29363e-03	-0.02902	8.42558e-04
$Y = A + B \cdot \log(X)$	9	53.0853	1.82663	0.06555	0.00429
$Y = A + B/X$	9	56.7457	-4.05656	-0.08711	0.00758
$Y = 1/(A + B \cdot X)$	9	1.80917e-02	4.48148e-04	0.08449	0.00713
$Y = X/(A + B \cdot X)$	9	-6.04118e-04	1.99120e-02	0.03102	9.62482e-04



Variable: Turbidity (NTU)
Independent variable: Degree of Artificial

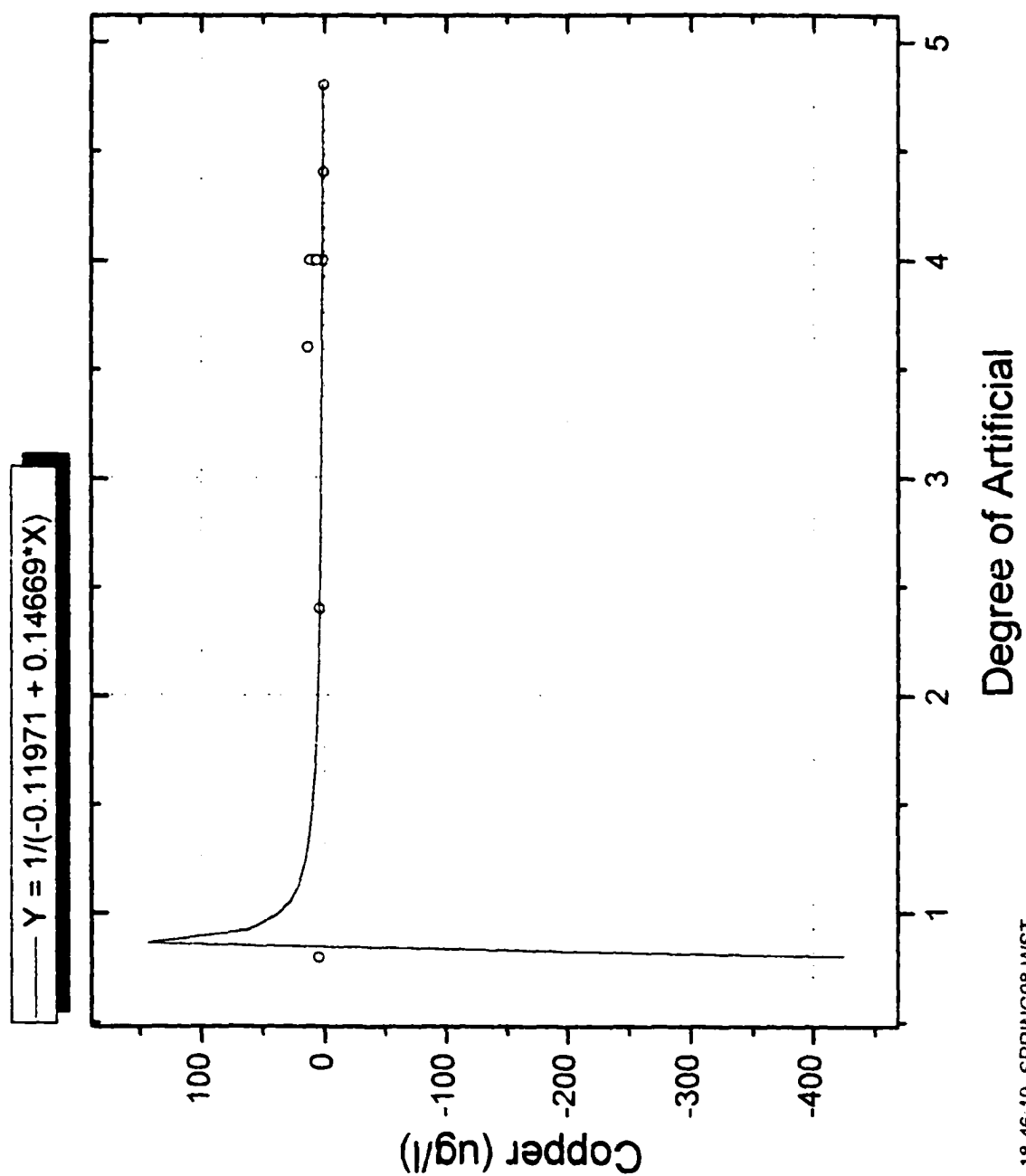
	N	A	B	R	R square
$Y = A + B \cdot X$	9	1.36944	2.28672	0.31401	0.0986
$Y = A \cdot X^B$	9	3.02823	0.70339	0.48002	0.23042
$Y = A \cdot \exp(B \cdot X)$	9	2.46570	0.28922	0.43359	0.188
$Y = A + B \cdot \log(X)$	9	3.33255	5.27200	0.32955	0.1086
$Y = A + B/X$	9	12.7432	-8.63572	-0.32299	0.10432
$Y = 1/(A + B \cdot X)$	9	0.38555	-5.61398e-02	-0.56052	0.31418
$Y = X/(A + B \cdot X)$	9	0.25423	9.04676e-02	0.69137	0.478



4/8/01 18:41.47 SPRING98.WST

Variable: Copper (ug/l)
Independent variable: Degree of Artificial

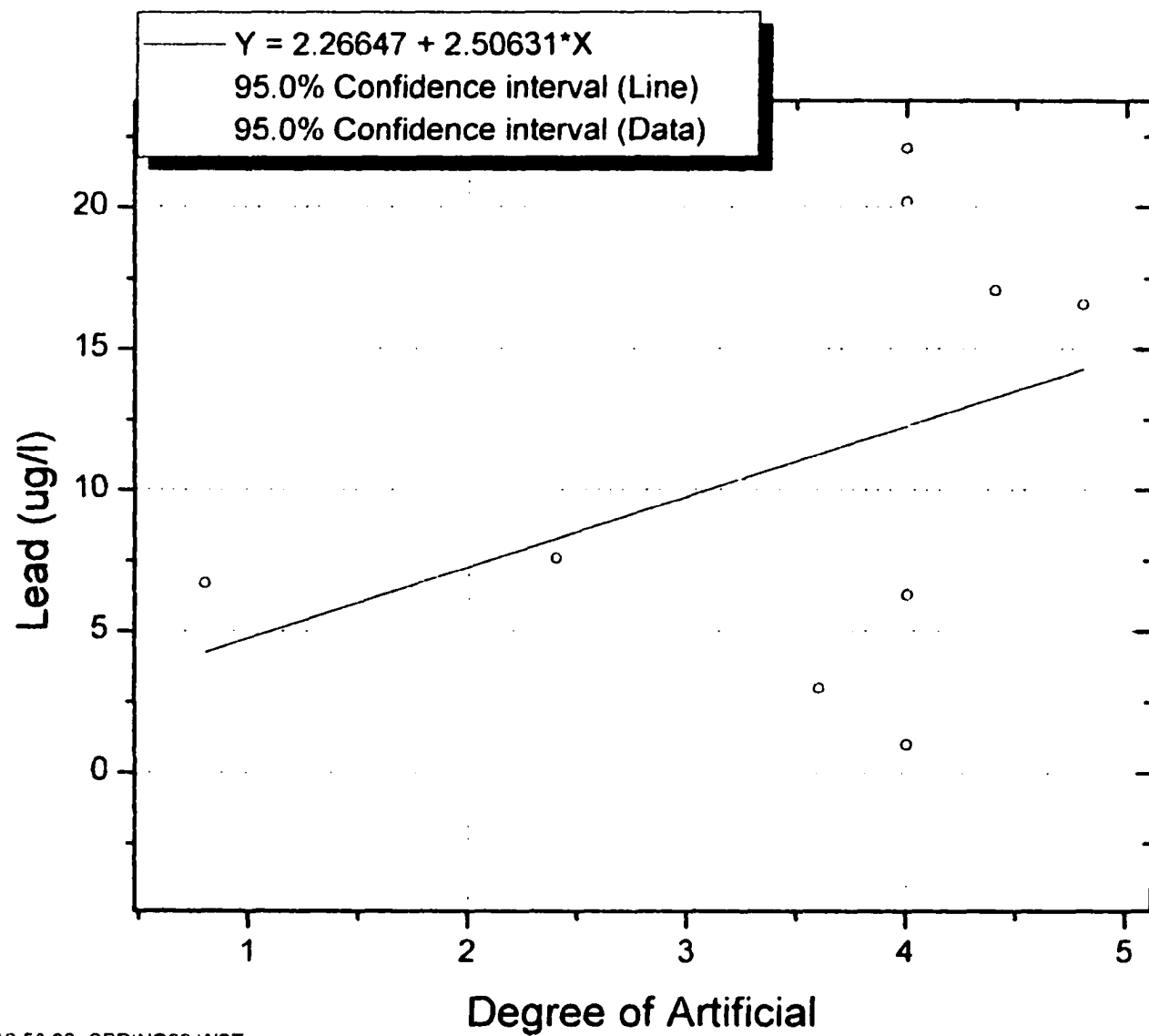
	N	A	B	R	R square
$Y = A + B \cdot X$	9	6.89941	-0.23108	-0.05829	0.00339
$Y = A \cdot X^B$	9	6.11894	-0.35310	-0.18597	0.03458
$Y = A \cdot \text{EXP}(B \cdot X)$	9	9.58866	-0.24251	-0.28058	0.07872
$Y = A + B \cdot \text{LOG}(X)$	9	5.86109	0.18522	0.02127	4.52436e-04
$Y = A + B/X$	9	6.43541	-0.95226	-0.06542	0.00428
$Y = 1/(A + B \cdot X)$	9	-0.11971	0.14669	0.44874	0.20137
$Y = X/(A + B \cdot X)$	9	-0.31144	0.51884	0.25949	0.06733



4/8/01 18 46 19 SPRING98.WST

Variable: Lead (ug/l)
Independent variable: Degree of Artificial

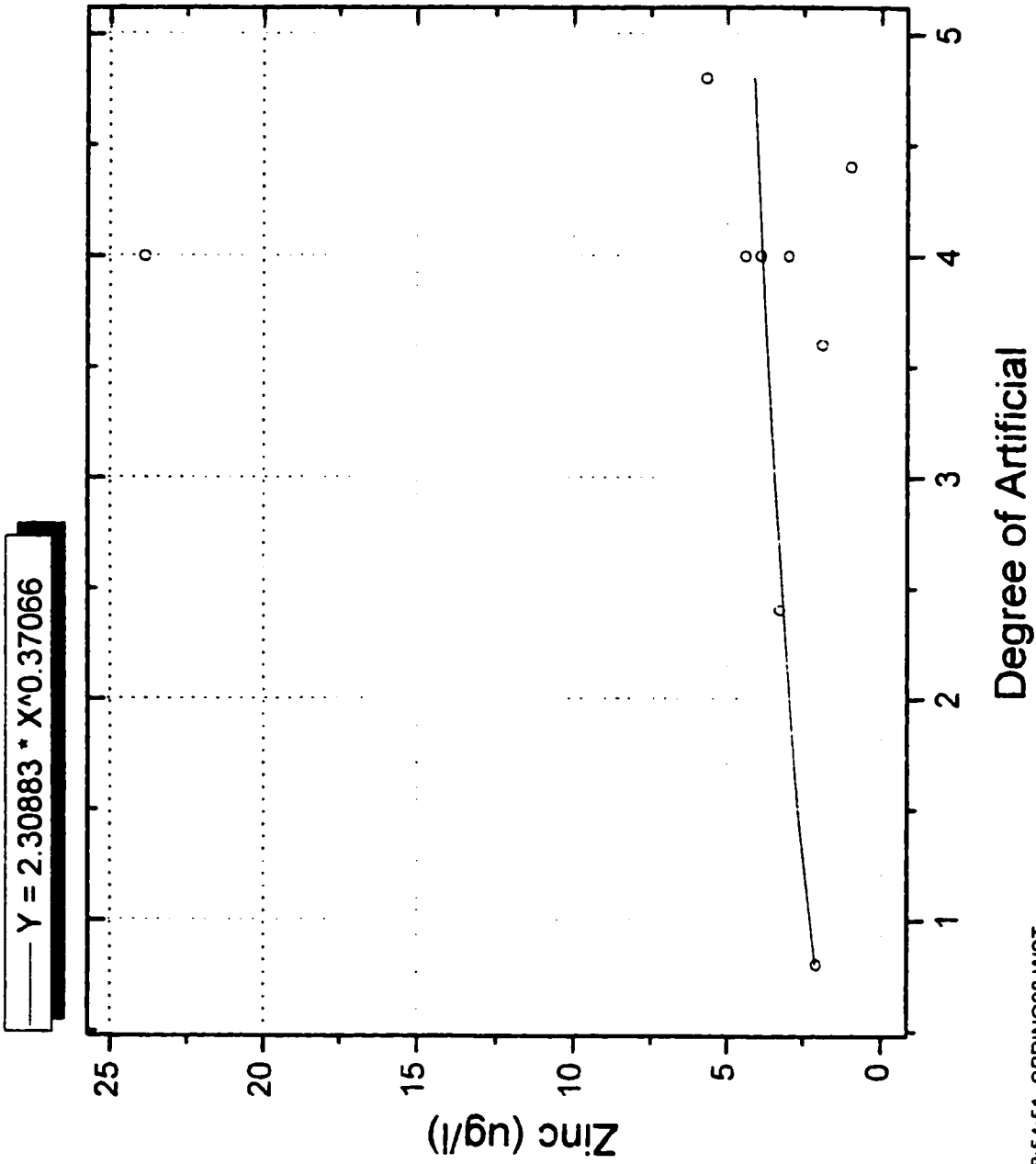
	N	A	B	R	R square
* $Y = A + B \cdot X$	9	2.26647	2.50631	0.39102	0.15289
$Y = A \cdot X^B$	9	5.96705	0.24152	0.13149	0.01729
$Y = A \cdot \exp(B \cdot X)$	9	4.52140	0.15749	0.18836	0.03548
$Y = A + B \cdot \log(X)$	9	5.78372	4.61089	0.32747	0.10723
$Y = A + B/X$	9	13.5698	-6.36931	-0.27065	0.07325
$Y = 1/(A + B \cdot X)$	9	0.18125	1.10951e-02	0.04437	0.00196
$Y = X/(A + B \cdot X)$	9	-8.19061e-02	0.25146	0.08922	0.00796



Variable: Zinc (ug/l)

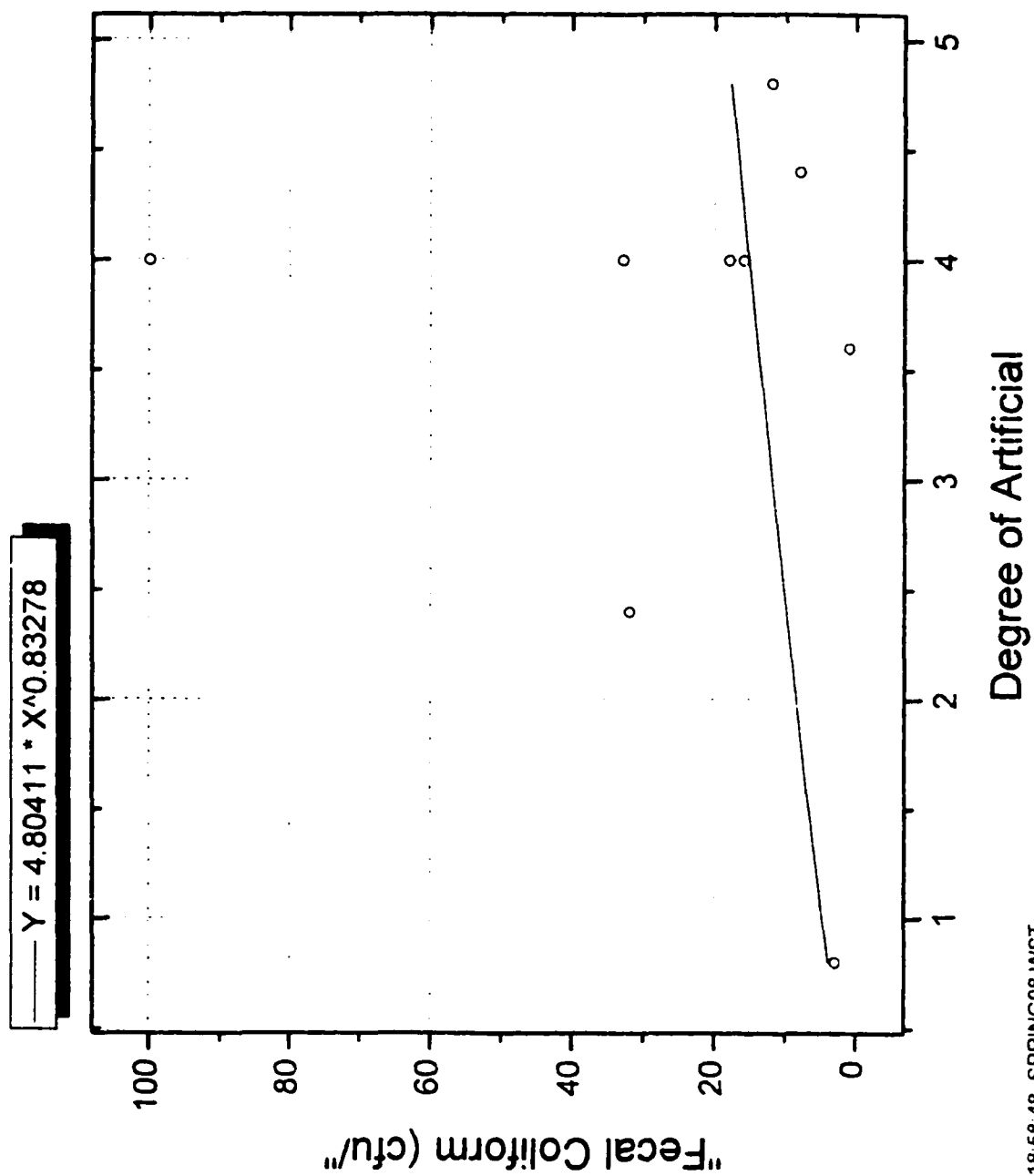
Independent variable: Degree of Artificial

	N	A	B	R	R square
$Y = A + B \cdot X$	9	1.29258	1.17396	0.20363	0.04146
$Y = A \cdot X^B$	9	2.30883	0.37066	0.23418	0.05484
$Y = A \cdot \exp(B \cdot X)$	9	2.00750	0.16128	0.22385	0.0501
$Y = A + B \cdot \log(X)$	9	2.39586	2.62495	0.20727	0.04296
$Y = A + B/X$	9	7.04471	-4.20183	-0.19852	0.03941
$Y = 1/(A + B \cdot X)$	9	0.42879	-1.62293e-02	-0.0715	0.00511
$Y = X/(A + B \cdot X)$	9	0.10341	0.33225	0.1241	0.0154



Variable: Fecal Coliform (cfu/
Independent variable: Degree of Artificial

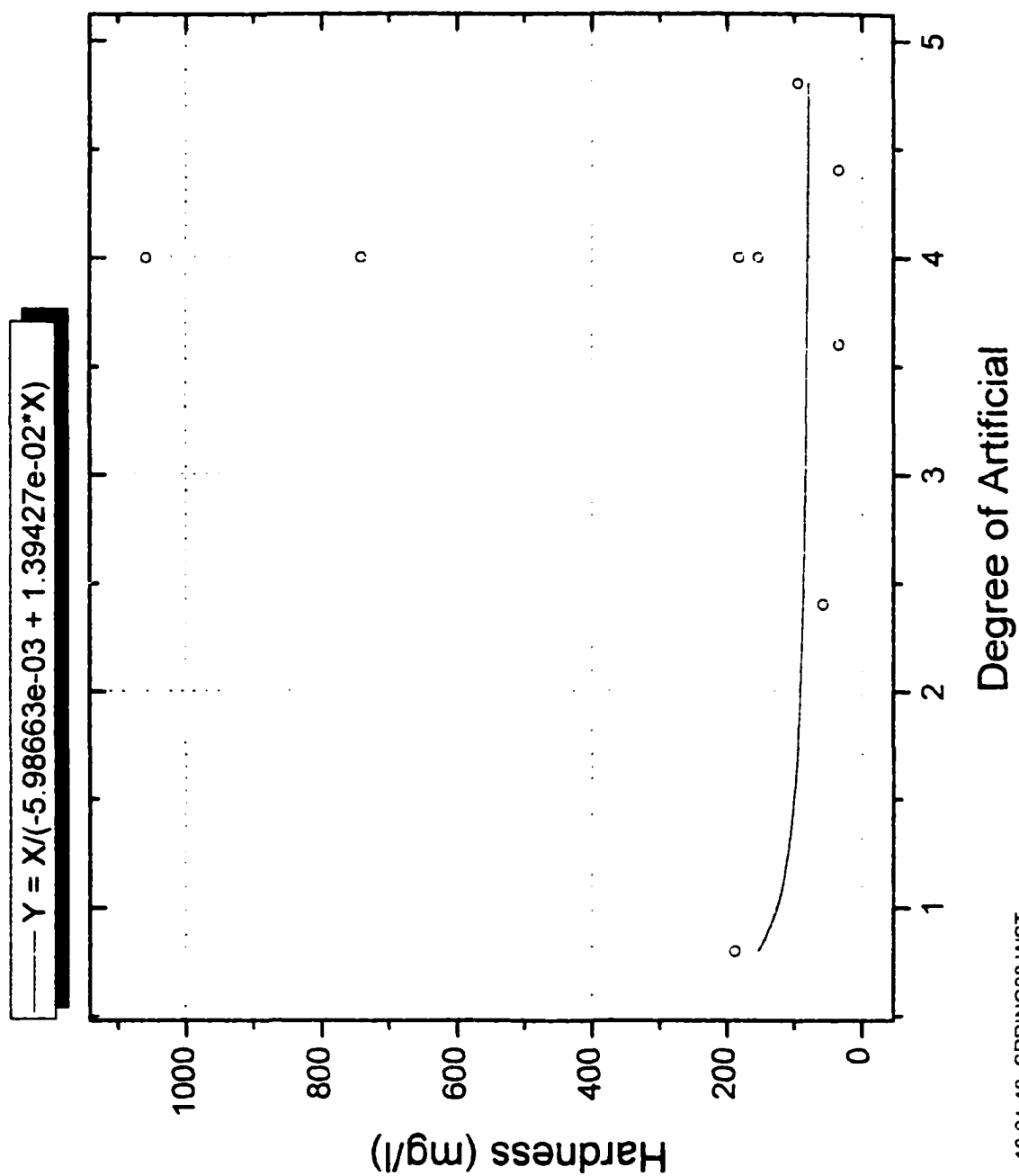
	N	A	B	R	R square
$Y = A + B \cdot X$	9	9.72997	4.23220	0.17046	0.02905
$Y = A \cdot X^B$	9	4.80411	0.83278	0.3393	0.11512
$Y = A \cdot \exp(B \cdot X)$	9	3.96066	0.32830	0.29383	0.08634
$Y = A + B \cdot \log(X)$	9	10.6732	12.0567	0.22106	0.04887
$Y = A + B/X$	9	33.3632	-22.8604	-0.25079	0.06289
$Y = 1/(A + B \cdot X)$	9	0.37946	-5.26233e-02	-0.20244	0.04098
$Y = X/(A + B \cdot X)$	9	0.16044	0.13210	0.16812	0.02826



4/8/01 18:58:48 SPRING98.WST

Variable: Hardness (mg/l)
Independent variable: Degree of Artificial

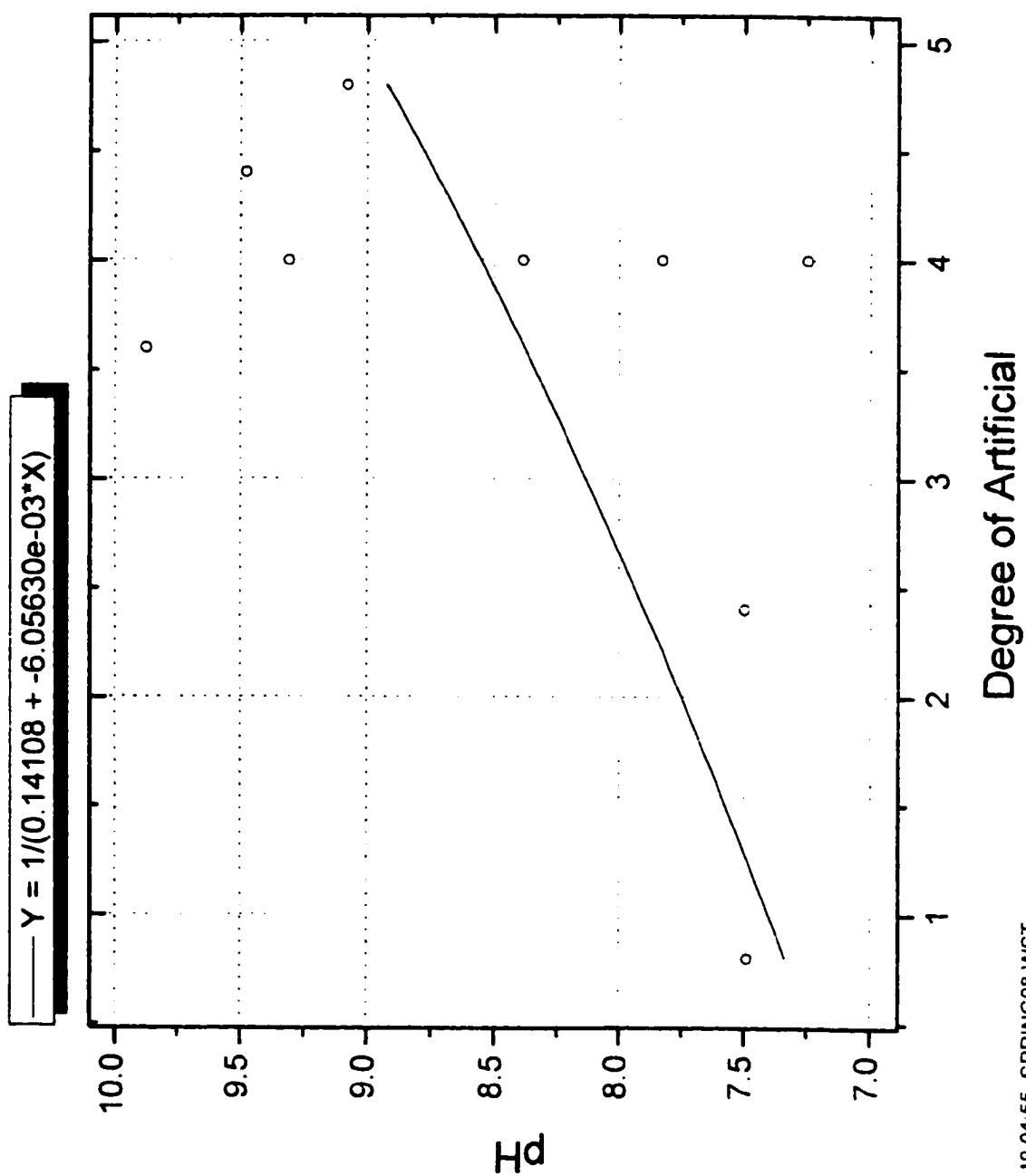
	N	A	B	R	R square
$Y = A + B \cdot X$	9	131.344	42.7782	0.14388	0.0207
$Y = A \cdot X^B$	9	146.217	-9.47478e-03	-0.00432	1.87413e-05
$Y = A \cdot \exp(B \cdot X)$	9	133.059	2.34034e-02	0.02349	5.51789e-04
$Y = A + B \cdot \log(X)$	9	172.534	94.8076	0.14516	0.02107
$Y = A + B/X$	9	336.446	-141.127	-0.12929	0.01671
$Y = 1/(A + B \cdot X)$	9	8.62465e-03	8.63352e-04	0.09641	0.00929
$Y = X/(A + B \cdot X)$	9	-5.98663e-03	1.39427e-02	0.18209	0.03315



4/8/01 19:01:48 SPRING98.WST

Variable: pH
Independent variable: Degree of Artificial

	N	A	B	R	R square
$Y = A + B \cdot X$	9	6.98199	0.41787	0.51491	0.26514
$Y = A \cdot X^B$	9	7.46412	0.10261	0.48713	0.23729
$Y = A \cdot \exp(B \cdot X)$	9	7.04005	5.02125e-02	0.52364	0.2742
$Y = A + B \cdot \log(X)$	9	7.48550	0.85675	0.48057	0.23095
$Y = A + B/X$	9	8.95296	-1.29187	-0.43357	0.18799
$Y = 1/(A + B \cdot X)$	9	0.14108	-6.05630e-03	-0.53084	0.2818
$Y = X/(A + B \cdot X)$	9	1.85224e-02	0.11259	0.4422	0.19554

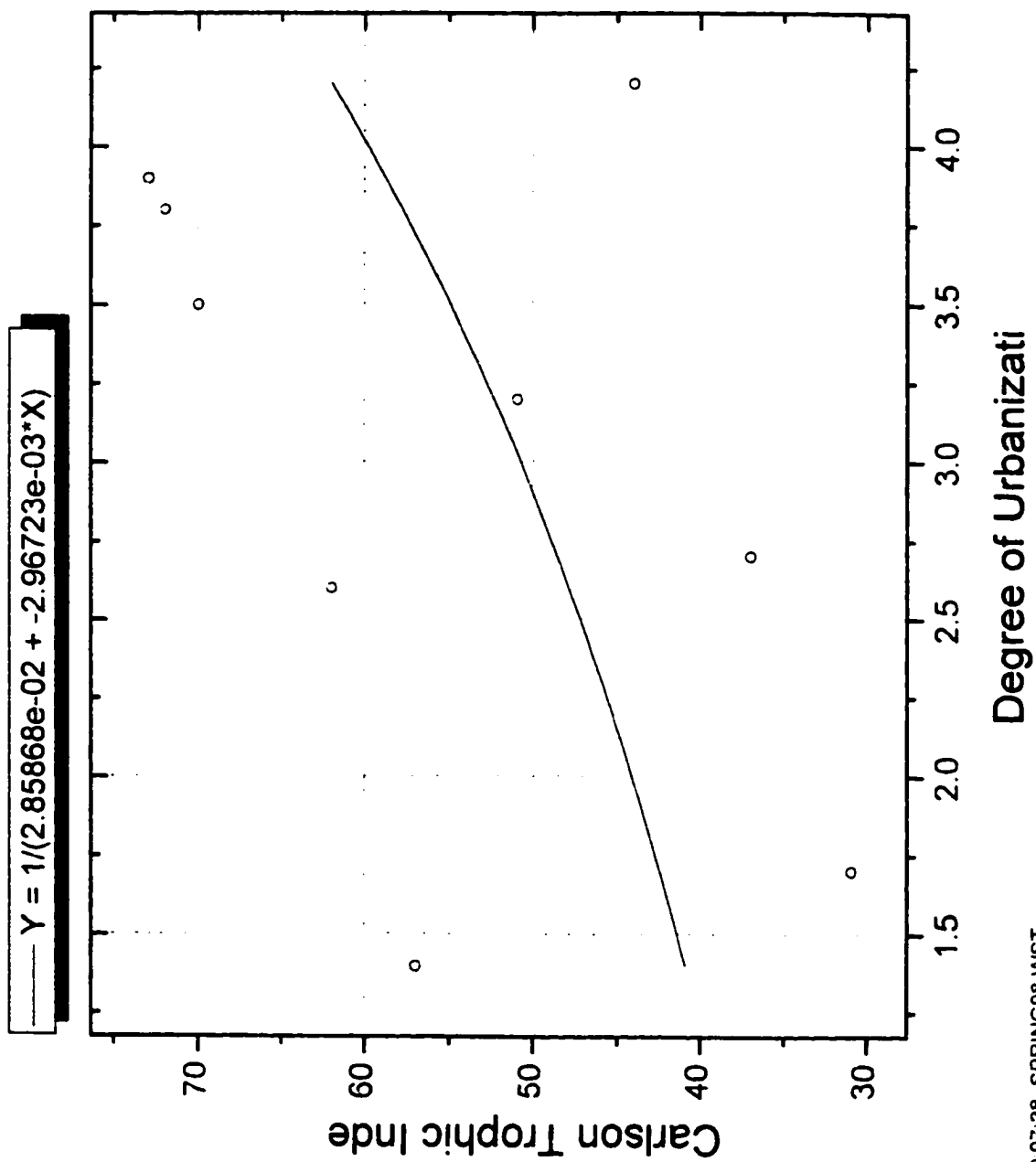


4/8/01 19:04:55 SPRING98 WST

SPRING98.WST:Simple regression

Variable: Carlson Trophic Inde
 Independent variable: Degree of Urbanizati

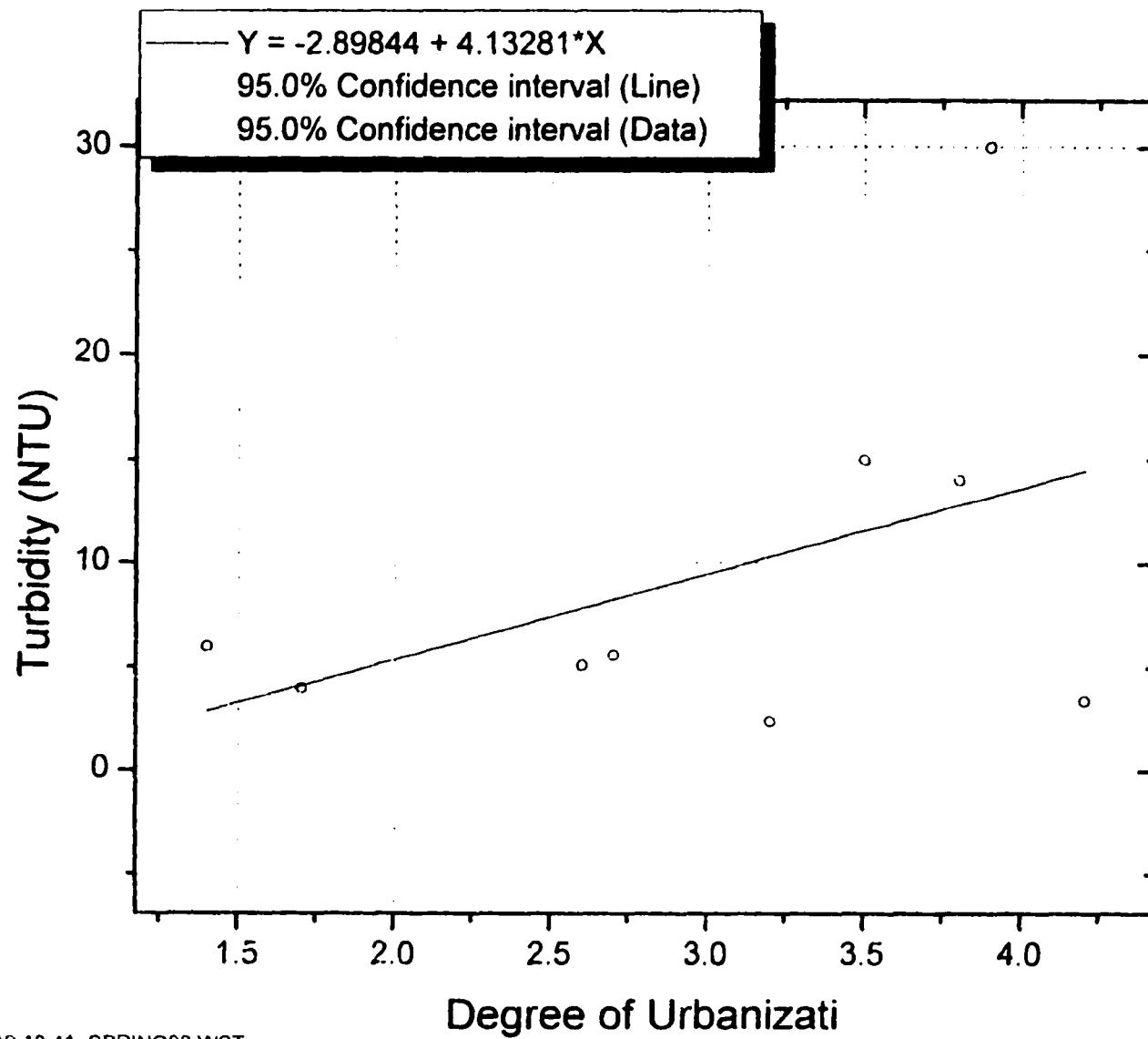
	N	A	B	R	R square
$Y = A + B \cdot X$	9	34.1675	7.01823	0.443	0.19625
$Y = A \cdot X^B$	9	37.2122	0.34145	0.42469	0.18036
$Y = A \cdot \exp(B \cdot X)$	9	34.9873	0.13895	0.44274	0.19602
$Y = A + B \cdot \log(X)$	9	37.2546	17.2713	0.42557	0.18111
$Y = A + B/X$	9	69.0117	-36.3584	-0.38641	0.14931
$Y = 1/(A + B \cdot X)$	9	2.85868e-02	-2.96723e-03	-0.44789	0.20061
$Y = X/(A + B \cdot X)$	9	1.52252e-02	1.39108e-02	0.38695	0.14973



4/8/01 19:07:38 SPRING98.WST

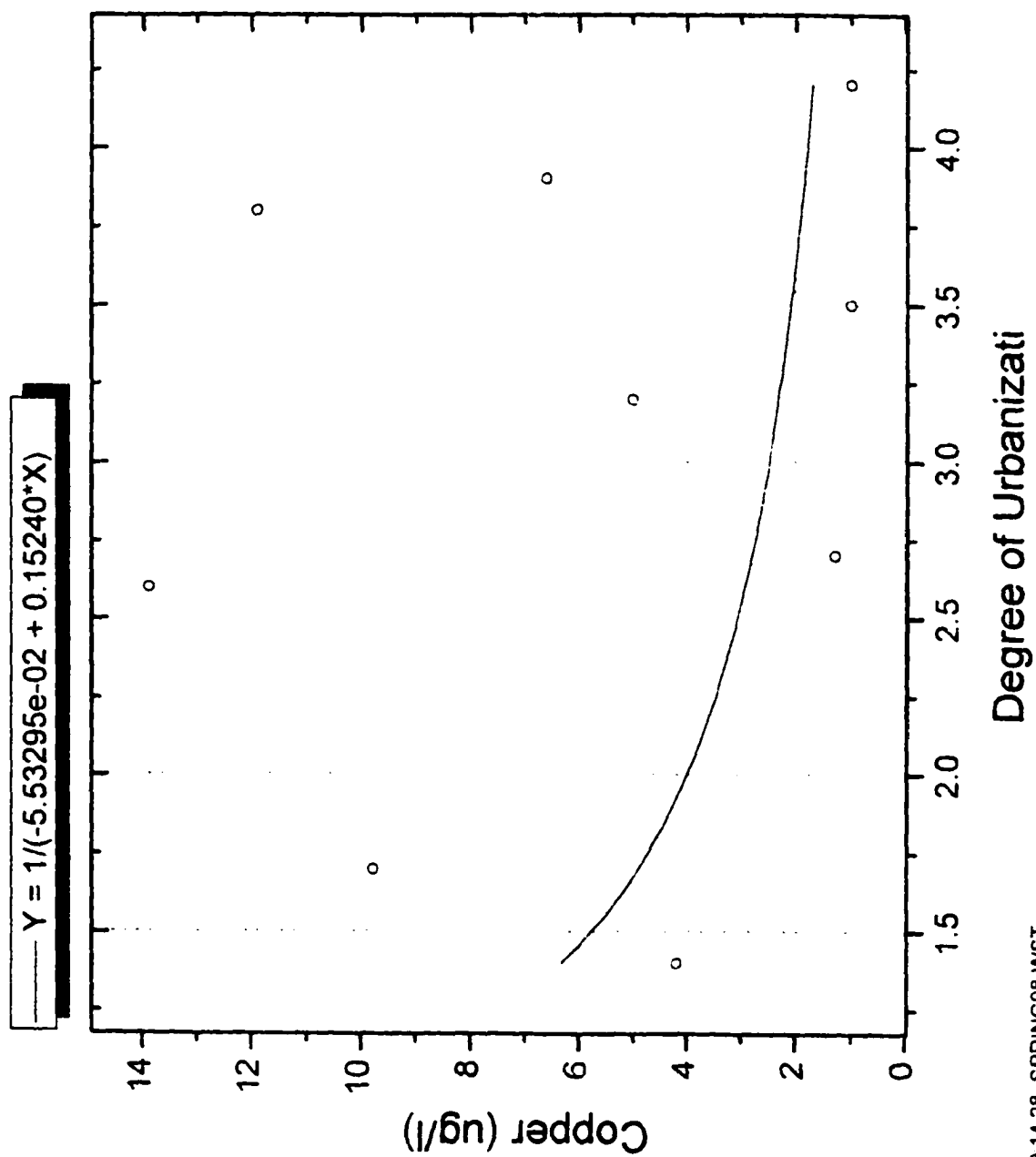
Variable: Turbidity (NTU)
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
* Y = A + B*X	9	-2.89844	4.13281	0.45434	0.20643
Y = A * X^B	9	3.24663	0.72403	0.33922	0.11507
Y = A * EXP(B*X)	9	2.77245	0.30370	0.3645	0.13286
Y = A + B*LOG(X)	9	-0.82153	9.92154	0.42578	0.18129
Y = A + B/X	9	17.3929	-20.8110	-0.38522	0.14839
Y = 1/(A + B*X)	9	0.25115	-2.17342e-02	-0.17373	0.03018
Y = X/(A + B*X)	9	8.99093e-02	0.15184	0.121	0.01464



Variable: Copper (ug/l)
Independent variable: Degree of Urbanizati

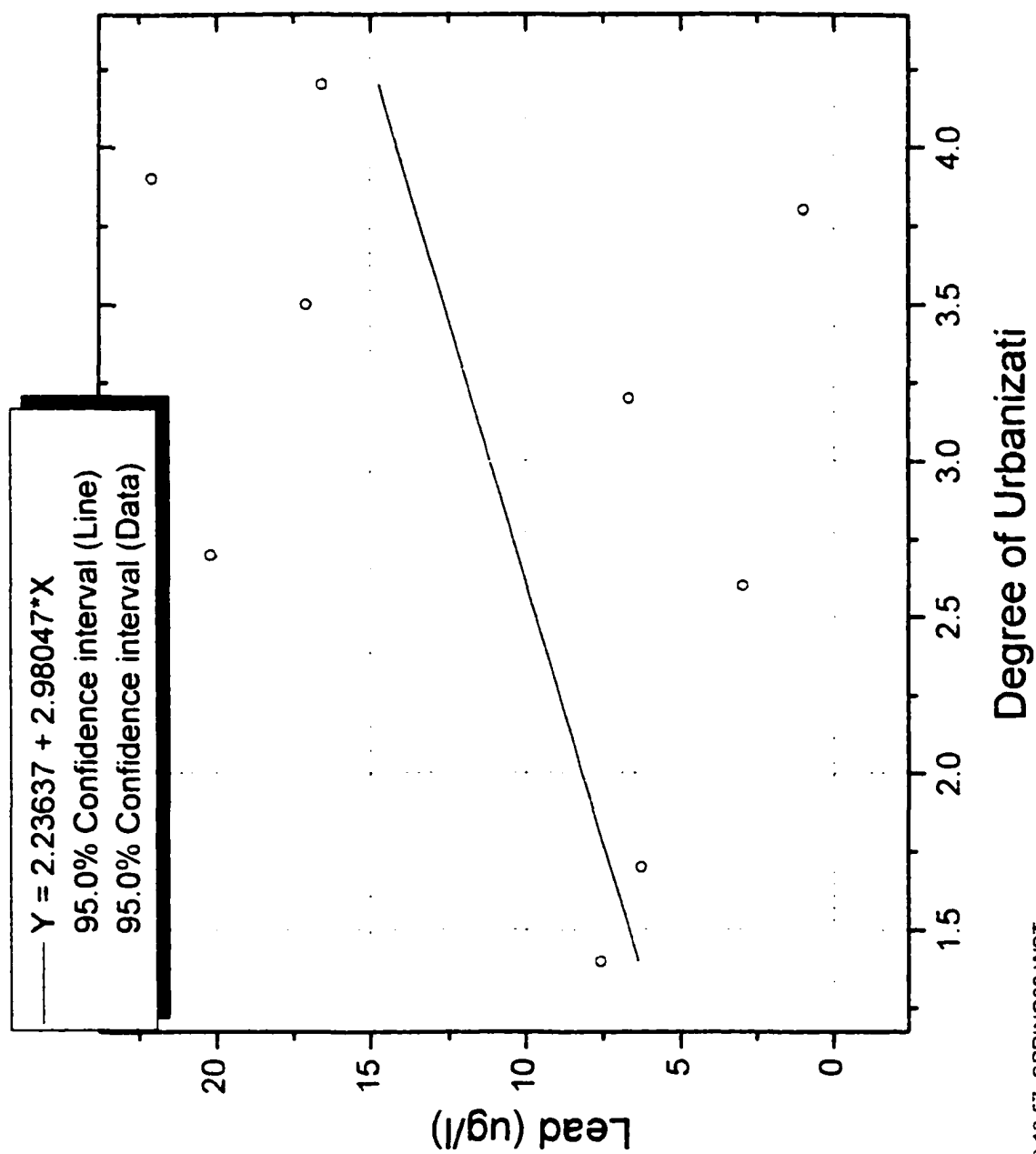
	N	A	B	R	R square
$Y = A + B \cdot X$	9	8.90981	-0.94401	-0.19065	0.03634
$Y = A \cdot X^B$	9	8.82229	-0.74878	-0.27074	0.0733
$Y = A \cdot \exp(B \cdot X)$	9	10.3104	-0.31161	-0.28863	0.08331
$Y = A + B \cdot \log(X)$	9	8.16365	-2.00504	-0.15807	0.02498
$Y = A + B/X$	9	4.75958	3.47585	0.11818	0.01396
$Y = 1/(A + B \cdot X)$	9	-5.53295e-02	0.15240	0.37323	0.1393
$Y = X/(A + B \cdot X)$	9	-0.83504	0.71857	0.34433	0.11856



4/8/01 19 14 28 SPRING98.WST

Variable: Lead (ug/l)
Independent variable: Degree of Urbanizati

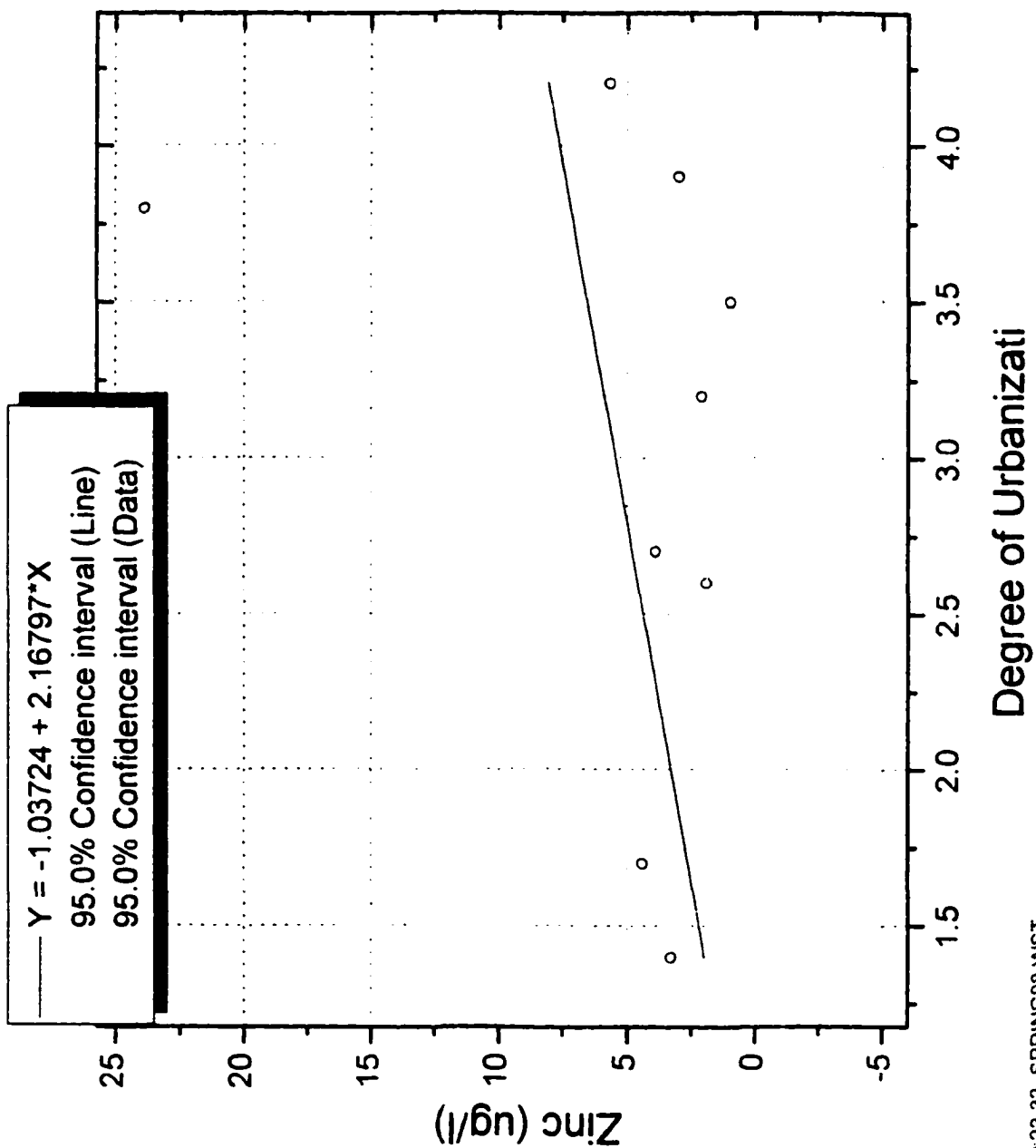
	N	A	B	R	R square
* $Y = A + B \cdot X$	9	2.23637	2.98047	0.37227	0.13858
$Y = A \cdot X^B$	9	5.85972	0.28904	0.10803	0.01167
$Y = A \cdot \exp(B \cdot X)$	9	5.40121	0.12739	0.12197	0.01487
$Y = A + B \cdot \log(X)$	9	3.51085	7.36981	0.35933	0.12912
$Y = A + B/X$	9	17.3139	-18.1789	-0.34025	0.11577
$Y = 1/(A + B \cdot X)$	9	6.17066e-02	5.30004e-02	0.16971	0.0288
$Y = X/(A + B \cdot X)$	9	-0.30777	0.33743	0.16593	0.02753



4/8/01 19:18:57 SPRING98.WST

Variable: Zinc (ug/l)
Independent variable: Degree of Urbanizati

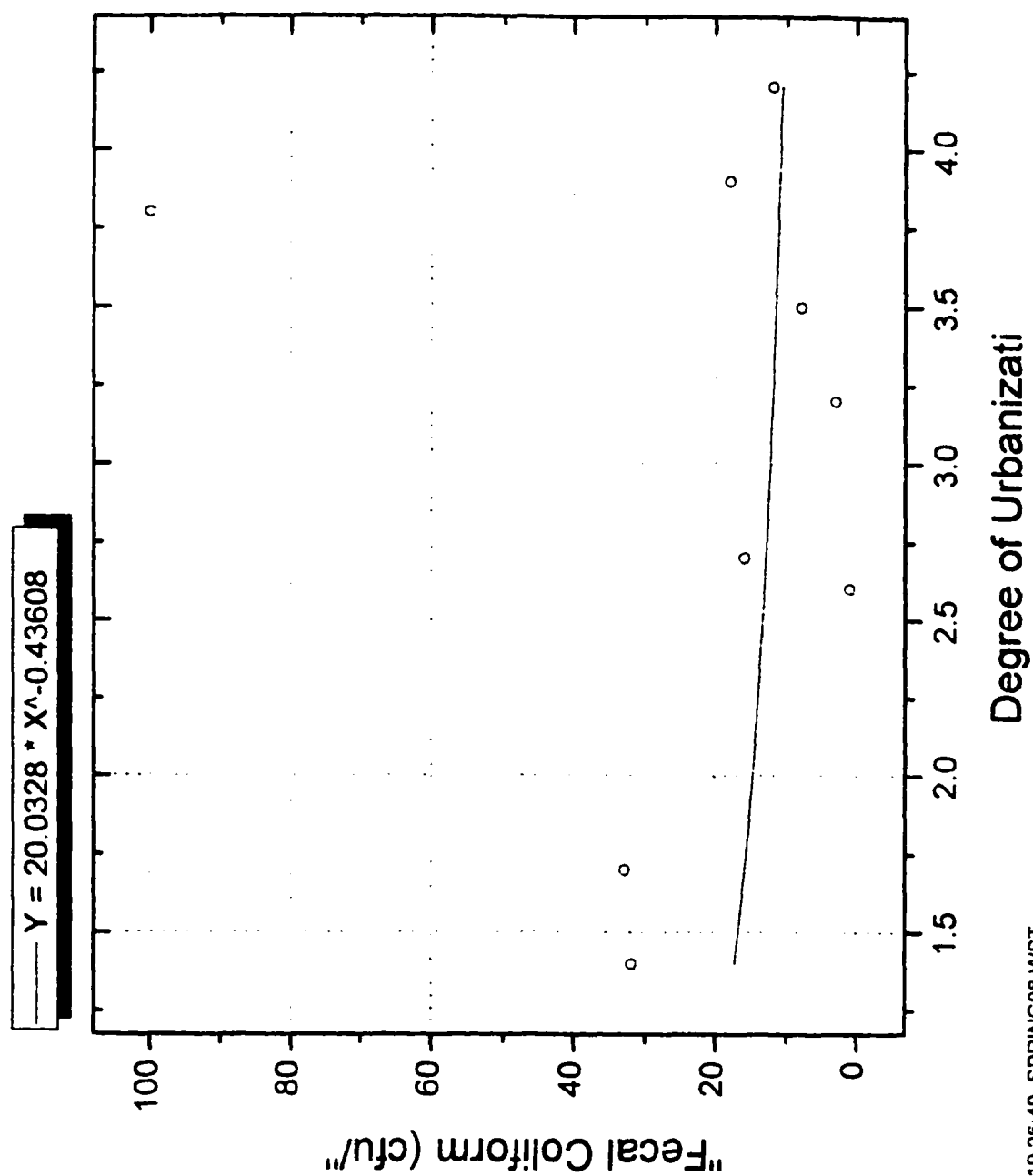
	N	A	B	R	R square
* Y = A + B*X	9	-1.03724	2.18797	0.30107	0.09084
Y = A * X^B	9	2.60548	0.30062	0.13039	0.017
Y = A * EXP(B*X)	9	2.17460	0.16450	0.18278	0.03341
Y = A + B*LOG(X)	9	0.29707	4.96925	0.26938	0.07257
Y = A + B/X	9	9.26655	-10.0191	-0.23427	0.05488
Y = 1/(A + B*X)	9	0.34316	9.30792e-03	0.03283	0.00107
Y = X/(A + B*X)	9	-0.21297	0.45186	0.12648	0.01599



4/8/01 19:22:32 SPRING98.WST

Variable: Fecal Coliform (cfu/
Independent variable: Degree of Urbanizati

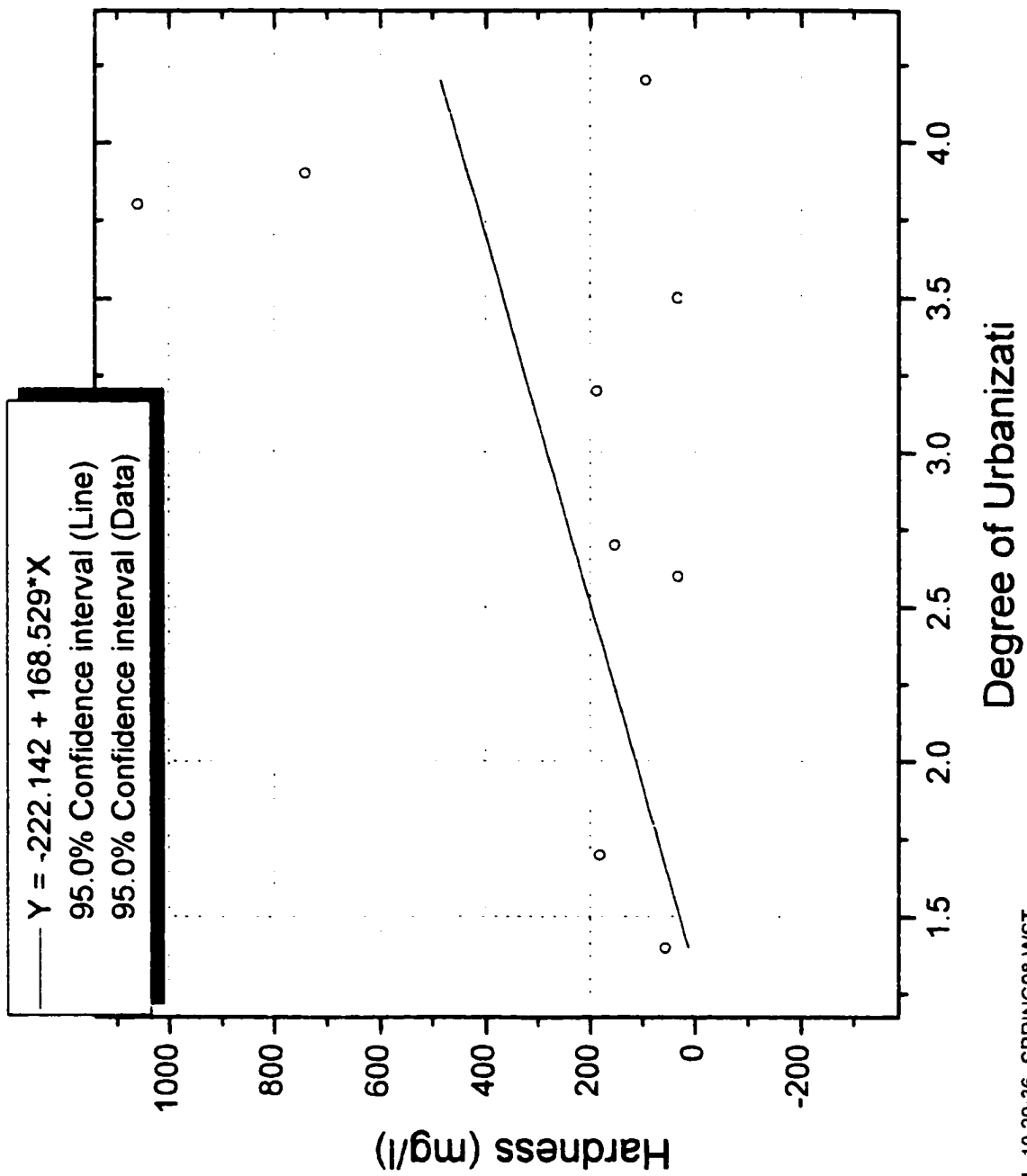
	N	A	B	R	R square
$Y = A + B \cdot X$	9	18.5668	2.07031	0.06676	0.00445
$Y = A \cdot X^B$	9	20.0328	-0.43608	-0.12198	0.01487
$Y = A \cdot \exp(B \cdot X)$	9	14.8536	-5.15120e-02	-0.03691	0.00136
$Y = A + B \cdot \log(X)$	9	23.1197	1.59384	0.02008	4.02537e-04
$Y = A + B/X$	9	23.0099	4.66133	0.0253	6.40544e-04
$Y = 1/(A + B \cdot X)$	9	0.27868	-2.87731e-02	-0.06861	0.00785
$Y = X/(A + B \cdot X)$	9	-0.14744	0.24828	0.07646	0.00584



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Variable: Hardness (mg/l)
Independent variable: Degree of Urbanizati

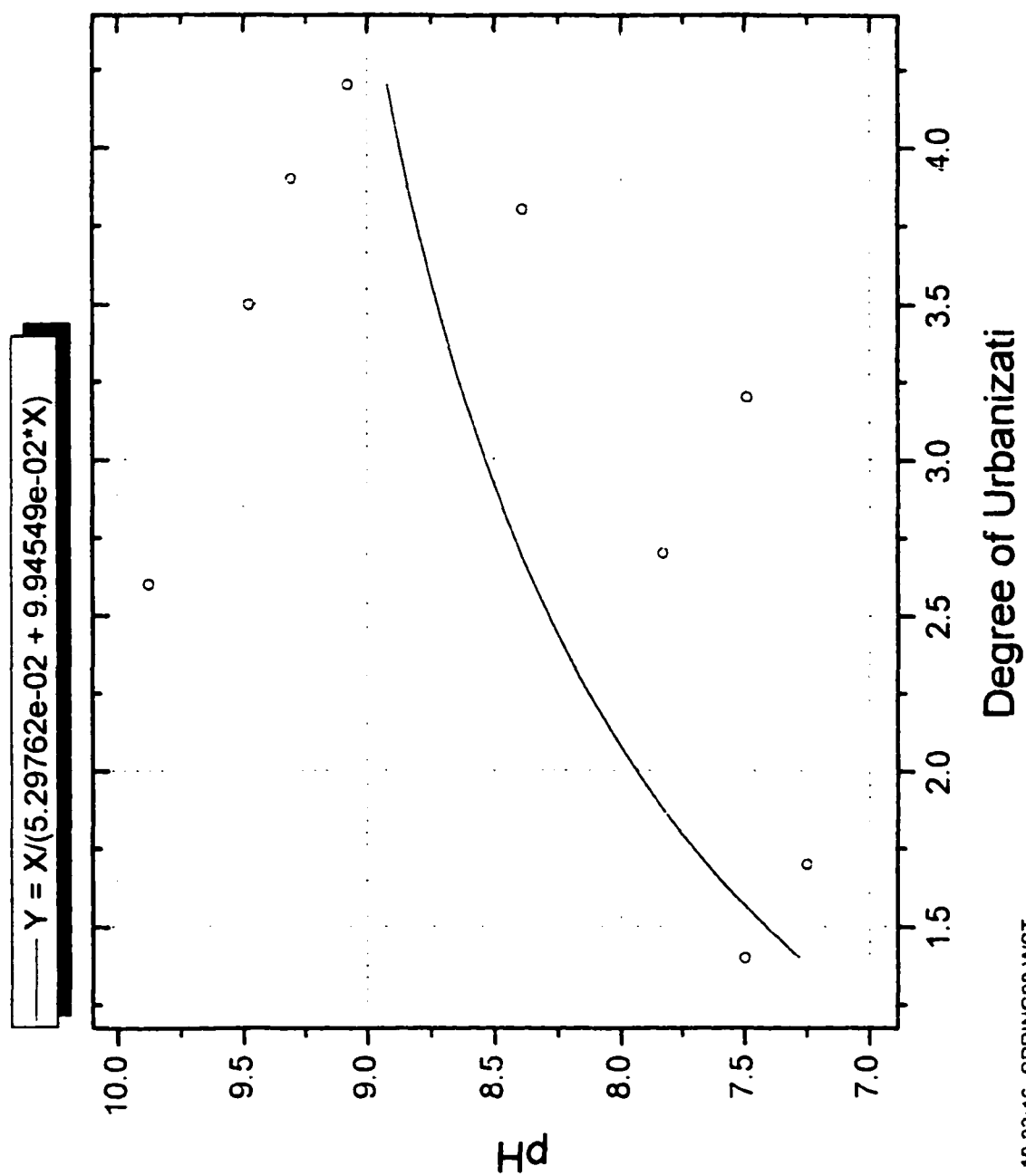
	N	A	B	R	R square
$Y = A + B \cdot X$	9	-222.142	168.529	0.45382	0.20595
$Y = A \cdot X^B$	9	44.7477	1.12751	0.35368	0.12508
$Y = A \cdot \exp(B \cdot X)$	9	35.1709	0.47126	0.37868	0.1434
$Y = A + B \cdot \log(X)$	9	-138.063	405.173	0.42591	0.1814
$Y = A + B/X$	9	809.288	-859.145	-0.38954	0.15174
$Y = 1/(A + B \cdot X)$	9	1.89002e-02	-2.40196e-03	-0.21474	0.04611
$Y = X/(A + B \cdot X)$	9	1.02462e-02	7.80831e-03	0.15424	0.02379



Variable: pH

Independent variable: Degree of Urbanizati

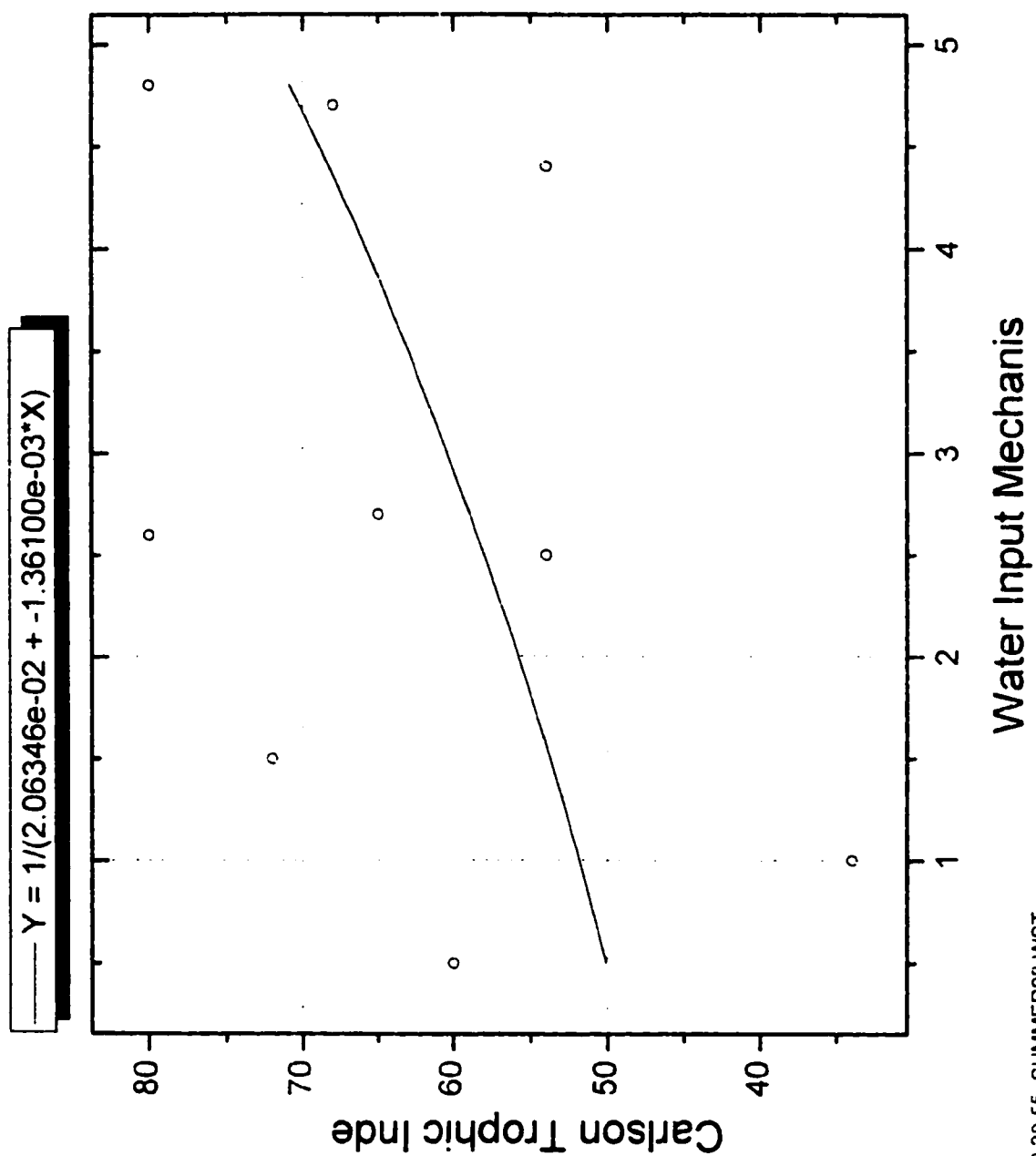
	N	A	B	R	R square
$Y = A + B \cdot X$	9	6.71036	0.58580	0.5779	0.33397
$Y = A \cdot X^B$	9	6.92533	0.18740	0.61078	0.37306
$Y = A \cdot \exp(B \cdot X)$	9	6.78512	7.18056e-02	0.5995	0.3594
$Y = A + B \cdot \log(X)$	9	6.87138	1.53453	0.59094	0.34921
$Y = A + B/X$	9	9.81909	-3.56297	-0.59181	0.35024
$Y = 1/(A + B \cdot X)$	9	0.14603	-8.83052e-03	-0.61967	0.38399
$Y = X/(A + B \cdot X)$	9	5.29762e-02	9.94549e-02	0.62593	0.3918



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Variable: Carlson Trophic Inde
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	52.8801	3.68741	0.40494	0.16398
$Y = A \cdot X^B$	9	54.6455	0.14292	0.41399	0.17139
$Y = A \cdot \exp(B \cdot X)$	9	50.7326	6.85901e-02	0.41432	0.17166
$Y = A + B \cdot \log(X)$	9	58.7798	7.80217	0.41086	0.16881
$Y = A + B/X$	9	68.1135	-8.41340	-0.33562	0.11264
$Y = 1/(A + B \cdot X)$	9	2.06346e-02	-1.36100e-03	-0.41859	0.17522
$Y = X/(A + B \cdot X)$	9	2.74240e-03	1.52327e-02	0.30638	0.09387

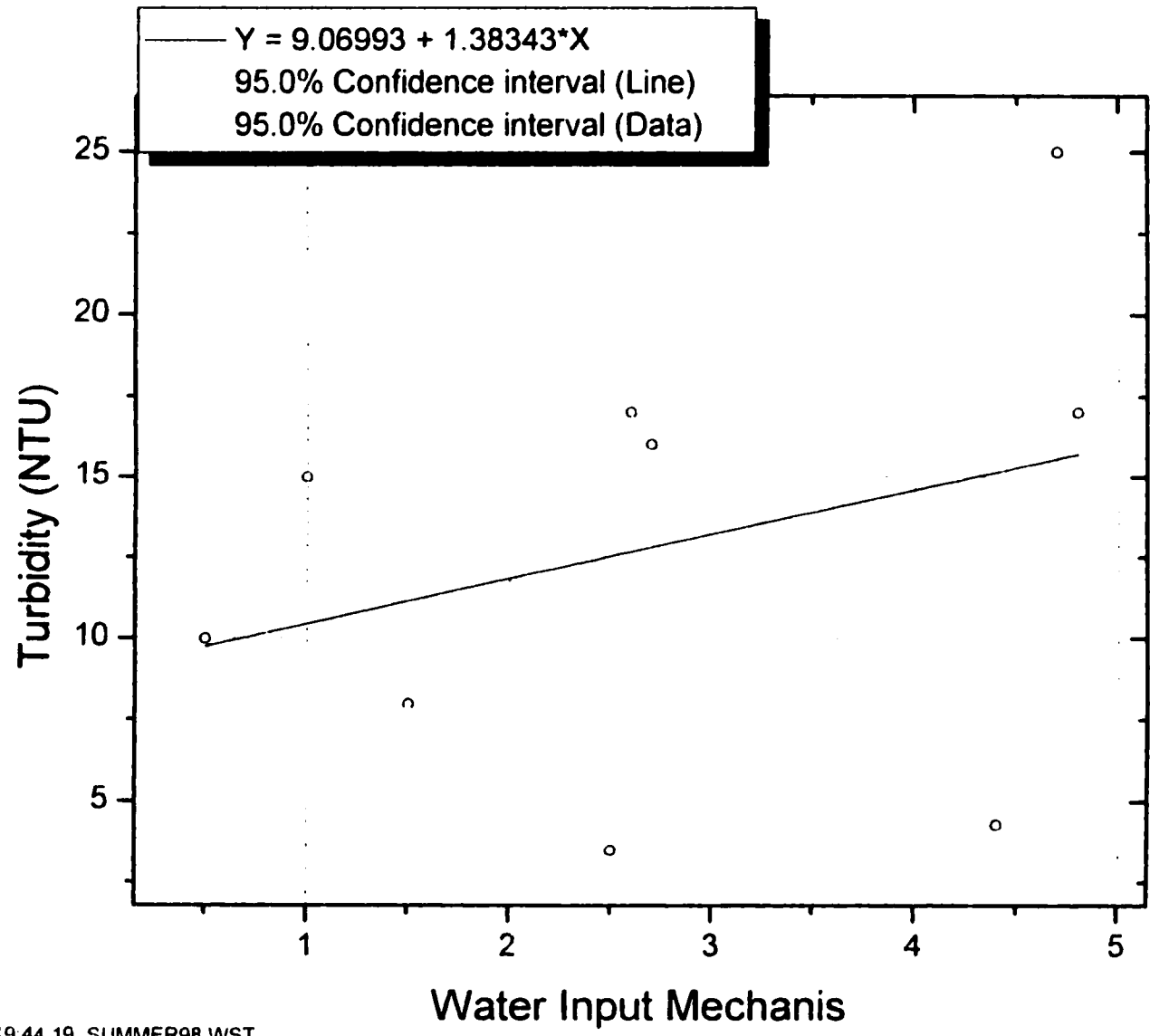


4/8/01 19:39:55 SUMMER98.WST

Variable: Turbidity (NTU)

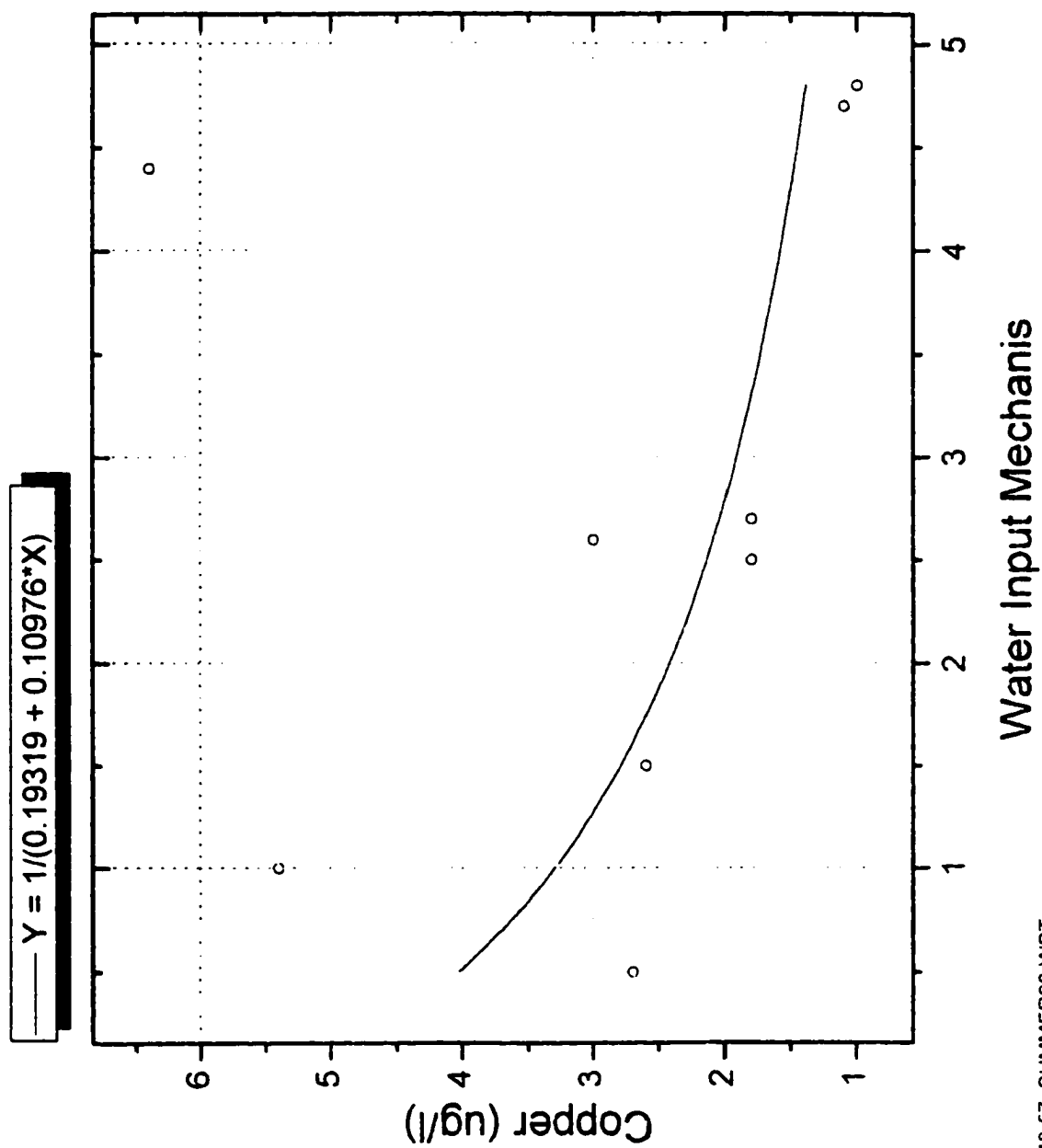
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	9.06993	1.38343	0.31769	0.10092
$Y = A \cdot X^B$	9	10.2553	7.09625e-02	0.08129	0.0066
$Y = A \cdot \exp(B \cdot X)$	9	9.22350	5.92531e-02	0.14156	0.02003
$Y = A + B \cdot \log(X)$	9	10.9961	2.34627	0.25836	0.06675
$Y = A + B/X$	9	14.2922	-2.34546	-0.19565	0.03827
$Y = 1/(A + B \cdot X)$	9	0.11355	3.28652e-04	0.00605	3.67156e-05
$Y = X/(A + B \cdot X)$	9	-1.56686e-02	0.12397	0.10493	0.01101



Variable: Copper (ug/l)
Independent variable: Water Input Mechanis

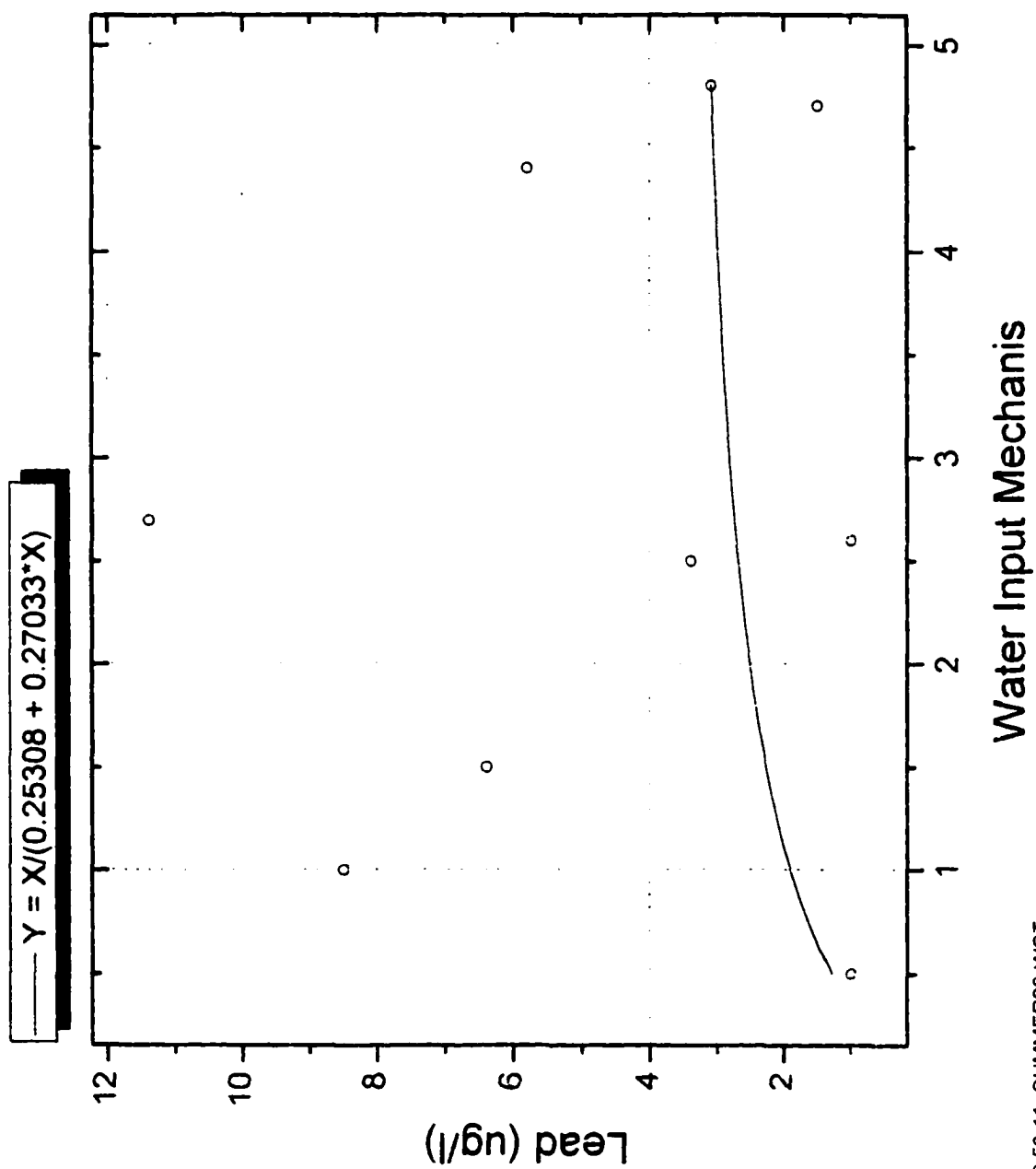
	N	A	B	R	R square
$Y = A + B \cdot X$	9	3.51812	-0.23737	-0.20348	0.0414
$Y = A \cdot X^B$	9	3.08575	-0.31779	-0.38391	0.14738
$Y = A \cdot \exp(B \cdot X)$	9	3.79037	-0.16725	-0.42136	0.17755
$Y = A + B \cdot \log(X)$	9	3.26055	-0.49405	-0.20308	0.04124
$Y = A + B/X$	9	2.57684	0.47685	0.14848	0.02204
$Y = 1/(A + B \cdot X)$	9	0.19319	0.10976	0.59471	0.35368
$Y = X/(A + B \cdot X)$	9	-0.19547	0.61324	0.3847	0.14799



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Variable: Lead (ug/l)
Independent variable: Water Input Mechanis

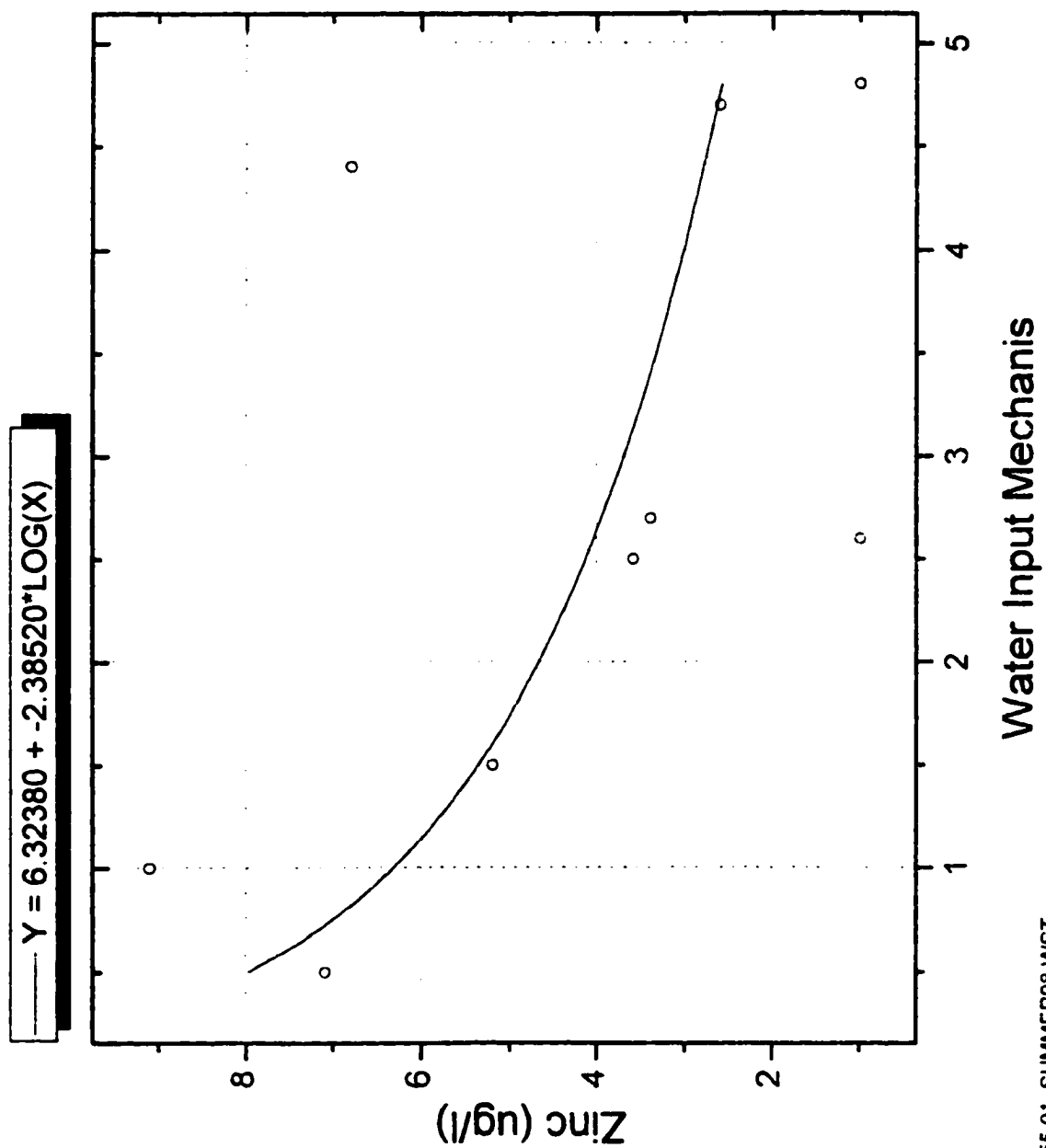
	N	A	B	R	R square
$Y = A + B \cdot X$	9	5.69661	-0.37123	-0.16381	0.02683
$Y = A \cdot X^B$	9	3.06554	0.12075	0.10158	0.01032
$Y = A \cdot \exp(B \cdot X)$	9	3.57140	-2.05729e-02	-0.03609	0.0013
$Y = A + B \cdot \log(X)$	9	4.76075	-0.10407	-0.02202	4.84909e-04
$Y = A + B/X$	9	5.25536	-0.95031	-0.15232	0.0232
$Y = 1/(A + B \cdot X)$	9	0.50609	-2.98567e-02	-0.12939	0.01674
$Y = X/(A + B \cdot X)$	9	0.25308	0.27033	0.39843	0.15874



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Variable: Zinc (ug/l)
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	7.24118	-1.02715	-0.58238	0.33916
$Y = A \cdot X^B$	9	5.67074	-0.61653	-0.58483	0.34202
$Y = A \cdot \exp(B \cdot X)$	9	7.36871	-0.27453	-0.54307	0.29493
$Y = A + B \cdot \log(X)$	9	6.32380	-2.38520	-0.64849	0.42055
$Y = A + B/X$	9	2.63214	2.94528	0.6066	0.36797
$Y = 1/(A + B \cdot X)$	9	0.11582	0.10138	0.45803	0.20979
$Y = X/(A + B \cdot X)$	9	-0.26153	0.55302	0.4292	0.18421

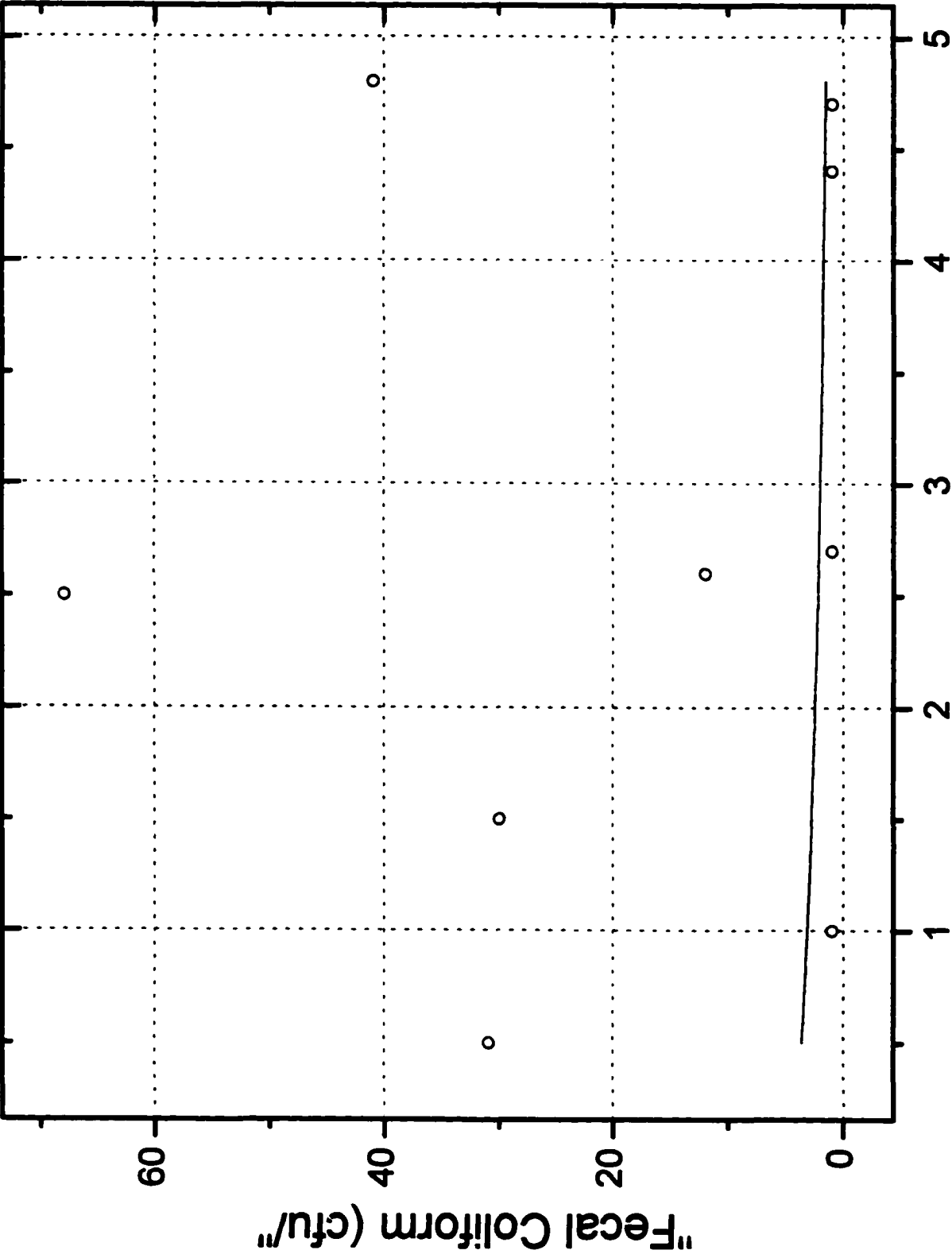


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Variable: Fecal Coliform (cfu/
Independent variable: Water Input Mechanis

	N	A	B	R	R square
$Y = A + B \cdot X$	9	25.9095	-1.91036	-0.12937	0.01673
$Y = A \cdot X^B$	9	10.7185	-0.57065	-0.23362	0.05472
$Y = A \cdot \exp(B \cdot X)$	9	14.5794	-0.27786	-0.23753	0.05642
$Y = A + B \cdot \log(X)$	9	23.2880	-3.28796	-0.10677	0.0114
$Y = A + B/X$	9	18.1683	4.11056	0.10112	0.01022
$Y = 1/(A + B \cdot X)$	9	0.23203	8.50075e-02	0.2681	0.07188
$Y = X/(A + B \cdot X)$	9	-0.22372	0.60131	0.25631	0.06569

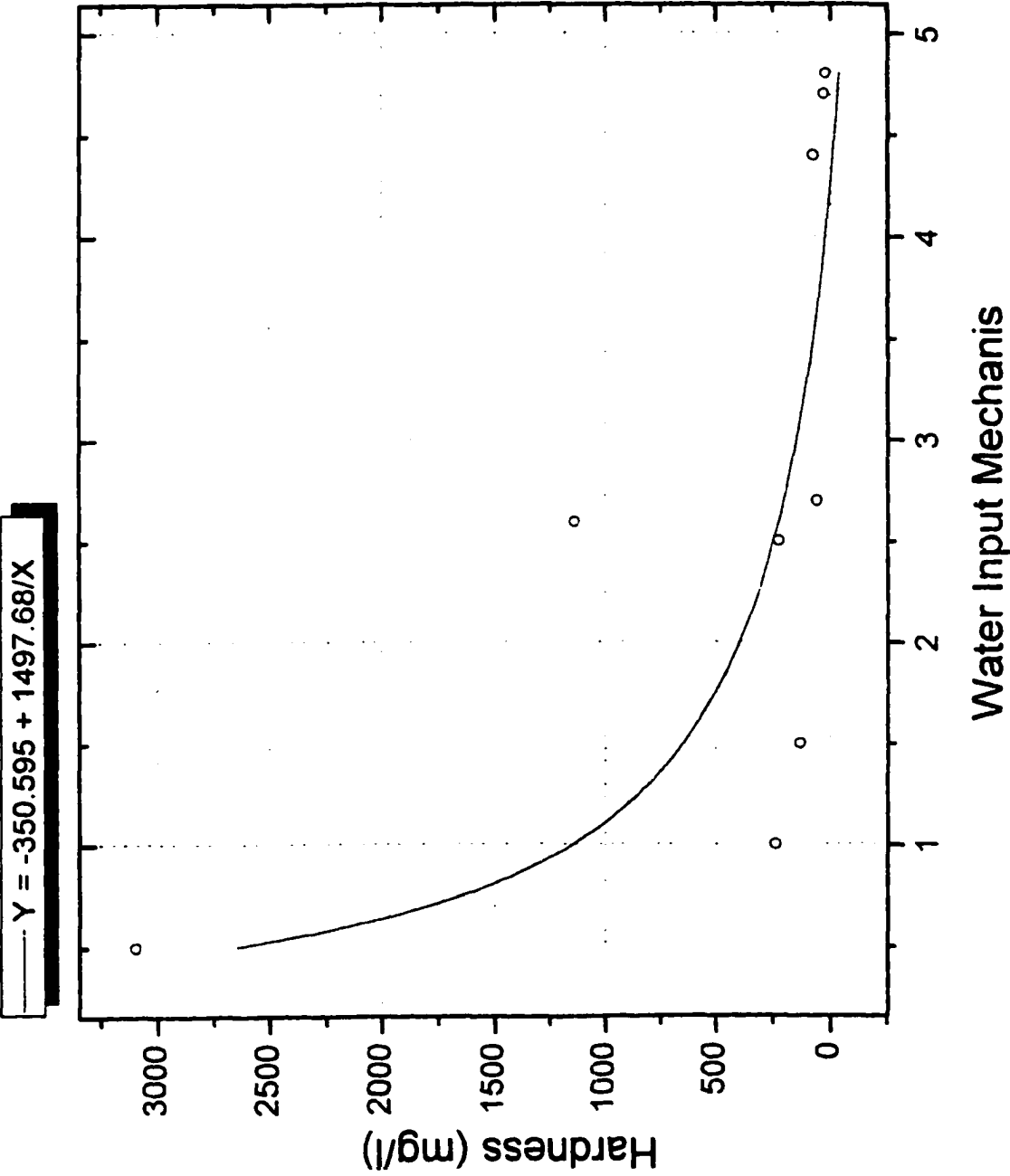
$Y = 1/(0.23203 + 8.50075e-02 * X)$



Water Input Mechanis

Variable: Hardness (mg/l)
Independent variable: Water Input Mechanis

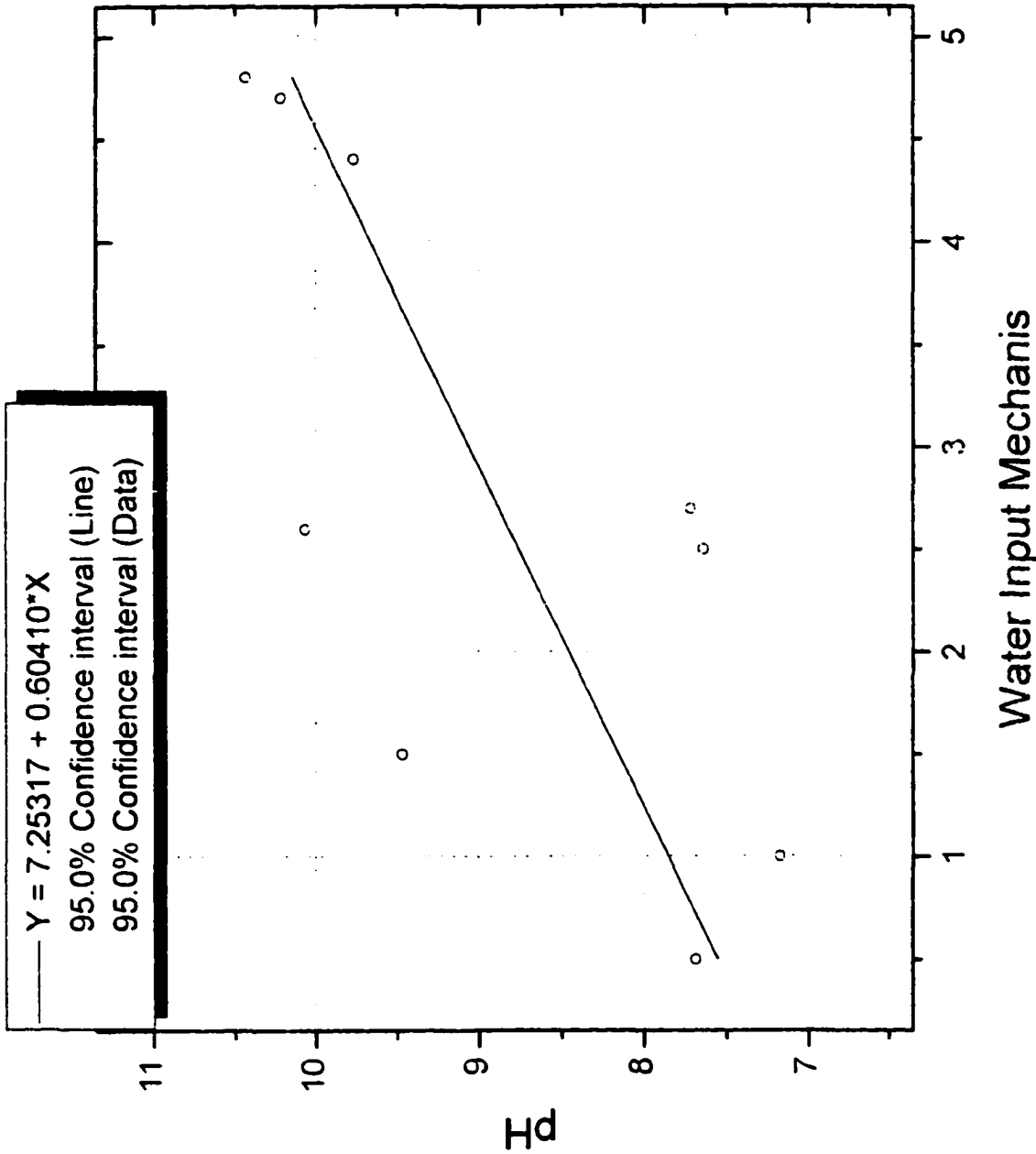
	N	A	B	R	R square
$Y = A + B \cdot X$	9	1568.30	-367.520	-0.58008	0.33649
$Y = A \cdot X^B$	9	610.258	-1.63859	-0.78148	0.61071
$Y = A \cdot \exp(B \cdot X)$	9	1380.34	-0.77340	-0.7692	0.59167
$Y = A + B \cdot \log(X)$	9	1329.55	-985.687	-0.73089	0.5342
$Y = A + B/X$	9	-350.595	1497.68	0.85868	0.73734
$Y = 1/(A + B \cdot X)$	9	-7.07187e-03	7.47248e-03	0.80658	0.65057
$Y = X/(A + B \cdot X)$	9	-1.37122e-02	2.17700e-02	0.53764	0.28906



Variable: pH

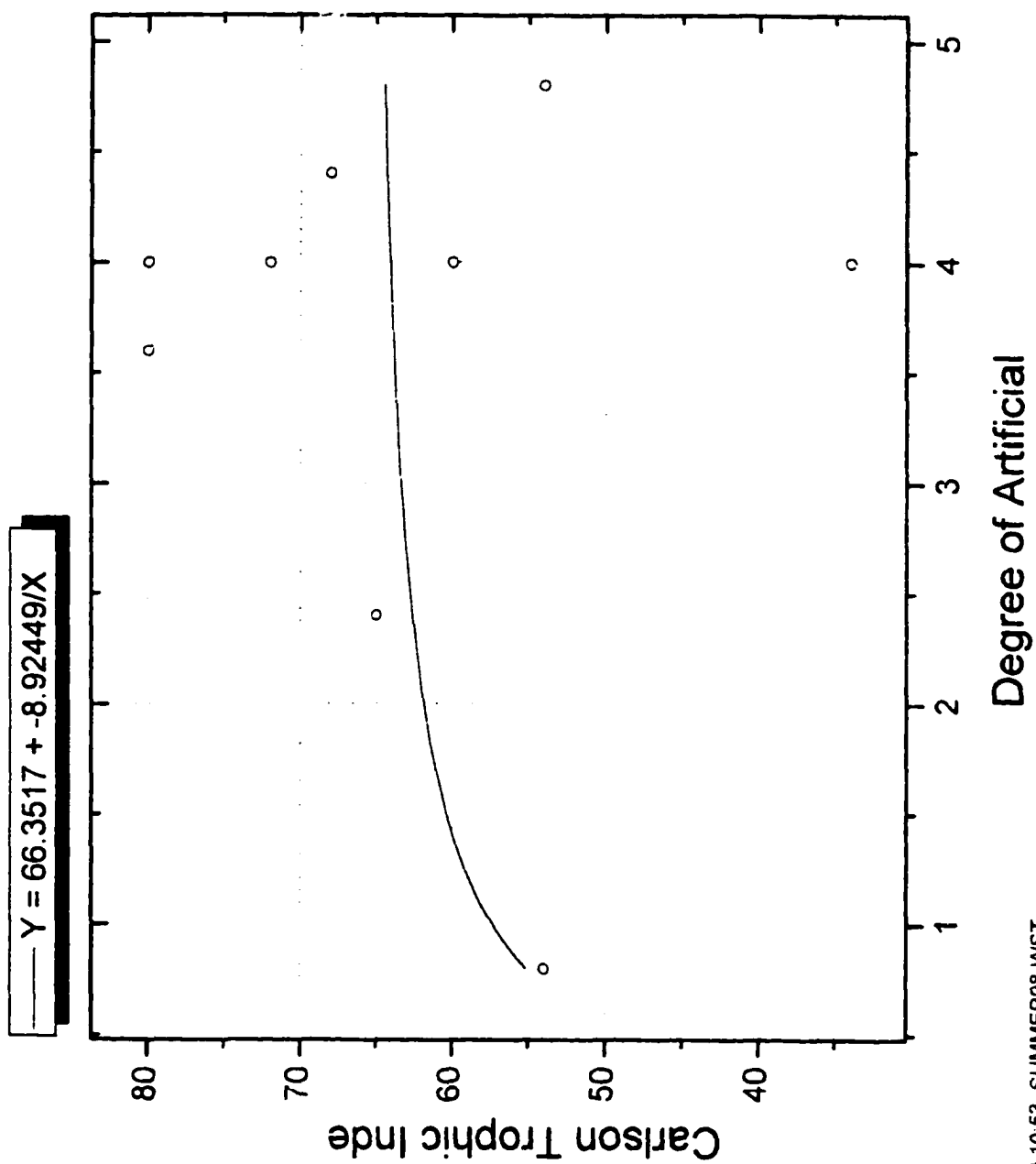
Independent variable: Water Input Mechanis

	N	A	B	R	R square
* $Y = A + B \cdot X$	9	7.25317	0.60410	0.73194	0.53574
$Y = A \cdot X^B$	9	7.93213	0.13339	0.67758	0.45912
$Y = A \cdot \exp(B \cdot X)$	9	7.31058	6.84829e-02	0.72543	0.52624
$Y = A + B \cdot \log(X)$	9	7.97612	1.17279	0.68138	0.46428
$Y = A + B/X$	9	9.70022	-1.29834	-0.57142	0.32652
$Y = 1/(A + B \cdot X)$	9	0.13601	-7.83518e-03	-0.71892	0.51685
$Y = X/(A + B \cdot X)$	9	1.69735e-02	0.10419	0.56573	0.32005



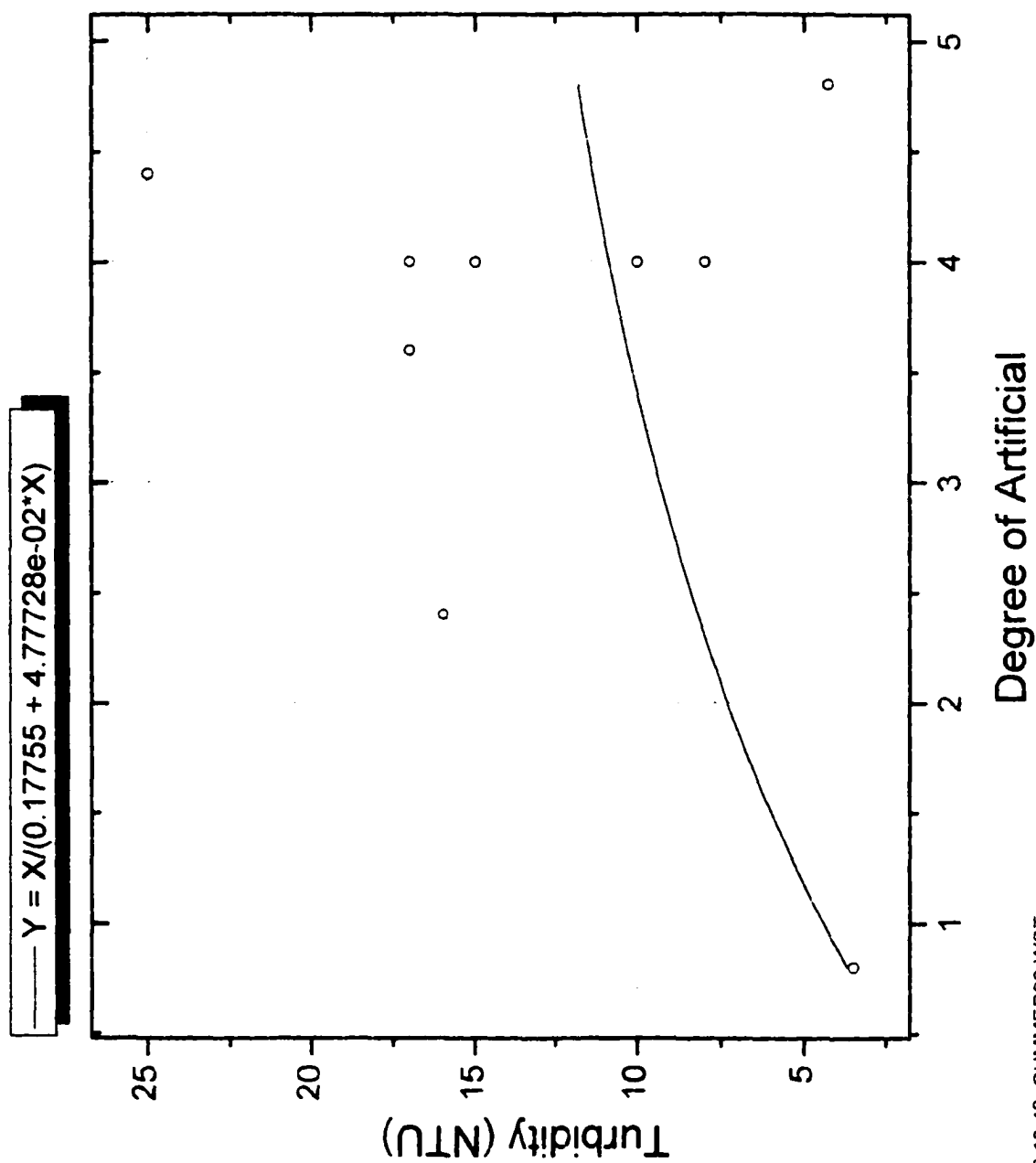
Variable: Carlson Trophic Inde
Independent variable: Degree of Artificial

	N	A	B	R	R square
$Y = A + B \cdot X$	9	58.9644	1.13501	0.09528	0.00908
$Y = A \cdot X^B$	9	57.5762	5.27415e-02	0.11087	0.01229
$Y = A \cdot \exp(B \cdot X)$	9	58.7198	1.18217e-02	0.05459	0.00298
$Y = A + B \cdot \log(X)$	9	58.0494	4.23186	0.16173	0.02615
$Y = A + B/X$	9	66.3517	-8.92449	-0.20407	0.04184
$Y = 1/(A + B \cdot X)$	9	1.70715e-02	-4.83852e-05	-0.01137	1.29429e-04
$Y = X/(A + B \cdot X)$	9	1.38012e-03	1.63811e-02	0.08838	0.00781



Variable: Turbidity (NTU)
Independent variable: Degree of Artificial

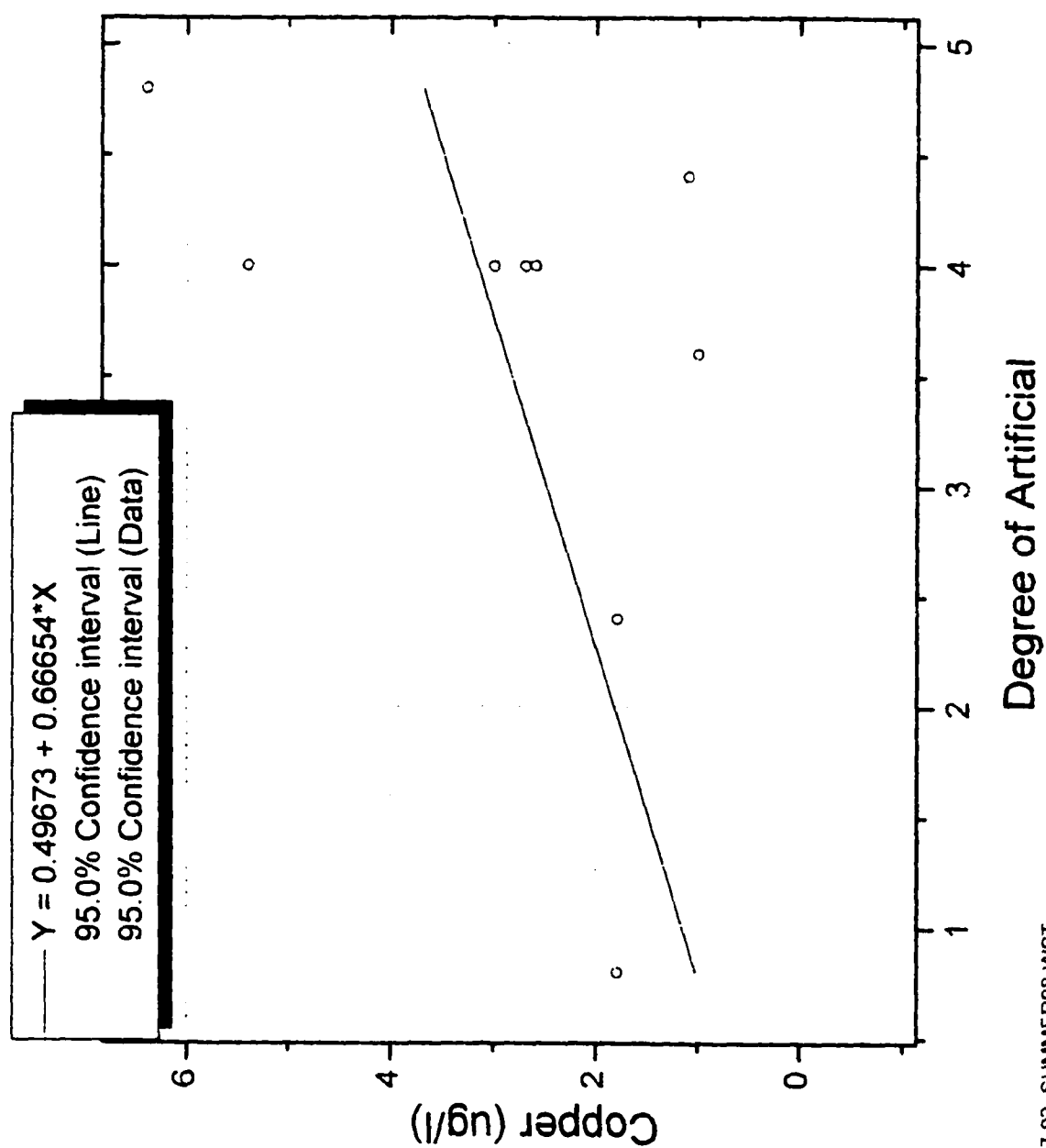
	N	A	B	R	R square
$Y = A + B \cdot X$	9	6.54421	1.77819	0.31217	0.09745
$Y = A \cdot X^B$	9	5.38743	0.59862	0.49771	0.24771
$Y = A \cdot \exp(B \cdot X)$	9	5.30236	0.20143	0.3679	0.13535
$Y = A + B \cdot \log(X)$	9	6.91452	5.08795	0.40661	0.16533
$Y = A + B/X$	9	16.5208	-9.72925	-0.46521	0.21642
$Y = 1/(A + B \cdot X)$	9	0.22660	-3.15428e-02	-0.44458	0.19765
$Y = X/(A + B \cdot X)$	9	0.17755	4.77728e-02	0.68161	0.4646



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Variable: Copper (ug/l)
Independent variable: Degree of Artificial

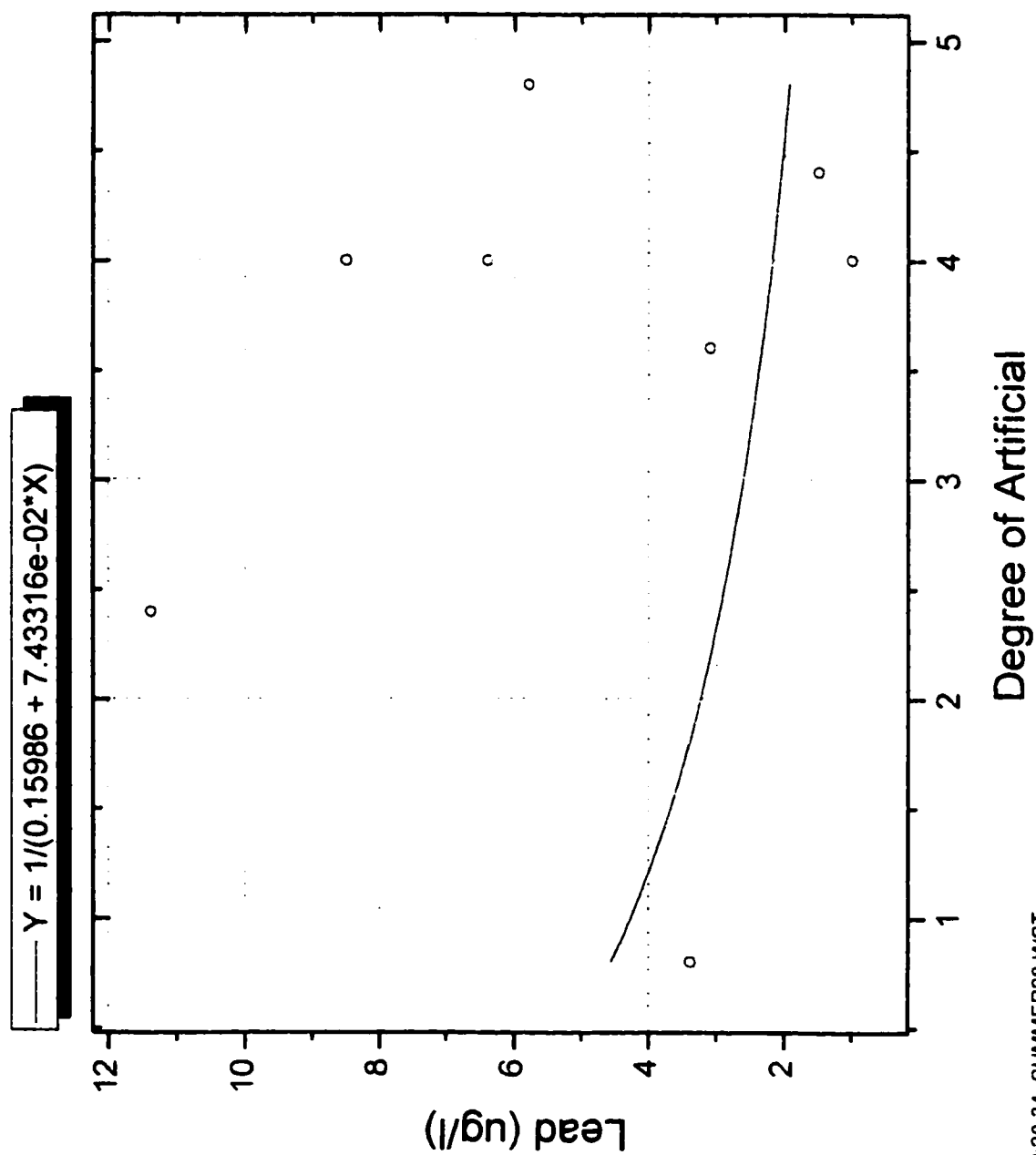
	N	A	B	R	R square
* Y = A + B*X	9	0.49673	0.66654	0.43681	0.1908
Y = A * X^B	9	1.64091	0.32328	0.28343	0.08033
Y = A * EXP(B*X)	9	1.24850	0.18323	0.3529	0.12453
Y = A + B*LOG(X)	9	1.48429	1.18167	0.35252	0.12427
Y = A + B/X	9	3.45958	-1.57875	-0.28179	0.07941
Y = 1/(A + B*X)	9	0.67256	-5.00969e-02	-0.2075	0.04305
Y = X/(A + B*X)	9	0.10126	0.45641	0.11424	0.01305



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Variable: Lead (ug/l)
Independent variable: Degree of Artificial

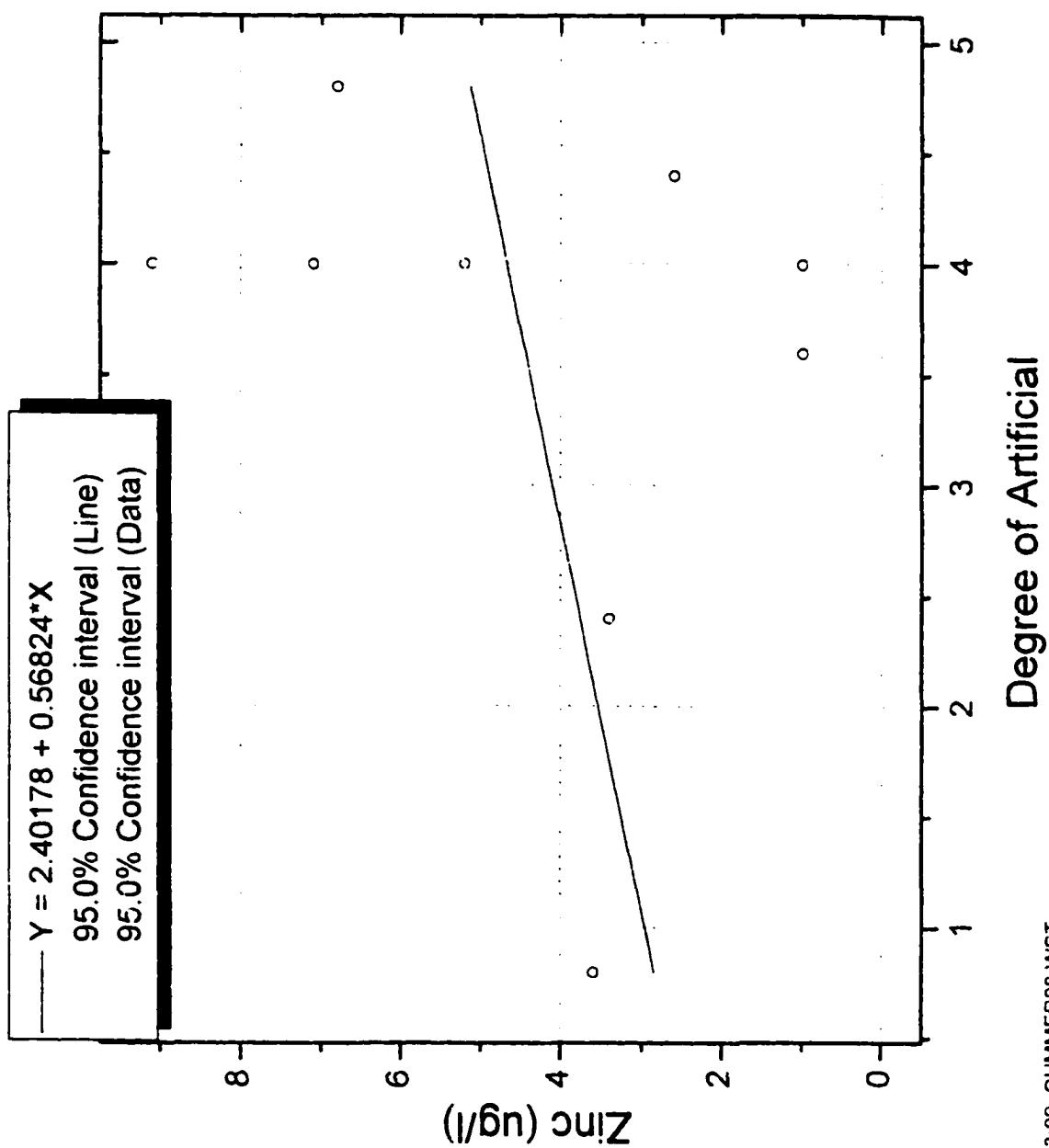
	N	A	B	R	R square
$Y = A + B \cdot X$	9	6.57952	-0.53486	-0.18043	0.03255
$Y = A \cdot X^B$	9	4.48452	-0.24288	-0.14828	0.02198
$Y = A \cdot \exp(B \cdot X)$	9	5.80616	-0.15255	-0.2046	0.04186
$Y = A + B \cdot \log(X)$	9	5.29489	-0.52734	-0.08098	0.00655
$Y = A + B/X$	9	4.75204	-0.19773	-0.01816	3.30087e-04
$Y = 1/(A + B \cdot X)$	9	0.15986	7.43316e-02	0.24627	0.06065
$Y = X/(A + B \cdot X)$	9	-0.20694	0.50187	0.18675	0.03487



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Variable: Zinc (ug/l)
Independent variable: Degree of Artificial

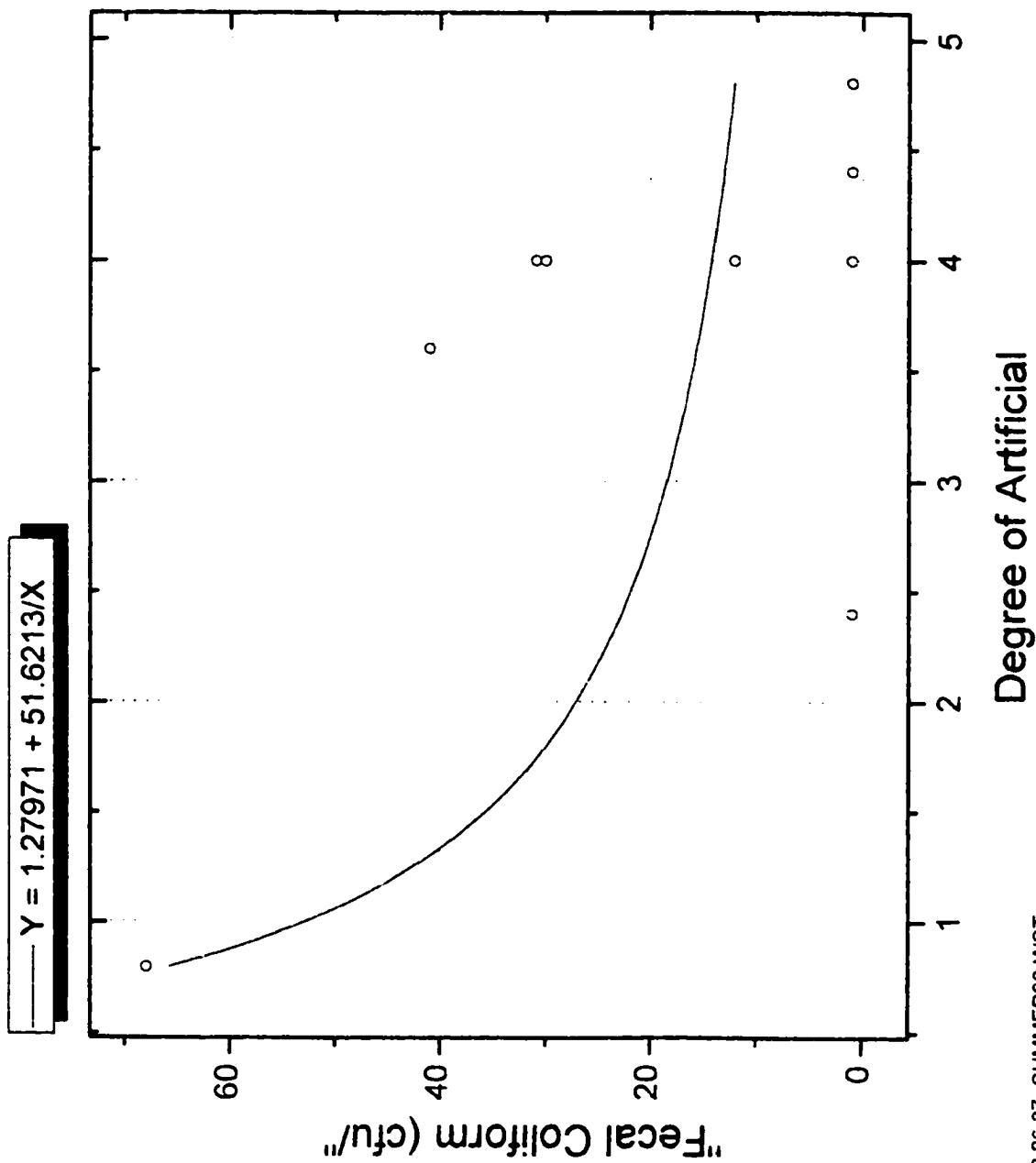
	N	A	B	R	R square
$Y = A + B \cdot X$	9	2.40178	0.56824	0.2463	0.06066
$Y = A \cdot X^B$	9	3.19160	7.11846e-02	0.049	0.0024
$Y = A \cdot \exp(B \cdot X)$	9	2.70837	6.95849e-02	0.10524	0.01107
$Y = A + B \cdot \log(X)$	9	3.26044	0.99310	0.19595	0.03839
$Y = A + B/X$	9	4.90811	-1.28845	-0.15211	0.02313
$Y = 1/(A + B \cdot X)$	9	0.36787	7.36826e-03	0.02544	6.47610e-04
$Y = X/(A + B \cdot X)$	9	-0.11880	0.43868	0.11176	0.01249



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Variable: Fecal Coliform (cfu/
Independent variable: Degree of Artificial

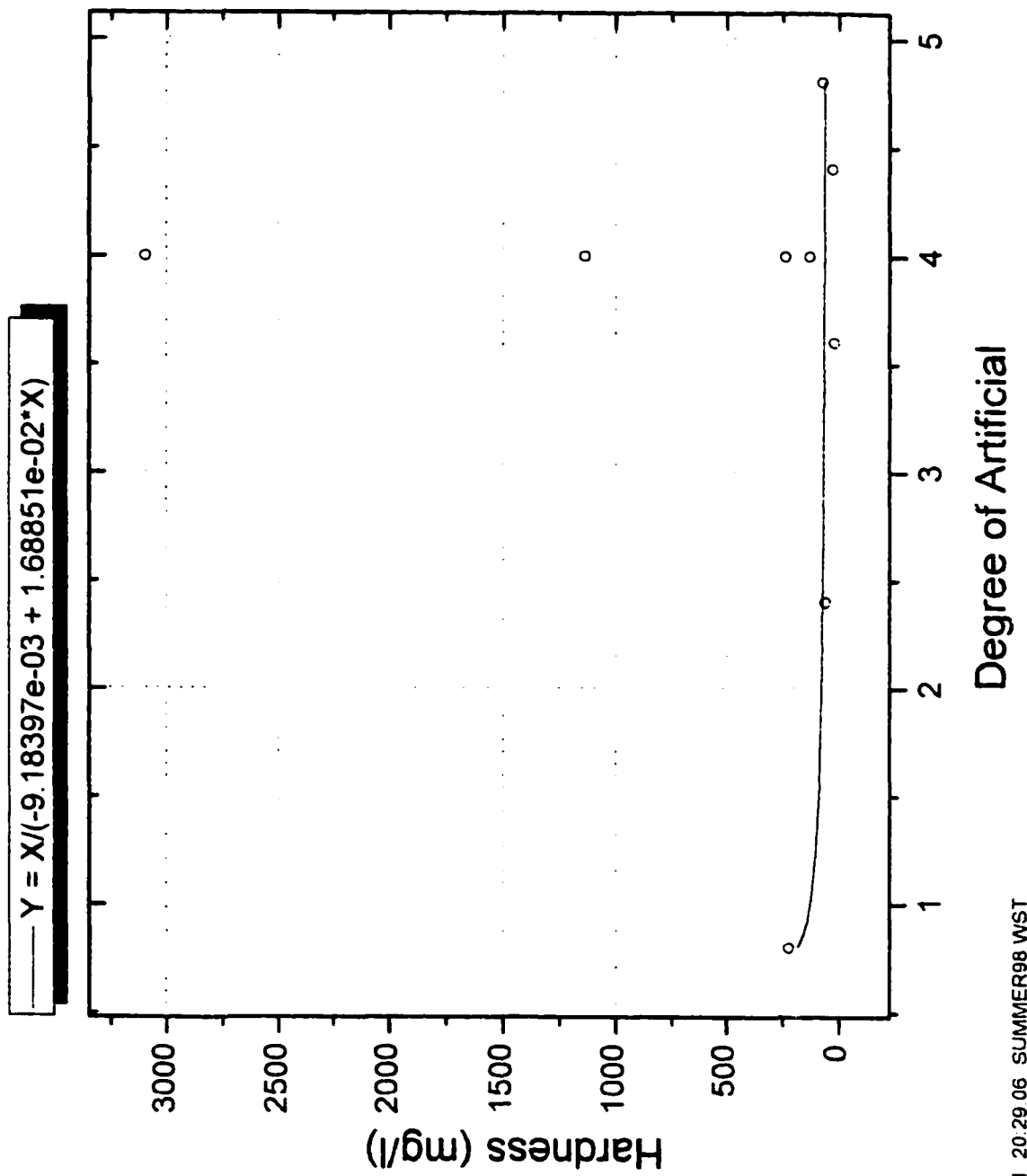
	N	A	B	R	R square
$Y = A + B \cdot X$	9	65.6914	-12.6632	-0.65563	0.42985
$Y = A \cdot X^B$	9	34.5182	-1.38861	-0.4131	0.17065
$Y = A \cdot \exp(B \cdot X)$	9	59.6838	-0.61088	-0.39922	0.15938
$Y = A + B \cdot \log(X)$	9	55.4067	-29.6961	-0.6999	0.48986
$Y = A + B/X$	9	1.27971	51.6213	0.72795	0.52991
$Y = 1/(A + B \cdot X)$	9	4.85618e-02	0.11721	0.28262	0.07987
$Y = X/(A + B \cdot X)$	9	-0.45921	0.63779	0.30157	0.09094



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Variable: Hardness (mg/l)
Independent variable: Degree of Artificial

	N	A	B	R	R square
$Y = A + B \cdot X$	9	120.775	123.438	0.14894	0.02218
$Y = A \cdot X^B$	9	173.353	-4.08585e-02	-0.01414	1.99996e-04
$Y = A \cdot \exp(B \cdot X)$	9	162.727	4.34667e-03	0.0033	1.09226e-05
$Y = A + B \cdot \log(X)$	9	225.726	285.456	0.15679	0.02458
$Y = A + B/X$	9	728.330	-449.096	-0.14759	0.02178
$Y = 1/(A + B \cdot X)$	9	7.55385e-03	1.65433e-03	0.13651	0.01863
$Y = X/(A + B \cdot X)$	9	-9.18397e-03	1.68851e-02	0.20641	0.0426



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Degree of Artificial

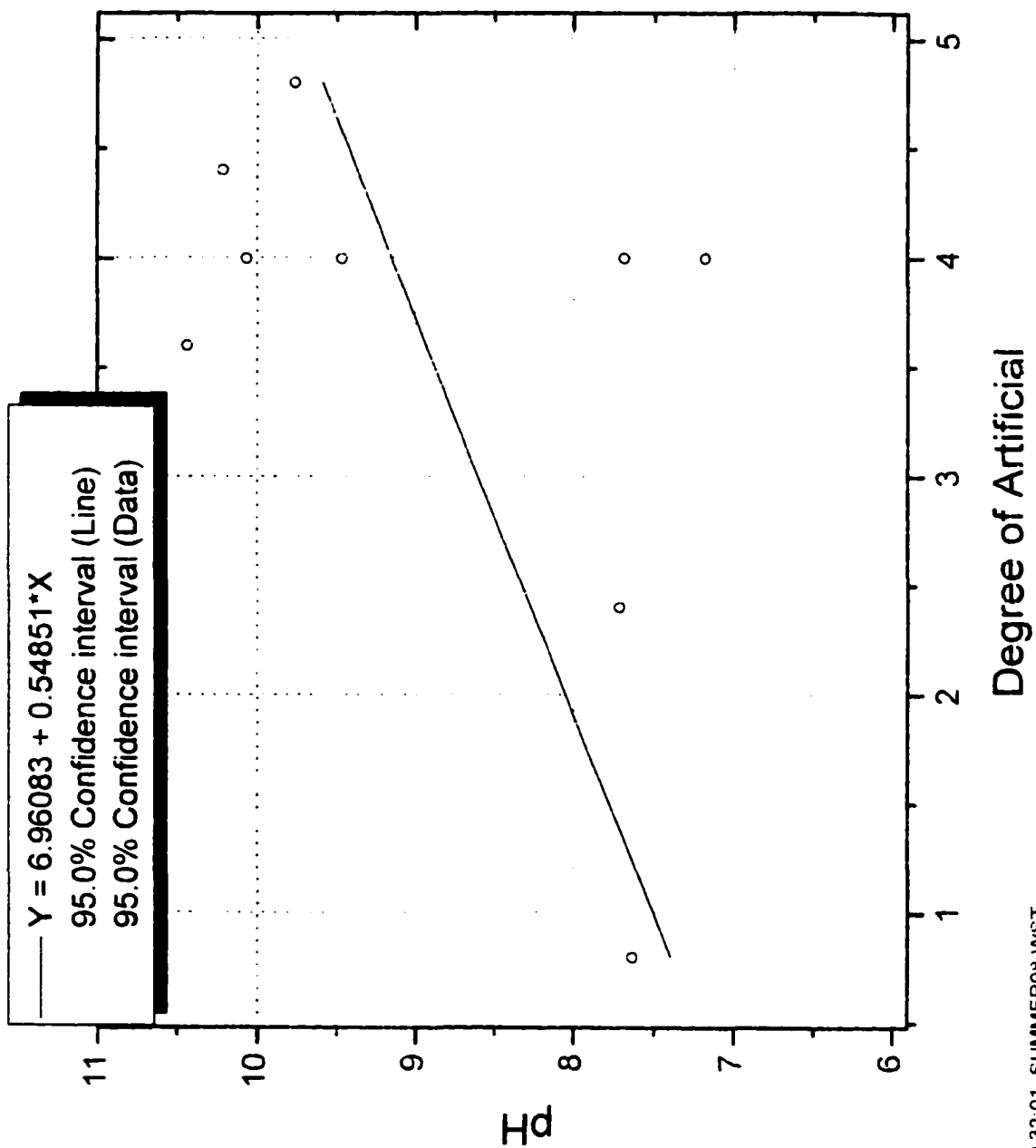
Hardness (mg/l)

$$Y = X/(-9.18397e-03 + 1.68851e-02 \cdot X)$$

Variable: pH

Independent variable: Degree of Artificial

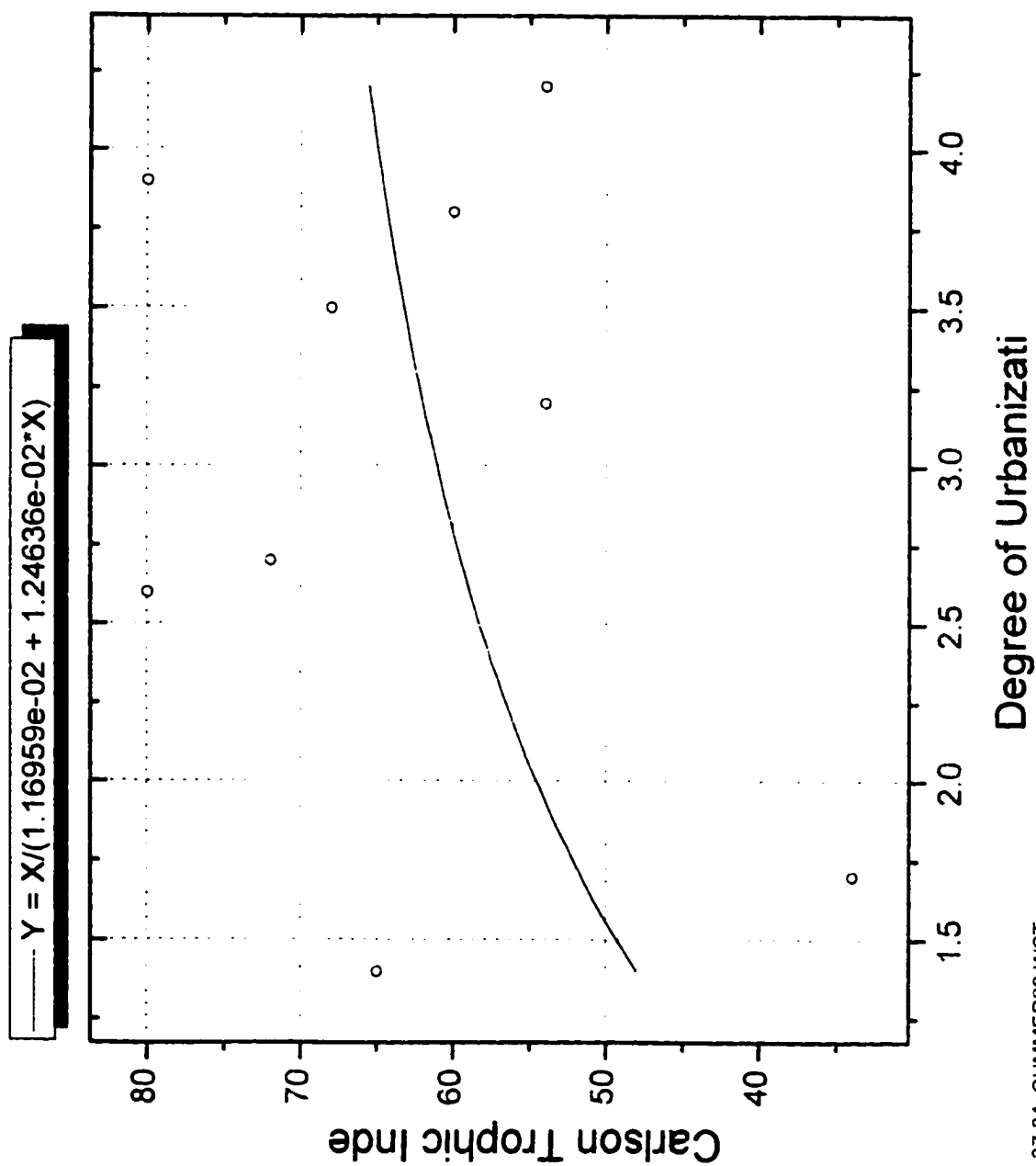
	N	A	B	R	R square
*Y = A + B*X	9	6.96083	0.54851	0.50808	0.25813
Y = A * X^B	9	7.60682	0.12670	0.46708	0.21816
Y = A * EXP(B*X)	9	7.06814	6.23455e-02	0.50467	0.2549
Y = A + B*LOG(X)	9	7.60394	1.11738	0.47114	0.22197
Y = A + B/X	9	9.54177	-1.67924	-0.42364	0.17947
Y = 1/(A + B*X)	9	0.13983	-7.12202e-03	-0.49958	0.24958
Y = X/(A + B*X)	9	2.16494e-02	0.10638	0.41362	0.17108



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Variable: Carlson Trophic Inde
Independent variable: Degree of Urbanizati

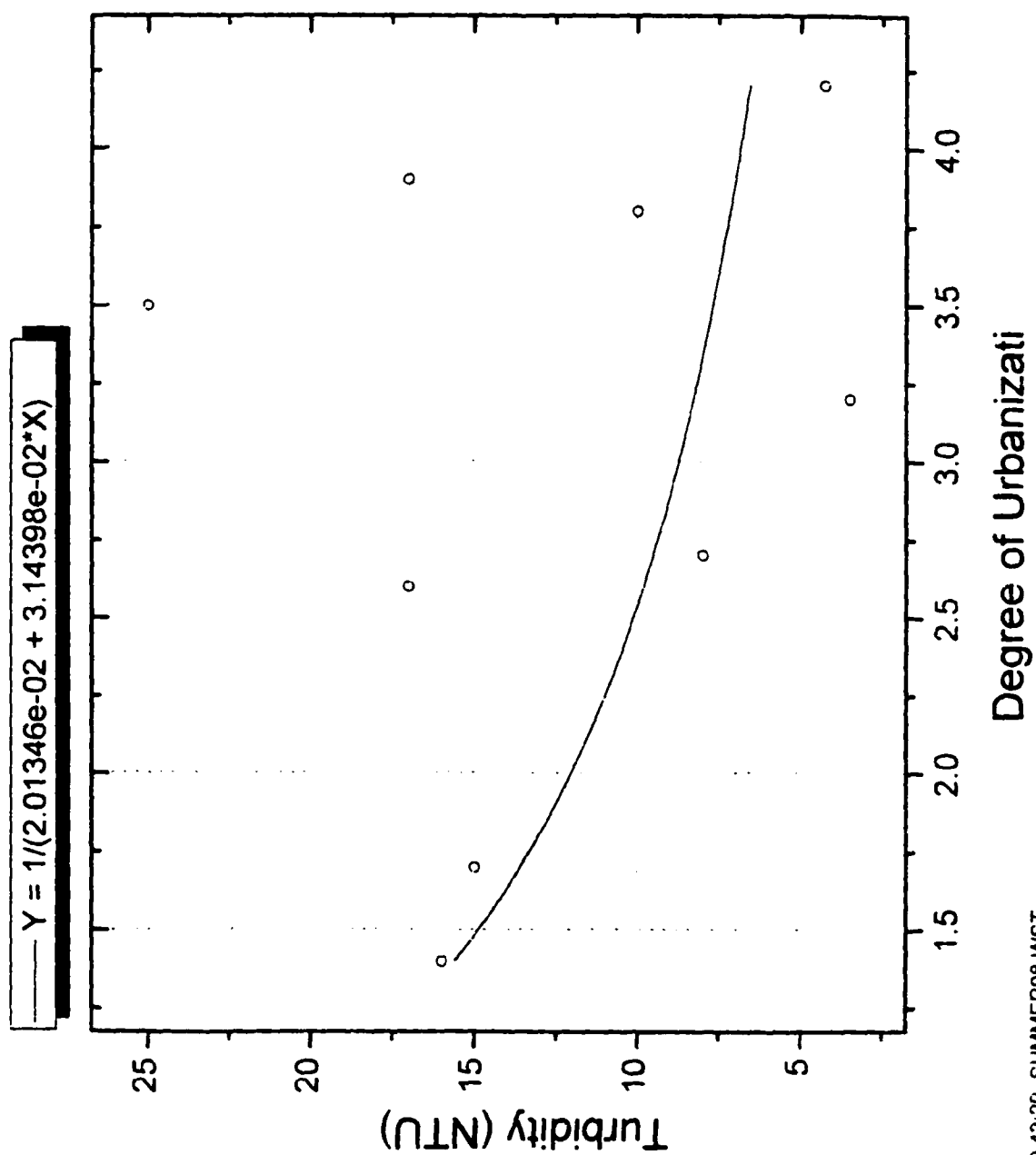
	N	A	B	R	R square
$Y = A + B \cdot X$	9	52.1406	3.61979	0.24329	0.05919
$Y = A \cdot X^B$	9	48.4099	0.22599	0.32615	0.10637
$Y = A \cdot \exp(B \cdot X)$	9	48.1711	8.00172e-02	0.29583	0.08751
$Y = A + B \cdot \log(X)$	9	51.9072	10.6630	0.27977	0.07827
$Y = A + B/X$	9	72.9564	-26.2518	-0.29709	0.08826
$Y = 1/(A + B \cdot X)$	9	2.24288e-02	-1.84312e-03	-0.34695	0.12037
$Y = X/(A + B \cdot X)$	9	1.16959e-02	1.24636e-02	0.3707	0.13741



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Variable: Turbidity (NTU)
Independent variable: Degree of Urbanizati

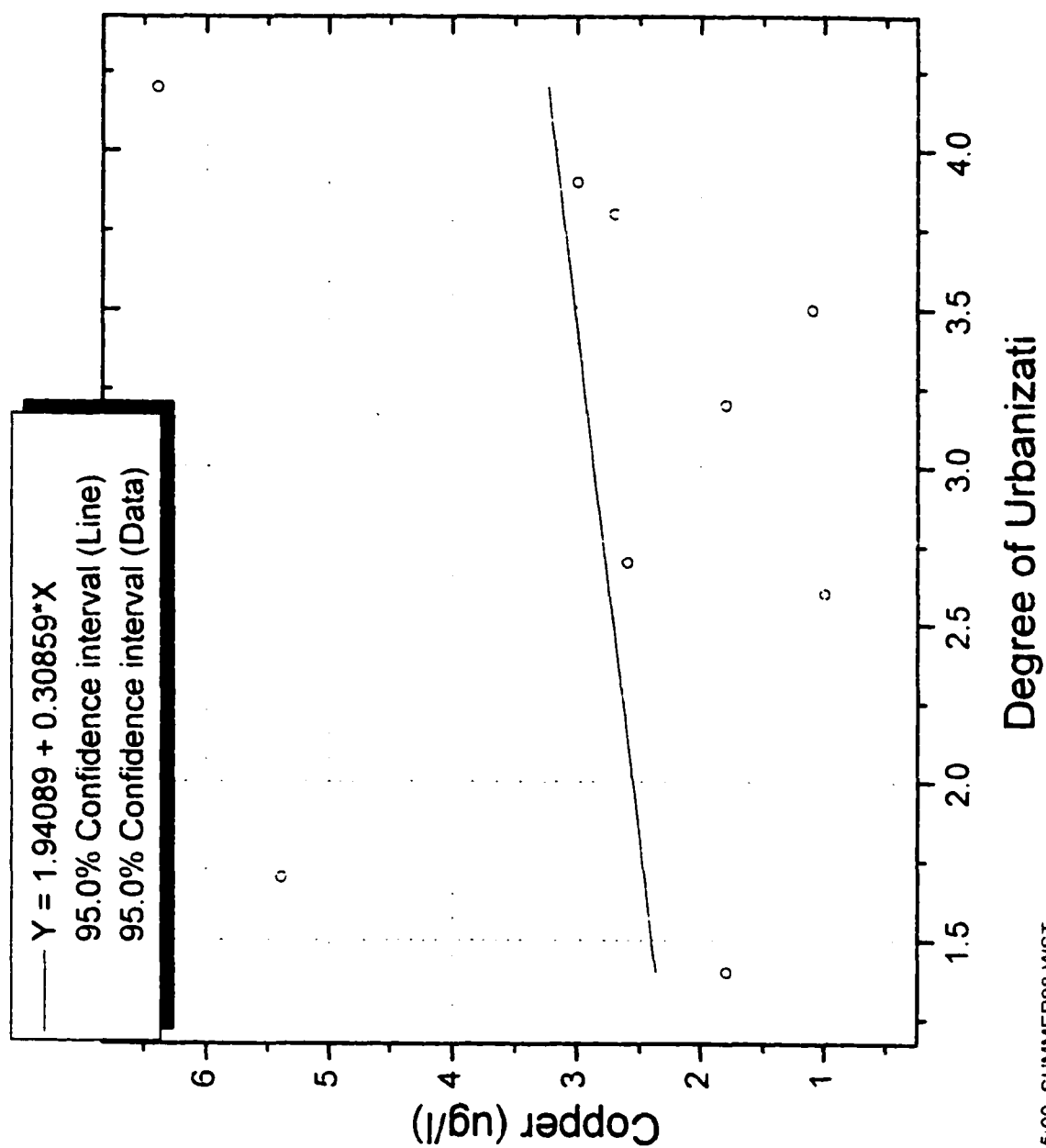
	N	A	B	R	R square
$Y = A + B \cdot X$	9	17.8042	-1.64583	-0.23132	0.0535
$Y = A \cdot X^B$	9	19.6742	-0.57188	-0.32642	0.10655
$Y = A \cdot \exp(B \cdot X)$	9	21.1767	-0.22284	-0.32584	0.10617
$Y = A + B \cdot \log(X)$	9	17.2120	-4.17690	-0.22916	0.05251
$Y = A + B/X$	9	9.23368	9.57902	0.22668	0.05138
$Y = 1/(A + B \cdot X)$	9	2.01346e-02	3.14398e-02	0.35477	0.12586
$Y = X/(A + B \cdot X)$	9	-0.18560	0.18484	0.35265	0.12436



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Variable: Copper (ug/l)
Independent variable: Degree of Urbanizati

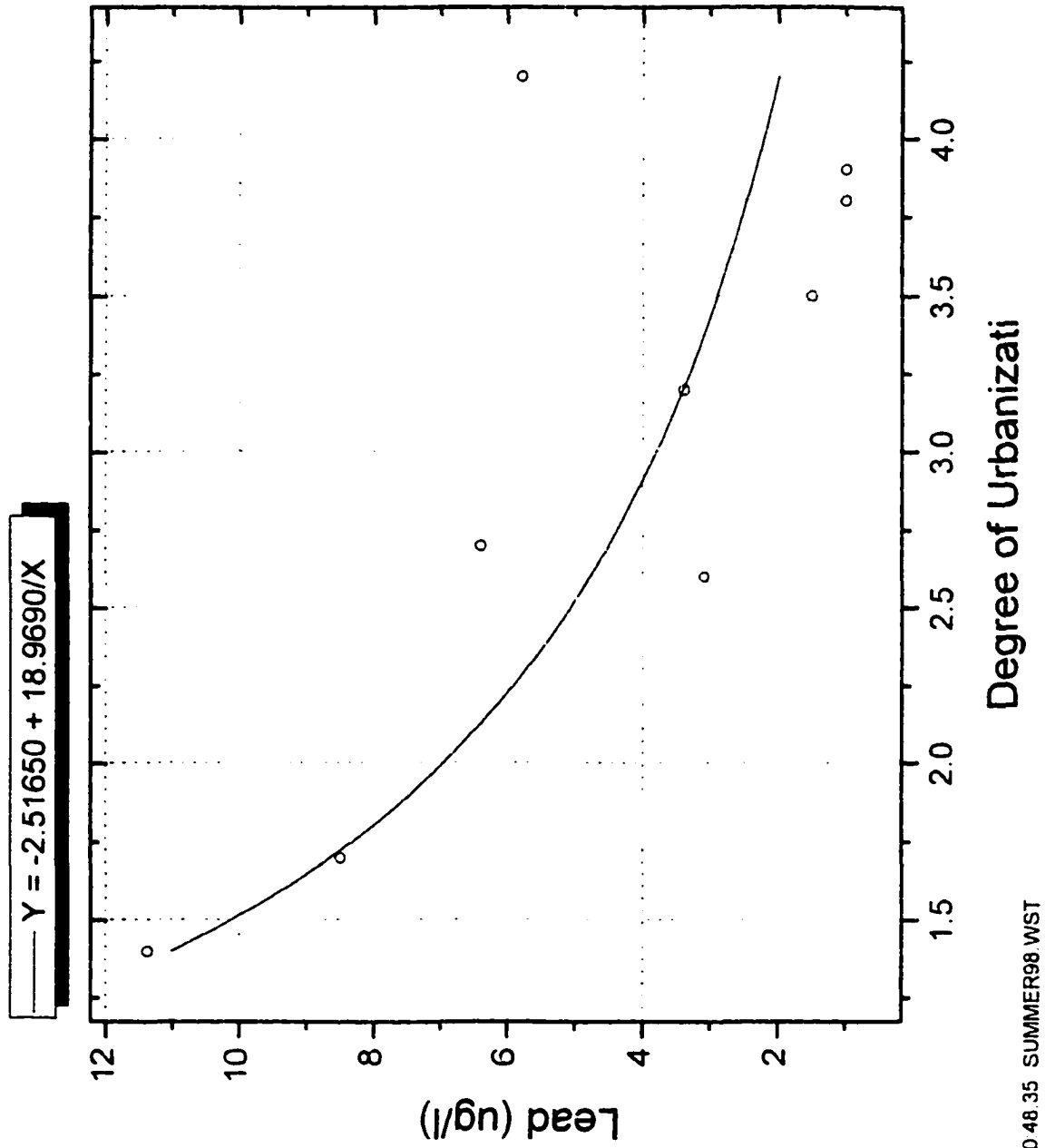
	N	A	B	R	R square
* $Y = A + B \cdot X$	9	1.94089	0.30859	0.1619	0.02621
$Y = A \cdot X^B$	9	2.09238	0.12989	0.07818	0.00611
$Y = A \cdot \exp(B \cdot X)$	9	1.78221	9.85276e-02	0.15192	0.02308
$Y = A + B \cdot \log(X)$	9	2.41105	0.43796	0.08969	0.00804
$Y = A + B/X$	9	3.03201	-0.43595	-0.03851	0.00148
$Y = 1/(A + B \cdot X)$	9	0.60989	-3.84846e-02	-0.12761	0.01628
$Y = X/(A + B \cdot X)$	9	-6.42665e-03	0.49687	0.00358	1.28756e-05



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Variable: Lead (ug/l)
Independent variable: Degree of Urbanizati

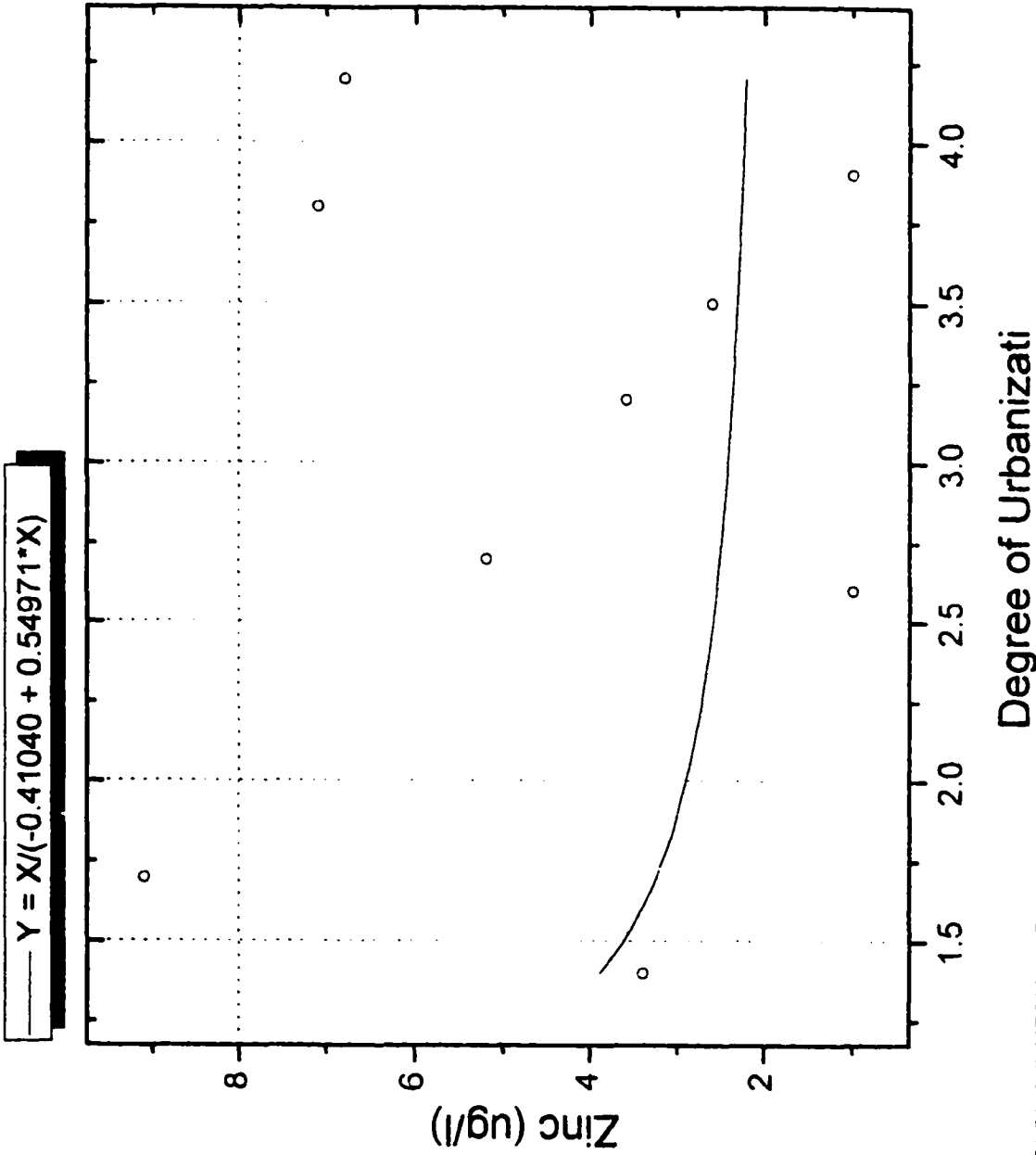
	N	A	B	R	R square
$Y = A + B \cdot X$	9	13.4122	-2.91146	-0.78629	0.61826
$Y = A \cdot X^B$	9	21.0018	-1.75727	-0.73654	0.5425
$Y = A \cdot \exp(B \cdot X)$	9	25.0226	-0.66776	-0.71699	0.51407
$Y = A + B \cdot \log(X)$	9	12.9280	-7.92861	-0.83587	0.69869
$Y = A + B/X$	9	-2.51650	18.9690	0.86257	0.74403
$Y = 1/(A + B \cdot X)$	9	-0.29063	0.23826	0.632	0.39943
$Y = X/(A + B \cdot X)$	9	-1.33652	0.93104	0.59692	0.35631



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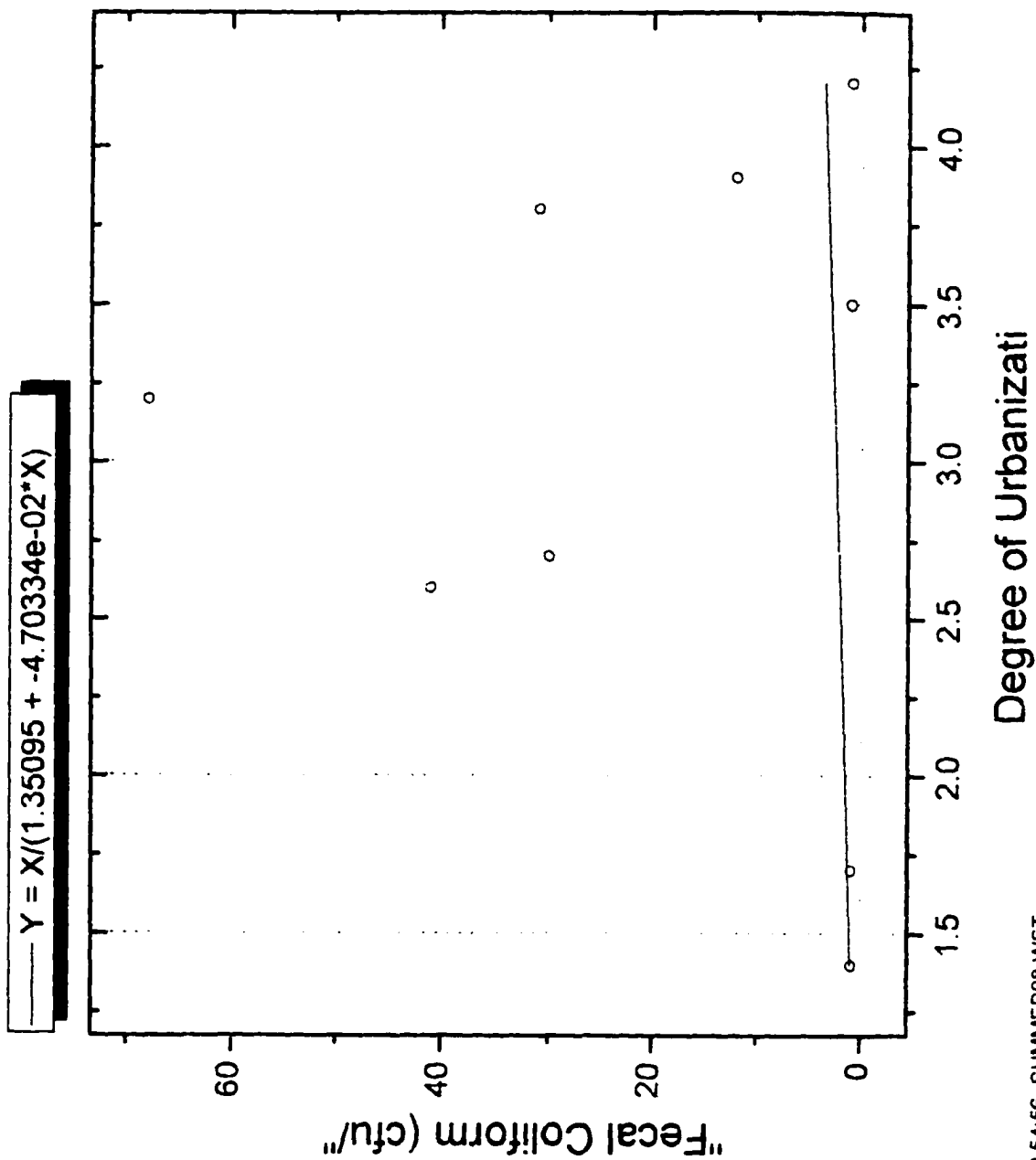
Variable: Zinc (ug/l)
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
$Y = A + B \cdot X$	9	5.38707	-0.32161	-0.1116	0.01245
$Y = A \cdot X^B$	9	4.81867	-0.31596	-0.14933	0.02229
$Y = A \cdot \exp(B \cdot X)$	9	4.59728	-9.38893e-02	-0.11367	0.01292
$Y = A + B \cdot \log(X)$	9	5.55011	-1.08418	-0.14686	0.02157
$Y = A + B/X$	9	3.36131	2.79728	0.16344	0.02671
$Y = 1/(A + B \cdot X)$	9	0.25114	4.76396e-02	0.13172	0.01735
$Y = X/(A + B \cdot X)$	9	-0.41040	0.54971	0.19106	0.0365



Variable: Fecal Coliform (cfu/
Independent variable: Degree of Urbanizati

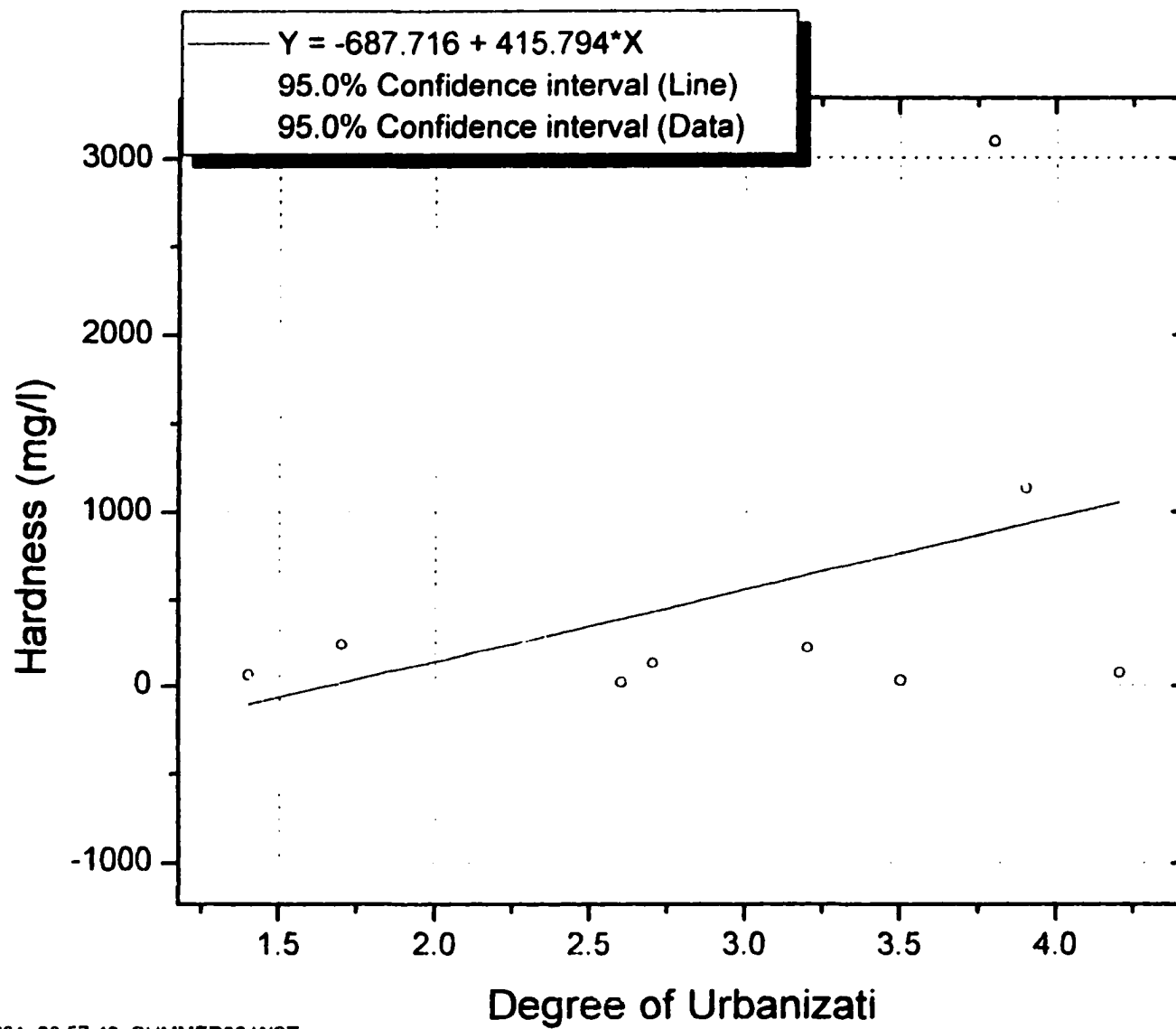
	N	A	B	R	R square
$Y = A + B \cdot X$	9	11.8385	2.94271	0.12197	0.01487
$Y = A \cdot X^B$	9	1.31085	1.58254	0.32321	0.10447
$Y = A \cdot \exp(B \cdot X)$	9	1.85795	0.43251	0.22629	0.0512
$Y = A + B \cdot \log(X)$	9	6.58544	13.5355	0.21901	0.04798
$Y = A + B/X$	9	36.9568	-42.9518	-0.29976	0.08988
$Y = 1/(A + B \cdot X)$	9	0.90127	-0.14531	-0.2805	0.07868
$Y = X/(A + B \cdot X)$	9	1.35095	-4.70334e-02	-0.43908	0.19279



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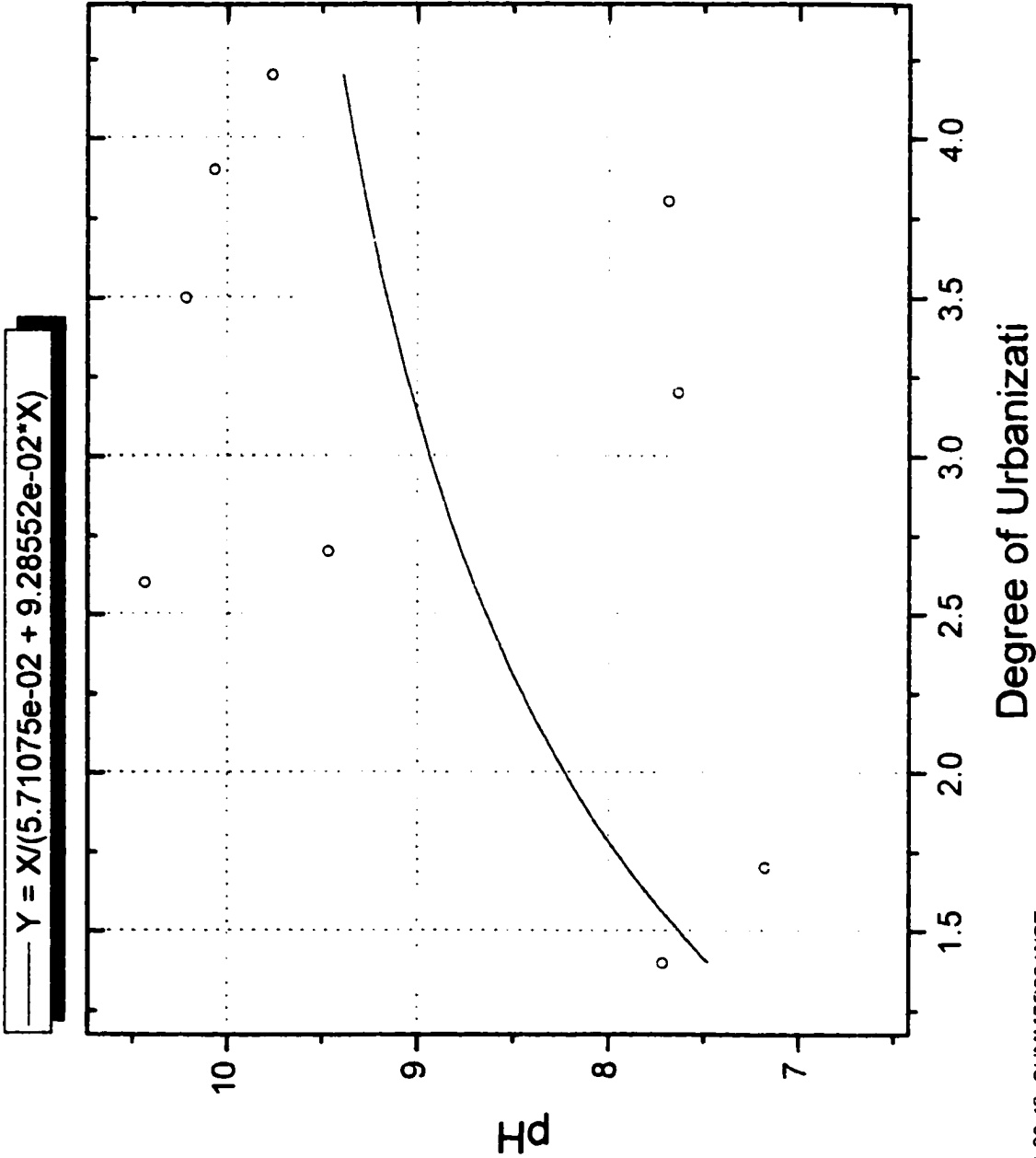
Variable: Hardness (mg/l)
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
* $Y = A + B \cdot X$	9	-687.716	415.794	0.40186	0.16133
$Y = A \cdot X^B$	9	42.5151	1.30506	0.31011	0.09616
$Y = A \cdot \exp(B \cdot X)$	9	30.9347	0.55855	0.34	0.1156
$Y = A + B \cdot \log(X)$	9	-478.283	997.726	0.37624	0.14155
$Y = A + B/X$	9	1357.81	-2104.46	-0.34229	0.11718
$Y = 1/(A + B \cdot X)$	9	2.00903e-02	-2.21814e-03	-0.14653	0.02147
$Y = X/(A + B \cdot X)$	9	5.17368e-03	1.14737e-02	0.05754	0.00331



Variable: pH
Independent variable: Degree of Urbanizati

	N	A	B	R	R square
$Y = A + B \cdot X$	9	7.00721	0.63463	0.47061	0.22146
$Y = A \cdot X^B$	9	7.14565	0.20259	0.51274	0.2629
$Y = A \cdot \exp(B \cdot X)$	9	7.06371	7.40996e-02	0.4804	0.23079
$Y = A + B \cdot \log(X)$	9	7.09995	1.74066	0.50397	0.25396
$Y = A + B/X$	9	10.5065	-4.21175	-0.52587	0.27654
$Y = 1/(A + B \cdot X)$	9	0.14067	-8.72048e-03	-0.46973	0.23963
$Y = X/(A + B \cdot X)$	9	5.71075e-02	9.28552e-02	0.53998	0.29156



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APPENDIX F

SEASONAL ANALYSES OF VARIANCE; PRIMARY WATER INPUT MECHANISM AS TREATMENT, WITH SELECTED WATER QUALITY PARAMETERS AS THE MEASURED EFFECTS

Variable: Fecal Coliform (cfu/

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	1.60453e+06	2	8.02267e+05	0.94192	0.44079
Within	5.11040e+06	6	8.51734e+05		
Total	6.71494e+06	8	8.39367e+05		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
3.31512	2	0.1906

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$652.585 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "" in the following table:

No significant differences.

Variable: Orthophosphate (mg/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	6.06200e-03	2	3.03100e-03	1.44885	0.30663
Within	1.25520e-02	6	2.09200e-03		
Total	1.86140e-02	8	2.32675e-03		

Bartlett test for homogeneity of variance

There is not enough data to perform the desired calculation.

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$3.23419e-02 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Total Kjeldahl Nitro

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	0.20906	2	0.10453	0.19591	0.82713
Within	3.20133	6	0.53355		
Total	3.41040	8	0.42630		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
9.99440e-02	2	0.95125

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$0.51650 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Zinc (ug/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	44.8822	2	22.4411	1.52212	0.29197
Within	88.4600	6	14.7433		
Total	133.342	8	16.6678		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
1.56623	2	0.45697

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$2.71508 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Lead (ug/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	102.282	2	51.1411	1.98185	0.22102
Within	158.407	6	26.0678		
Total	258.689	8	32.3361		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
0.49914	2	0.77913

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$3.61025 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Hardness (mg/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	4.00337e+05	2	2.00168e+05	1.16554	0.37355
Within	1.03044e+06	6	1.71739e+05		
Total	1.43077e+06	8	1.78847e+05		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
11.4729	2	0.00322

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$293.035 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: pH

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	0.70388	2	0.35194	0.93395	0.44348
Within	2.26100	6	0.37683		
Total	2.96489	8	0.37061		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.37555	2	0.30489

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$0.43407 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "" in the following table:

No significant differences.

Variable: Turbidity (NTU)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	29.6600	2	14.8300	1.11086	0.38865
Within	80.1000	6	13.3500		
Total	109.760	8	13.7200		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.40754	2	0.30006

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$2.58360 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "" in the following table:

No significant differences.

Variable: Carlson Trophic Inde

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	328.222	2	164.111	2.54217	0.1506
Within	387.333	6	64.5556		
Total	715.556	8	89.4444		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.32318	2	0.31298

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$5.68135 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by ** in the following table:

No significant differences.

Variable: Color (cu)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	2422.22	2	1211.11	0.55050	0.60324
Within	13200.0	6	2200.00		
Total	15622.2	8	1952.78		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
5.02927	2	0.08089

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$33.1662 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Chlorophyll a (mg/cu

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	117.567	2	58.7837	3.57168e-02	0.96511
Within	9874.98	6	1645.83		
Total	9992.55	8	1249.07		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
9.47742e-02	2	0.95371

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$28.6865 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Fecal Coliform (cfu/

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	2958.22	2	1479.11	2.00452	0.21541
Within	4427.33	6	737.889		
Total	7385.56	8	923.194		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
5.63192	2	0.05984

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$19.2079 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by *** in the following table:

No significant differences.

Variable: Orthophosphate (mg/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	3.64089e-03	2	1.82044e-03	1.00000	0.42187
Within	1.09227e-02	6	1.82044e-03		
Total	1.45636e-02	8	1.82044e-03		

Bartlett test for homogeneity of variance

There is not enough data to perform the desired calculation.

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$3.01699e-02 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Total Kjeldahl Nitro

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	13.2698	2	6.63480	1.82382	0.24054
Within	21.8272	6	3.63787		
Total	35.0968	8	4.38710		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
0.62997	2	0.72979

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$1.34868 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by ** in the following table:

No significant differences.

Variable: Zinc (ug/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	124.827	2	62.4133	1.36975	0.32359
Within	273.393	6	45.5656		
Total	398.220	8	49.7775		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
9.33150	2	0.00941

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$4.77313 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by ** in the following table:

No significant differences.

Variable: Lead (ug/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	18.2156	2	9.10778	0.11527	0.89304
Within	474.060	6	79.0100		
Total	492.276	8	61.5344		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
7.85488e-02	2	0.96148

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$6.28530 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Hardness (mg/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	2.63407e+05	2	1.31703e+05	0.99312	0.42406
Within	7.95695e+05	6	1.32616e+05		
Total	1.05910e+06	8	1.32388e+05		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
6.55015	2	0.03781

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$257.503 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: pH

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	4.72549	2	2.36274	4.47762	0.06457
Within	3.16607	6	0.52767		
Total	7.89156	8	0.98644		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
1.54690	2	0.46141

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$0.51365 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Turbidity (NTU)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	49.0067	2	24.5033	0.25070	0.78801
Within	586.433	6	97.7389		
Total	635.440	8	79.4300		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.12442	2	0.34569

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$6.99067 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "" in the following table:

No significant differences.

Variable: Carlson Trophic Inde

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	892.667	2	446.333	0.75835	0.50859
Within	3531.33	6	588.556		
Total	4424.00	8	553.000		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.72712	2	0.25574

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$17.1545 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Color (cu)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	200.000	2	100.000	0.21818	0.81008
Within	2750.00	6	458.333		
Total	2950.00	8	368.750		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.73130	2	0.25521

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$15.1383 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Chlorophyll a (mg/cu

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	74.6171	2	37.3085	3.17831e-02	0.96887
Within	7043.08	6	1173.85		
Total	7117.70	8	889.713		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
0.15350	2	0.92811

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$24.2265 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Fecal Coliform (cfu/

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	240.667	2	120.333	0.17071	0.84701
Within	4229.33	6	704.889		
Total	4470.00	8	558.750		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
0.91762	2	0.63203

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$18.7735 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Orthophosphate (mg/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	3.17758e-03	2	1.58878e-03	0.85597	0.55252
Within	1.45320e-02	6	2.42200e-03		
Total	1.77096e-02	8	2.21369e-03		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
8.10206	2	0.0174

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$3.47994e-02 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Total Kjeldahl Nitro

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	1.75895	2	0.87947	1.09489	0.39322
Within	4.81951	6	0.80325		
Total	6.57846	8	0.82230		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
7.46160	2	0.02397

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$0.63374 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by ** in the following table:

No significant differences.

Variable: Zinc (ug/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	34.0356	2	17.0178	3.43331	0.1014
Within	29.7400	6	4.95667		
Total	63.7756	8	7.97194		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
0.87268	2	0.64639

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$1.57427 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Lead (ug/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	6.60222	2	3.30111	0.20068	0.82344
Within	98.6933	6	16.4489		
Total	105.296	8	13.1619		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
1.23159	2	0.54021

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$2.86783 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "" in the following table:

No significant differences.

Variable: Hardness (mg/l)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	1.89720e+06	2	9.48601e+05	0.89879	0.45559
Within	6.33252e+06	6	1.05542e+06		
Total	8.22972e+06	8	1.02872e+06		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
12.0032	2	0.00247

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$726.436 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "" in the following table:

No significant differences.

Variable: pH

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	7.03069	2	3.51534	3.04122	0.12245
Within	6.93540	6	1.15590		
Total	13.9661	8	1.74576		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.56931	2	0.27674

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$0.76023 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by *** in the following table:

No significant differences.

Variable: Turbidity (NTU)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	31.6867	2	15.8433	0.26620	0.77487
Within	357.093	6	59.5158		
Total	388.780	8	48.5975		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
1.58243	2	0.45329

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$5.45507 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Carlson Trophic Inde

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	1020.22	2	510.111	0.80941	0.48841
Within	3781.33	6	630.222		
Total	4801.56	8	600.194		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
3.23790	2	0.1981

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$17.7514 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Color (cu)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	12288.9	2	6144.44	0.85677	0.55216
Within	56133.3	6	9355.56		
Total	68422.2	8	8552.78		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
3.81573	2	0.14839

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$68.3943 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

Variable: Chlorophyll a (mg/cu)

Grouped by: Prim Water Input Mec

	Sum of squares	D.F.	Mean SS	F	P
Between	6322.58	2	3161.29	0.41606	0.6773
Within	45588.2	6	7598.04		
Total	51910.8	8	6488.85		

Bartlett test for homogeneity of variance

Chi square	D.F.	P
2.27243	2	0.32103

Multiple comparisons by method: Tukey

Level of significance: 0.05

No. of groups in Subset	Critical value R for significant difference
2	4.54199
3	4.54199

Above values are tabulated values 'R'. The actual comparison values are calculated by the formula:

$$61.6362 * R * \text{SQRT}(1/N1 + 1/N2)$$

N1 and N2 are the number of observations in the two groups being compared.

Significant differences between pairs of groups are indicated by "*" in the following table:

No significant differences.

APPENDIX G

DRAFT NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION URBAN LAKES STUDY REPORT

REGION 2 URBAN LAKES SURVEY - 1997 through 1998

By Richard L. Newman

REGIONAL SETTING

The New York State Department of Environmental Conservation's Region 2, which consists of the five counties of New York City, is unique among the Regions of the State in that:

- 1 - It is intensely urbanized;
- 2 - It is characterized by a deteriorated infrastructure and an aged housing stock, which give rise to substantial inflow, infiltration (or exfiltration when the wastewater collection system lies above the water table (1)) and water wastage;
- 3 - It is served primarily by a vast combined sewer system having about 540 overflow points. Periodic wet weather overflows from this system constitute a major source of surface water pollutants;
- 4 - The relatively small portion of the collection system which is nominally separate is compromised by numerous illicit connections. This has been abetted by an historical failure to install storm and sanitary sewers concurrently, leading to continuous sewage discharges (due to illegal sanitary connections to storm sewers), sanitary sewer overflows (due to illegal storm connections to sanitary sewers), and excessive flooding (due to the partial or total absence of storm sewers or any other sound form of drainage);
- 5 - It is in the center of a metropolitan area having a population of close to 20 million;
- 6 - The primary receiving waters for wastewater discharges are complex, tidally affected estuaries, having numerous extensions ("tributaries"), many of which have minimal waste assimilative capacity and are severely degraded;
- 7 - Complicated interstate relationships exist within the Metropolitan Area, characterized by excessive finger pointing on environmental (and other) issues;
- 8 - The groundwater resource beneath two of its counties (Kings and Queens) has been mismanaged for over a century. It is characterized by quality deterioration (due in part to sewerage system exfiltration) (1), excessive drawdown along with associated saltwater intrusion, and by subsurface flooding in other areas wherein pumping has been discontinued after low lying structures and infrastructure had been installed without any apparent awareness that the water

table had been artificially depressed;

9 - Much of the shoreline is characterized by derelict piers, bulkheads, and marginal industrial facilities. It is prone to nocturnal dumping and yet it offers little access to the general public. However, the formerly inward-looking population is now looking out to the estuary, and new varieties of shoreline use and development are appearing. The battle is on to retain open space, and to assess and control the impacts of these new developments;

10 - Long term continuous and intermittent raw discharges have continually been discovered. Failure can occur anywhere in the Region's far-flung wastewater infrastructure (due to malfunctioning regulators (there are 490), pump stations (90) and/or associated force mains, siphons, tide gates, treatment facilities, or any of the improper connections discussed in item 4 (as well as sanitary connections to combined sewers downstream of regulators));

11 - In spite of the urbanized character of most of the Region, many as yet unsewered areas experience numerous on-site disposal system failures which result in sewage flows in the streets which, in turn, ultimately discharge to streams or wetlands. This gives these areas (some of which are fairly affluent) an anomalous third world aura;

12 - An extensive system of ponds and lakes, many within municipal parks, had been allowed to deteriorate during the City's fiscal crisis of the mid-70s (most being characterized by excessive eutrophication and sedimentation). Also, numerous streams or parts thereof have been incorporated into the sewer system (wherein some actually end up receiving treatment at water pollution control plants). Where streams have escaped the sewer system, they are often characterized by flash flooding due to the growth of impervious ground cover within their watersheds, and by routine flooding due to the accumulation of trash at culvert entrances and to sedimentation resulting from streambank erosion. Additionally, other streams have endured reduction or elimination of base flow due to urbanization-induced loss of recharge (and over pumping of groundwater (2)), as well as contamination due to urban runoff and on-site disposal system failures (along with direct sewage discharges and discharges from poorly performing package wastewater treatment facilities). Historically, standard gridiron street patterns, along with associated utilities, have been imposed on pre-existing local topography and natural drainage systems.

13 - The intensely developed nature of the Region puts a high premium on land, making the siting of wastewater management facilities very difficult. This has resulted in some innovative approaches such double and triple decking of facilities, siting them over water or underground, and the development of such treatment

processes as step aeration which accomplishes the same secondary treatment results as does conventional activated sludge but with far less tank capacity. Additionally, much of the development in the Region occurred long before the advent of land use planning and zoning, with the result that heavy industry is often located in very close proximity to residential development (and buffers are almost always absent). Since wastewater treatment plants must be located in zones designated for heavy industry (which are sometimes retroactively “spot zoned”), the Region has made it a high priority to ensure that these plants continuously function as good neighbors. Given the potential for process upsets, and a long history of mostly mediocre operation and maintenance, along with periodic intervals of municipal indifference or financial stress, this Regional effort has not always been easy nor successful.

14 - In pursuit of the holy buck, intensive development has long been permitted to proceed on the barrier islands and in other low lying flood-prone areas (including wetlands) along the coast. This was responsible for the extensive damage done by the Ash Wednesday nor'easter of 1962 and the December 1992 nor'easter. The National Weather Service's SLOSH (Sea, Lake and Overland Surges from Hurricanes) Model predicts that if a Saffir-Simpson Category 3 hurricane's right eyewall strikes the apex of the New York Bight, substantial portions of these low lying areas will be inundated. (3)

CONTAMINATION SOURCES

As indicated earlier, there exist within Region 2 the wide variety of contamination sources that one might expect to find in any intensely developed area. These include:

1 - Municipal Wastewater Treatment Facilities, which tend to be sources of oxygen demanding substances (usually measured as five day biochemical oxygen demand), suspended solids, settleable solids, floatable materials, and pathogenic microorganisms. Since these 14 municipal treatment facilities are specifically designed to substantially reduce the discharges of these foregoing pollutants, their impact on the estuary has been to drastically improve water quality relative to the days of massive untreated (or inadequately treated) discharges (which reached into the late 1980s). (4) Additionally, the large regional treatment plants are sources of nutrients, such as nitrogen and phosphorus, as well as toxic organic and inorganic substances (such as metals). New York City's sewage treatment plants (STPs) are not designed to remove these additional substances, but they do, coincidentally, get removed to some extent (or more properly transferred to another medium) by the various processes employed at the STPs. For example, in the aeration tanks, volatile organics are stripped out of the wastewater flow and into the atmosphere, while less volatile organics and metals, which tend to display

an affinity toward particulate matter, are sorbed onto/into organic and biological solids in the aeration and sedimentation tanks, and are thereby transferred to the sludge sidestream. Additionally, some portion of the organic nitrogen load is converted by the suspended media biological process (which is the heart of secondary treatment in New York City), to nitrate (nitrification) and subsequently, to gaseous molecular nitrogen (denitrification), which is emitted to the atmosphere.

2 - Combined Sewer Overflows, which occur during and after substantial wet weather events when the resulting high mixed flows exceed the capacities of the treatment facilities, contain the same contaminants as do wastewater treatment plant effluents, but currently have a more profound impact on the Region's estuarine waters because these discharges are mostly untreated. Furthermore, during intense rainfall (typical of summer thunderstorms), the resulting high flows may resuspend contaminants in particulate form which accumulate on the inverts of large combined sewers during antecedent dry weather periods, and discharge them into local waterways while the regulator devices are in a throttled position (a concentrating mechanism known as the first flush phenomenon). Similarly, accumulated oils, metals and other contaminants on streets, roofs, industrial sites, parks and turf are concentrated and conveyed by early high flows of runoff into combined sewers and discharged to the estuaries when the regulators are throttled. Combined sewer overflows (or CSOs) are responsible for intermittent bacterial standard exceedences at beaches, the presence of floatable materials in the estuary, some toxicity, and nuisance conditions within and adjacent to tidal tributaries due to emergent sludge mounds and their associated sediment oxygen demand (SOD).

3 - Discharges from the Municipal Separate Storm Sewer System (MS4), have a somewhat lower impact than do CSOs because close to 80 percent of the Region is served by a combined collection system, and because much of the area designated as separate does not yet have storm sewers available. While storm sewers do not generally discharge sewage and industrial wastes, they do discharge contaminants flushed off the urban landscape such as metals, toxic organics, nutrients, oils, floatables, oxygen demanding materials, pathogens, salts, and sediments. (5) Additionally, numerous inappropriate sewage and commercial/industrial connections to the MS4 have been discovered, (6,7,8) along with interconnections with the combined sewer system. Furthermore, the aforementioned absence of storm sewers in designated separate areas has led to severe flooding and to attempts to relieve or prevent flooding problems by connecting catch basins and roof leaders to inadequate sanitary sewers. This, in turn, has resulted in some residual flooding, as well as flows that exceed treatment plant capacity, leading to sanitary sewer overflows (SSOs) during and after many rain events. (9) These SSOs, which are similar to CSOs, are controlled in much

the same way through the use of regulator devices. Contaminant discharges from “separate” storm sewers pose an additional problem in that unlike combined sewer outlets which are virtually all located on tidal waters, some storm outfalls are located on the limited freshwater bodies (streams and lakes) of the Region, which generally have very limited waste assimilative capacities. In addition to the runoff that is discharged through storm and combined sewer outlets, a portion flows across the land surface directly into surface waterways. This Non-Point Source of contamination closely resembles separate storm sewer discharges, but unlike other regions of the State, its relative contribution of pollution is small (except in the few remaining undeveloped or very lightly developed sections of the Region) because of the extremely high density of drainage infrastructure).

4 - Small continuous Point Discharges of Untreated Wastewater to surface waters in areas not yet reached by the municipal collection system or where appropriate connections have not yet been made. Closely related, but far more widespread and dangerous to public health is the problem of Failing On-Site Disposal Systems (septic systems or cesspools) wherein poorly treated sewage, which is not able to percolate into the ground, backs up onto the ground surface and subsequently flows into gutters, drains, ditches, streams or wetlands. Both types of sources exist almost solely within Queens and Staten Island, but the on-site disposal system failures on Staten Island, generally caused by a thick clay soil strata that lies close to the surface and/or high perched groundwater, has resulted in high bacterial counts in most interior streams (although small private point discharges have also contributed to this problem).

CORRECTIVE MEASURES

Through major commitments of resources, several of the aforementioned problems have been ameliorated, and some progress has been made to correct others. However, in some cases, corrective action has, thus far only involved repeated rounds of planning.

Wastewater treatment plant problems have been addressed through the upgrading of poorly performing facilities and through the construction of new treatment facilities where none previously existed. Odor problems have been addressed by enclosing process units known to be sources and venting the off-gasses through odor control devices such as chemical scrubbers and/or activated carbon columns, by process improvements, and by improved housekeeping.

The metal loads reaching the headworks of the treatment facilities have been drastically reduced through the implementation of a highly effective permit mandated industrial pretreatment program, along with the implementation of a program designed to reduce the aggressiveness of the water supply through the addition of phosphates and caustic. (10)

The matter of nitrogen reduction (nitrogen is considered to be the limiting nutrient in estuaries within and adjacent to the Region with regard to eutrophication) is still in dispute, with the City of New York resisting the current conclusions of the Comprehensive Conservation and Management Program (CCMP) developed by the Long Island Sound Estuary Study. Much of the City's objection is based on their belief that their predictive tool (the System Wide Eutrophication Model (SWEM)), which was calibrated and verified through an intensive sampling program, is far superior to the tool used by the Long Island Sound Program (the LIS 3 Model), which utilized "off the shelf" data for calibration and verification. Nevertheless, the City is moving forward with a variety of nitrogen removal pilot plant studies, and they have reached their own internal consensus on the most appropriate technology to apply when an overall interagency consensus is achieved on the required levels of nitrogen removal necessary to relieve the severe hypoxic conditions frequently observed in the Sound. Unified strategies have yet to be developed for addressing the other severely eutrophic estuarine waters of the Region, which include Jamaica Bay and Raritan Bay. It must be noted that the nitrogen problem has been exacerbated by the decision of Congress to end ocean disposal of sewage sludge at the 106 mile site (the centrate that is a byproduct of the dewatering of sludge (which is necessary in order to reduce the volume of the sludge to manageable levels for beneficial use or disposal) is very high in nitrogen content, and this nitrogen is not currently removed to any great degree when the centrate is cycled back through the plant).

Discharge permit mandated programs such as combined sewer overflow abatement, MS4 control, regulator improvement, the shoreline survey, and inflow and infiltration studies, along with excessive flow/water conservation and CSO/floatables administrative orders have led to:

- 1- The discovery and elimination of many untreated discharges;
- 2 - The retention of about 42 percent of the wet weather flow in combined sewers (it was about 18 percent prior to 1990), with associated substantial reductions in ambient bacterial concentrations (and the resulting opening of beaches by the New York City Department of Health at Sea Gate (Brooklyn) and at South and Midland Beaches (Staten Island));
- 3 - A vast reduction in the discharge of floatables (mainly through the implementation of booming and skimming at major combined outfalls, and through the replacement of hoods (which are designed to create a water seal which prevents sewer gases from reaching street level) in catch basins (about 70,000 were missing));
- 4 - The elimination of hydraulic overloads at the treatment plants (which allows for far more wet weather treatment capacity);

5 - A substantial reduction in water demand; and

6 - The ongoing modernization, alarming and telemetering of about 100 major regulators and all remote and unmanned pumping stations, that allows for far more rapid responses to system failures which may result in bypasses.

Most on-site disposal system failures and small privately owned point sources can only be corrected through further extension of the municipal wastewater collection system, and it has been only through whining, cajoling or through innovative grafting of environmental benefit projects onto unrelated administrative orders that we have been able to have the City provide the infrastructure which helped us to correct a few of these problems. Full correction lies far in the future. Full CSO abatement consistent with EPA's Policy, our TOGS (Technical and Operational Guidance Series), and the current discharge permits also lies far in the future, with the City and its consultants grudgingly pursuing or more frequently rejecting innovative approaches and best management practices (BMPs), although there appear to be few alternatives to the more traditional heavy construction approaches to abating the large CSOs located on the badly degraded tidal "tributaries".

In order to address the coastal flooding problem, the Department has, in partnership with the Army Corps of Engineers and the City of New York, pursued a program of beach nourishment. This involves re-occurring efforts wherein sand is dredged from appropriate subaqueous sources and placed in a pre-designed fashion on a beach in order to widen it and raise its elevation. This high maintenance approach is currently favored over hardening or armoring the shoreline.

The subsurface or groundwater flooding problem is only being addressed at the planning level, if at all. Comprehensive planning for managing the aquifer system under Kings and Queens Counties has been stimulated both by droughts and by occasional public outrage over flooding directly caused by the abandonment of pumping by public utilities (the Flatbush Water Supply in 1947 and the Woodhaven Water Supply in 1974; the City would have completely stopped pumping the Jamaica system when they took it over earlier in the decade if they could have supplied the entire former franchise area with upstate reservoir water through the existing distribution system (as it is, they reduced pumping enough to flood the newly constructed Archer Avenue Subway Line)). In 1982, H2M completed a study (Brooklyn-Queens Aquifer Management Feasibility Study) for the Corps of Engineers, as requested by DEC pursuant to a then existing cooperative agreement, which recommended the use of three major pumping centers (at Prospect Park, at Highland Park, and at Cunningham Park) in order to obtain groundwater for use as a municipal water supply supplement (this study did not dwell on subsurface flooding). In 1987, O'Brien and Gere completed another study (Brooklyn/Queens Aquifer Study) for the New York City Department of Environmental Protection, who in partnership with DEC (we gained entry by contributing 205(j) pass-through funds, as authorized by former Water Division

Director Dan Barolo) and with the US Geological Survey (who constructed a Brooklyn/Queens Aquifer Model, through refinement of their Long Island Aquifer Model). This study constituted the only real effort to develop a truly comprehensive management plan for the aquifer system, since it addressed the use of the resource as a water supply supplement, recharging, monitoring and protecting the resource, and “alleviating adverse impacts of low and high groundwater levels.” Interestingly, as a result of the urgency created when elected officials (stimulated by community outrage over subsurface flooding) assailed former NYCDEP Commissioner McGough’s office (as well as our Region 2 Office), DEP was able to rapidly initiate the study by amending their CSO Abatement contract with O’Brien and Gere. This effort was to be followed up with additional study and the development of a facility plan, but no action was taken for several years, and this writer was reduced to carrying a copy of the O’Brien and Gere Report to meetings on groundwater flooding convened by elected officials or afflicted public agencies (like the NYC Board of Education), and calling for implementation of the document. Finally, at the end of 1998, Malcolm Pirnie completed a report (Feasibility Report for Use of the Brooklyn/Queens Aquifer as an Additional Potable Water Supply) for NYCDEP’s Bureau of Water and Sewer Operations (which was not involved in the previous efforts and which developed a scope of services that omitted the flooding issue as well as the necessary refinement of the comprehensive approach suggested by the 1987 Report), again in cooperation with the USGS who further refined their aquifer model and utilized it to assess alternatives. We provided input at monthly progress meetings (but this time, we brought no funding), and provided a rather harsh review of the product (not of what was produced but rather, what was not produced). This draft final report recommended an array of specifically sited wells (to be used both for supply and diffusion (recharge)) for three different pumping scenarios (100 mgd, 150 mgd and 225 mgd, with a different duration for each scenario), raw water mains, two regional treatment plants, and treated water distribution infrastructure. Well siting was based on modeling optimization for water supply (but definitely not for flood control) and on minimum buffers with regard to contamination sources (real and potential) as determined by the GIS prepared for the Study by Hunter College (exfiltrating municipal sewers were not considered). Based on concerns expressed by DEP Commissioner Miele late in the study (probably based on the ever worsening Archer Avenue Subway flooding fiasco), the Report also recommended further study to address the flooding issue and to develop a comprehensive aquifer management plan (or perhaps our incessant badgering has finally paid off).

In order to avoid the long standing practices of imposing a gridiron street pattern on the local topography and drainage pattern, and routinely incorporating all streams into the municipal sewer system (separate or combined), the City has, with our strong support, initiated a program of watershed level drainage planning for the southern end of Staten Island (the Bluebelt Program). This involves planning for sanitary sewers (to eliminate failing septic systems, direct sewage discharges and badly acting private, commercial and institutional (PCI) package plants), maximum use of existing streams and wetlands for stormwater conveyance and storage with culverts and storm sewers being planned only

where the capacities of the natural systems are exceeded, and the extensive use of best management practices (BMPs) for erosion control, sedimentation control, flood control and stormwater treatment. The BMPs include ponds, stilling basins, detention basins, filters, stream enhancements, streambank enhancements, wetland enhancements, artificial wetlands, vegetative buffers and micropools.

AMBIENT MONITORING PROGRAMS

The severity of the water quality problem in and around Region 2, as well as the degree of improvement derived from the various correction measures being implemented, is best evaluated through a well designed comprehensive and long term ambient monitoring program. Several such programs have been in effect for varying periods of time, including the following:

- 1 - New York City's Harbor Survey, which was initiated in 1909, performs an ever increasing series of conventional and eutrophication related analyses at 52 open water stations throughout the Region;
- 2 - EPA's Bight Monitoring Program, which was substantially enhanced after the twin disasters of the summer of 1976 (the washup of sewage related floatables onto the beaches of southern Long Island (from the Hamptons to Rockaway) and the intense Ceratium tripos bloom off the New Jersey Coast), consists of a series of points along the coasts of Long Island and New Jersey, along with a series of transects perpendicular to the coasts. Samples are analyzed for conventional pollutants, nutrients, chlorophyll, and algal speciation.
- 3 - The Interstate Sanitation Commission's sampling network, which consisted of five runs within the Metropolitan Area. Water column samples were analyzed for conventionals, nitrogen and chlorophyll. The runs were replaced by intensive monitoring when that approach became all the rage, but general ambient monitoring was discontinued in the late 1980's when the Commission's resources could no longer support the program.
- 4 - The New York City Department of Health's Beach Sampling Program wherein water column samples are collected at designated points at public and regulated private beaches during the bathing season. Samples are analyzed for total and fecal coliforms, with the total coliform indicator used for decision making on beach closure.
- 5 - Pursuant to State requirements and the requirements of the United States Food and Drug Administration (FDA), the Department's Bureau of Shellfisheries conducts routine monitoring of waters from which shellfish are harvested for

intrastate and interstate shipment. Coliform analyses are performed and determinations are made, based on very rigorous standards, as to whether harvesting can be continued. The Bureau also monitors waters from which harvesting is conducted for subsequent relaying in cleaner waters or for controlled biological cleansing (depuration). There are no current depuration operations within New York State (but several exist within New Jersey's portion of the Metropolitan Area. Both our Bureau of Shellfisheries and New Jersey's Department of Environmental Protection are assisted in their shellfish monitoring programs by the Interstate Sanitation Commission.

6 - The United States Geological Survey monitors a series of wells, mainly on Long Island (including Brooklyn and Queens), for elevation and for an array of water quality parameters.

7 - Numerous special efforts have taken place over the last three decades which have involved intense sampling activities, including; 208 planning and associated tributary assessments, the various past and ongoing CSO abatement projects, clean lakes projects funded under section 314, and the ongoing bluebelt program.

8 - The Regional Office has attempted to maintain ambient water quality monitoring through the statewide water quality surveillance network (WQSN), and through a regionally initiated tributary monitoring network, utilizing the laboratory services provided by the Interstate Sanitation Commission in the late 1970s and early 1980s. Both programs were eventually phased out; the WQSN when it was replaced by the Rotating Intensive Basin Sampling (RIBS) Program (which entered the Metropolitan Area for the first time in 1998), and the Regional tributary program when other priorities advanced to the forefront.

As discussed above, only through the development and implementation of a comprehensive ambient water monitoring program have we been able to assess the extent to which our expenditure of vast billions of dollars on wastewater treatment facilities have brought about desired enhancements in water quality. Additionally, along with appropriate water quality modeling, the results of ambient monitoring will allow us to make all necessary mid-course adjustments. Furthermore, these results will permit us to make more refined decisions with regard to our Priority Waterbody List, and to advance better stream reclassification proposals. Finally, we can utilize ambient water monitoring results to evaluate the impacts of nonpoint sources (or more properly in Region 2, urban runoff) as well as the effectiveness of future measures designed to control them.

NEW REGION 2 AMBIENT MONITORING PROGRAM

In 1996, Region 2 proposed an ambient monitoring program which was designed to provide a continuing assessment of water quality throughout the City at sensitive locations not visited by any other public agencies. The new network includes 32 tidal extensions (tributaries) and interior streams, eight of which are to be sampled each year for a three year cycle; nine beaches which are likely influenced by combined sewer overflows, three of which are to be sampled each year for a three year cycle; and 27 lakes and ponds, nine of which are to be sampled each year for a three year cycle. To determine seasonal impacts, each lake/pond will be sampled during the spring, summer and fall. Due to resource limitations, only water column samples will be gathered. In spite of their obvious great value, sediment and biological sample gathering must be held off for another day. The Interstate Sanitation Commission has agreed to perform the necessary analyses (or have them performed by their contract laboratory), making it unnecessary for us to expend the Department's sampling funds, which we were recently permitted to utilize for ambient as well as source monitoring.

YEAR ONE PROGRAM

To initiate the program, we decided to confine the first year's effort strictly to the first nine lakes. These included Wolf's Pond and the Richmondtown Millpond in Staten Island, the Harlem Meer in Manhattan, Van Cortlandt Lake in the Bronx, Prospect Lake in Brooklyn, and Conselyea's Pond, Oakland Lake, Kissena Lake and Meadow Lake, all within Queens. All lakes and ponds in the first set lie wholly or partially within New York City Parks, and all are either totally artificial or anthropogenically enhanced to a substantial degree (as opposed to many of the lakes in the proposed second set which have preponderantly private frontage with only minimal public access). The Richmondtown Millpond, Van Cortlandt Lake and Conselyea's Pond were created by impounding Richmond Creek, Tibbetts Brook, and Laurelton Creek respectively. Prospect Lake and the Harlem Meer were excavated during the construction of Prospect and Central Parks, the remarkable creations of Frederick Law Olmsted and Calvert Vaux. Both are mainly fed by City Water. Wolf's Pond was created by artificially cutting off a small, partially enclosed portion of Raritan Bay. (11) The enclosure was subsequently filled by runoff, tributary flow and fresh groundwater (however, an alternative source holds that the Pond originated as a kettlehole (12)). Meadow Lake, which was excavated for the 1939 World's Fair, is underlain by a tidal wetland which was filled over many years with coal ash collected mainly from Brooklyn. It is fed primarily by groundwater. Kissena Lake sits astride an old millpond. It now has a concrete shoreline and it is fed by City water. Finally, Oakland Lake is the closest in the group to approaching a natural state, originating as a kettlehole in the ground moraine formed by the Wisconsin Glaciation. (13)

The sampling program was designed assess the trophic state of each lake/pond, and to

determine the impact of urbanization. We attempted determine trophic state by examining secchi transparency, nutrient species, and chlorophyll pigments. The impact of urbanization was evaluated by examining samples for turbidity (as a surrogate for sediment input) and metals (zinc, copper, lead and cadmium). While no raw sewage outlets, CSOs nor treatment plant outlets are known to discharge directly into the lakes or their tributaries (with the exception of the Wolf's Pond and Richmondtown Millpond systems), we chose to examine a few sanitary parameters such as fecal coliform, fecal streptococcus (while the ratio of fecal coliform to fecal strep is no longer considered to be a reliable mechanism to differentiate between human fecal contamination and that from other warm-blooded animals because of the variable decay rates of the various fecal strep species (14), the ratios may still be valid over small areas and we chose to utilize them as a guide), and total organic carbon in order to assess possible impacts of failing on-site disposal systems, sewer leakage, animal wastes in urban runoff, and contributions from flocks of waterfowl. In order to evaluate the behavior of the lakes seasonally, we tried to sample in the spring, summer and fall. To determine the extent, if any, of thermal stratification, we conducted vertical profiling of temperature, pH, conductivity and dissolved oxygen with a Hydrolab Reporter Water Quality Multiprobe in association with a Hydrolab Scout 2 Display Unit at the deepest point of the lake, which we located by means of soundings with the secchi disk along several transects. Water samples were collected for all but bacteriological analyses with a Lab-Line water sampler at a depth of one foot below the surface, and also at one foot above the bottom for nutrients and oxidation-reduction potential (ORP or Eh). Bacteriological samples were taken directly with appropriate sample bottles at one foot below the surface. Visual observations were made following the general protocols used in the CSLAP (Citizens State Lake Assessment Program). As an afterthought, during the third seasonal set, we decided to include toxicity samples which would be sent to the Hale Creek Laboratory for the microtox test (which utilizes luminescent microorganisms (reduction in light emission is proportional to the toxicity of the sample)).

The seasonal sampling sets (which were preceded by a field reconnaissance and a discarded summer of 1977 sampling effort during which we attempted to refine our techniques) each involved four field days of effort wherein we visited Wolf's Pond and the Richmondtown Millpond on day one, the Harlem Meer and Van Cortlandt Lake on day two, Prospect Park Lake and Conselyea's Pond on day three, and Oakland Lake, Kessina Lake and Meadow Lake on day four. We navigated on the lakes (except for the Richmondtown Millpond which was too shallow and inaccessible) using a canoe borrowed from the New York City Department of Parks' Natural Resources Group (who also gave us written permission to ply their lakes (which bear our classifications)). Logistical challenges included equipment transfer between vehicle and canoe, launching and landing the equipment laden canoe, security of equipment in an urbanized environment (as well as patiently coping with a mild barrage of citizen commentary and interrogation), traversing ground heavily occupied by flocks of waterfowl, coping with the six hour shelf life of the bacteriological samples, and heavy traffic congestion encountered in moving between the lakes, the Interstate Sanitation Commission's contract laboratory (Chemtech in Teaneck,

New Jersey, which is no longer considered acceptable by the Department), and the ISC laboratory in Staten Island. The major laboratory problem was that the method detection limits used for nutrients, especially for the phosphorous species (0.1 mg/l) was far too high (it should have been two orders of magnitude lower). Additionally, the pH probe on the Hydrolab failed during the third (summer of 98) round and pH subsequently had to be read in the laboratory.

SAMPLING RESULTS AND CONCLUSIONS

The results developed from the first round of the urban lake/pond sampling program can be observed in the attached ISC data sheets and the resulting excel spreadsheet developed by the Region. Some observations that could be made and conclusions that could be drawn are as follows:

- 1 - Only Oakland Lake, the deepest by far, stratifies during the summer.
- 2 - The outlet structures at Conselyea's Pond and at Meadow Lake were not in good repair, allowing for substantial saltwater intrusion into these impoundments.
- 3 - Based on Carlson's Trophic Index, all lakes/ponds are either eutrophic or hypereutrophic (except for the Richmondtown Millpond, because of its extremely short residence time), with surface waters tending to be substantially supersaturated with respect to dissolved oxygen during daylight hours (during warm weather).
- 4 - Thanks to appropriate maintenance (such as aquatic weed harvesting), some of the lakes/ponds are still somewhat aesthetically appealing and are generally meeting designated uses (fishing and passive recreation along the shoreline). Others, however, appear to be badly degraded (Conselyea's Pond occasionally emits hydrogen sulfide gas, while the Richmondtown Millpond boasts of signs warning of dangers due to polluted waters (in the middle of an historic restoration zone)).
- 5 - The base flow in Laurelton Creek, the feeder stream to Conselyea's Pond, is virtually nonexistent (due to loss of recharge and overpumping), resulting in a series of unconnected hypereutrophic impoundments which receive flow only after wet weather events.
- 6 - The summer round of toxicity testing using Microtox revealed a problem in the Richmondtown Millpond.
- 7 - pH readings seem to indicate that all lakes are adequately buffered against acid

rain.

8 - Low metals concentrations and the virtual absence of oil sheens seems to indicate that parklands are providing some buffering against contaminated urban runoff.

PRELIMINARY REMEDIAL RECOMMENDATIONS

In order to begin to correct the multifaceted problems observed at the nine first round urban lakes and ponds of Region 2, we suggest the following:

General -

- 1 - Initiate efforts to reduce the infestation of all lakes/ponds by large flocks of waterfowl;
- 2 - Develop a nutrient budget for each watershed;
- 3 - Continue the triennial monitoring program, and add sediment and biological monitoring.

Specific -

1 - Wolf's Pond

Implement Bluebelt recommendations, including the provision of sanitary sewers throughout the developed portion of the watershed to eliminate all remaining raw sewage discharges and all failing on-site disposal systems, and implement drainage improvements including the provision of BMPs designed to improve stormwater quality and to reduce erosion and sedimentation by attenuating storm flows and velocities, and by enhancing the stream and its banks.

2 - Richmondtown Millpond

Implement Bluebelt recommendations, including the provision of sanitary sewers throughout the developed portion of the watershed to eliminate all remaining raw sewage discharges and all failing on-site disposal systems, and implement all drainage improvements, including the provision of BMPs designed to improve stormwater quality and to reduce flooding, erosion and sedimentation by attenuating storm flows and velocities, and by providing improvements to the stream (Richmond Creek) and its banks. Dredge the Millpond. (15) Trackdown the source of the toxicity.

3 - Harlem Meer

Improve erosion control within the watershed. Increase municipal water input to reduce residence time. Consider reuse of water, with treatment as necessary, to avoid adding an additional demand to the City water supply, and an additional hydraulic burden to the combined sewer system and to the Wards Island Wastewater Treatment Plant.

4 - Van Cortlandt Lake

Implement the recommendations of the Section 314 Clean Lakes Diagnostic - Feasibility Study, including dredging and rehabilitation of the Henry Hudson Lagoons (which were designed to remove sediment and other pollutants from Tibbetts Brook, upstream of the Lake), and divert highway drainage around the Lake. (16) The long festering McLean Avenue raw sewage discharge to Tibbetts Brook was abated by Region 3 about 15 years ago when they obliged the City of Yonkers to terminate illegal sewage discharges from several apartment buildings to the storm sewer system, and to correct numerous interconnections between the municipal sanitary system and the storm sewer system.

5 - Prospect Lake

Increase municipal water supply inflow to reduce residence time. Consider reuse of water (with treatment as appropriate) to reduce burden on the municipal water supply system, and on the wastewater collection and treatment system. Divert road drainage around Lake. Develop a phosphorous budget. Consider phosphorous removal from City water supply inputs. Consider dredging to interrupt cycling of phosphorous.

6 - Conselyea's Pond

Repair outlet weir to eliminate inflow of saline water. Provide municipal water or pumped groundwater to the head of tributary Laurelton Creek to restore baseflow (Laurelton Creek and the no longer existing Brookfield Pond (which was located a few blocks upstream of Conselyea's Pond) were once part of the City of Brooklyn's water supply (as were many of the other streams of southern Long Island which originated at the terminal moraine and flowed south across the outwash plain to the back bays)). (17) Today, the Laurelton Creek system, which includes a series of small, stagnant, hypereutrophic impoundments is ephemeral, having storm runoff as its only source of fresh water. Dredge the Pond (and the upstream impoundments) to remove anoxic deposits (which are the source of the hydrogen sulfide observed by staff during the study), and to interrupt cycling of nutrients. Re-assess the possibility of leakage from adjacent sewers into the Pond. Consider in-lake aeration if aforementioned measures fail. Maintain Laurelton Creek and the adjacent shoreline.

7 - Oakland Lake

Implement recommendations of the Oakland Ravine Project, including diversion of additional stormwater to the lake (and away from existing combined sewers which currently overflow to Alley Creek), dissipation of energy from this stormwater by passing it through a series of plunge pools, check dams and rock channels, and removal of sediment, floatables, debris and other pollutants by passing the stormwater through additional pools and wetlands. (18) Replant eroded portions of the watershed.

8 - Kissena Lake

Increase flow of City water through the lake to reduce residence time. Reuse water and treat as appropriate to minimize stress on the water supply system, on the combined sewer system (the interceptor sewer is constricted to the extent that twice design flow cannot be brought to the wastewater treatment plant (a State requirement designed to minimize the frequency, duration and intensity of combined sewer overflows)), and on the Tallman Island Wastewater Treatment Plant. Dredge the Lake to interrupt cycling of nutrients.

9 - Meadow Lake

Repair the outlet tidegate to prevent the inflow of polluted marine water from Flushing Bay into the Lake. While the Lake is currently overwhelmed by the inflow of groundwater very high in phosphorous as the result of being constructed on an old tidal marsh, because it is the focus of a major park in Queens County, correction should not take the “band-aid” approach recommended by New York City’s consultants. (19) Rather, it should involve dredging to remove superficial nutrient and copper (due past copper sulfating operations) laden organic sediments and to deepen the lake, and the installation of an impervious liner to prevent the infusion of phosphorous saturated groundwater from the underlying tidal marsh. Water input should then be provided by the municipal system (since the alternative of deep wells might also supply water with elevated phosphorous content due the fact that a portion of it would have recharged down through the marsh, and since intensive, long term pumping might encourage saltwater intrusion into the aquifer). To minimize stress on the water supply system, the water should be reused, with treatment provided as appropriate.

Special thanks to Region 2 Staff Engineers Alexander Becker and Brian Mitchell for their work in gathering data and developing this report.

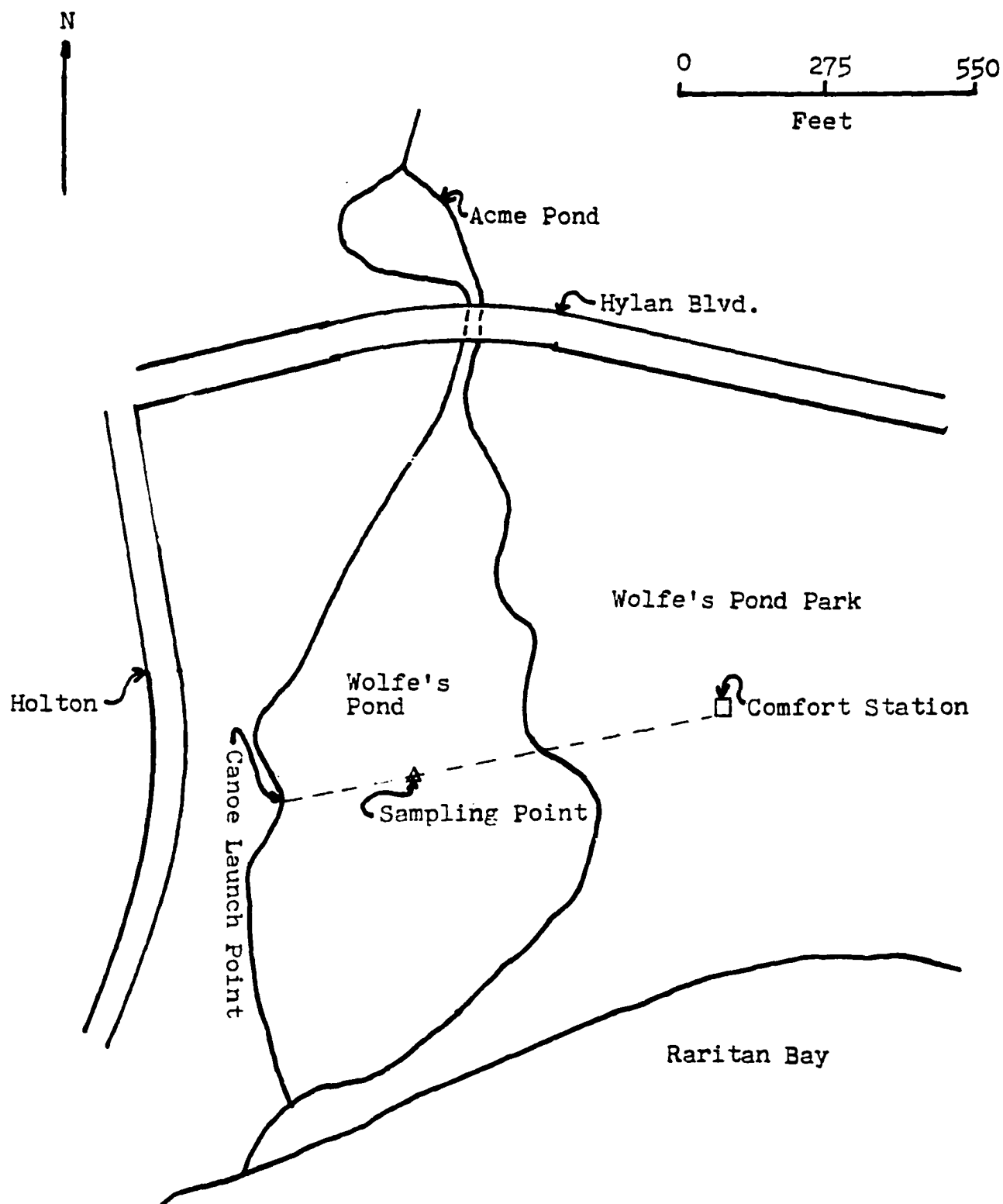
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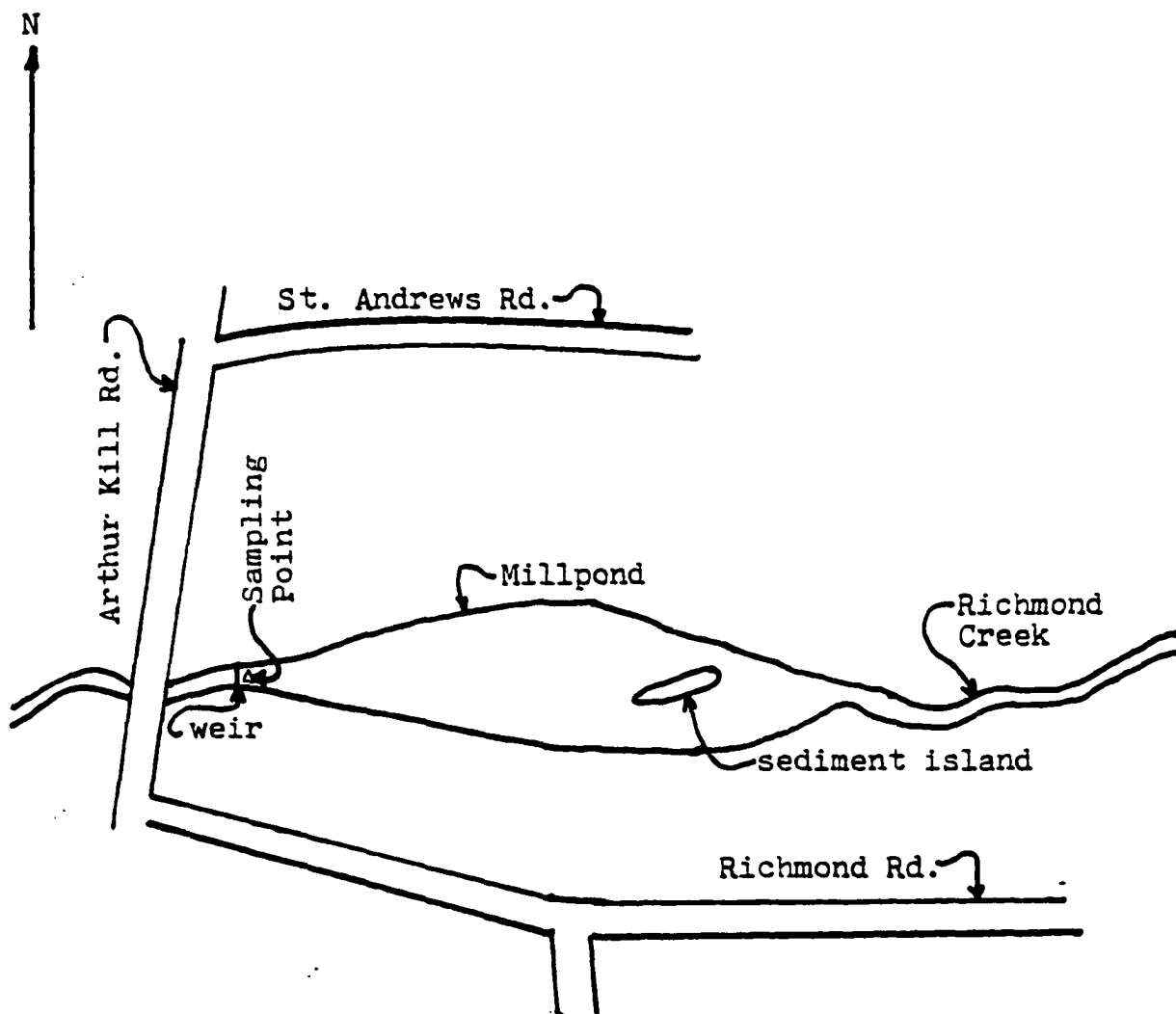
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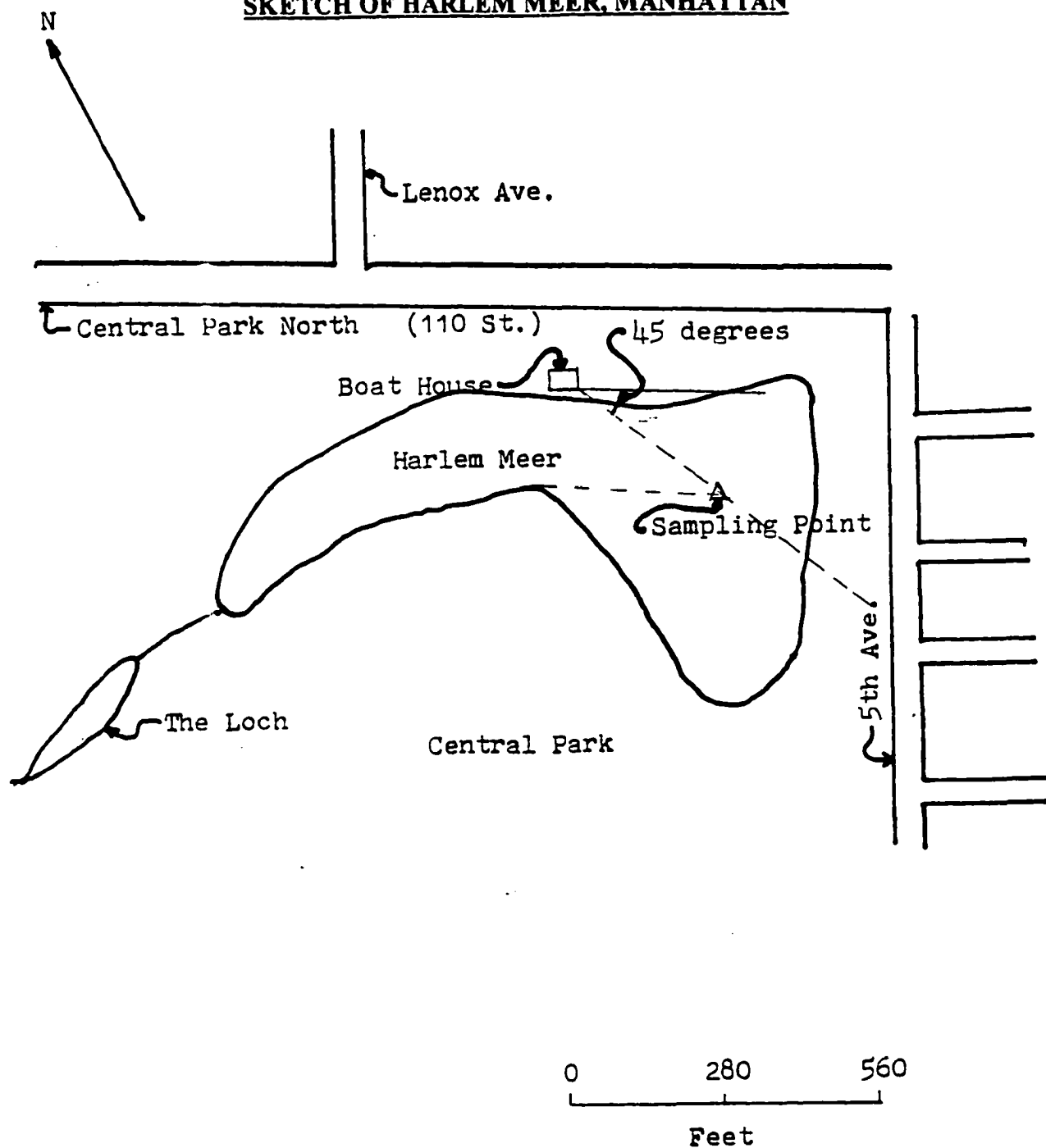
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SKETCH OF RICHMONDTOWN MILLPOND, STATEN ISLAND

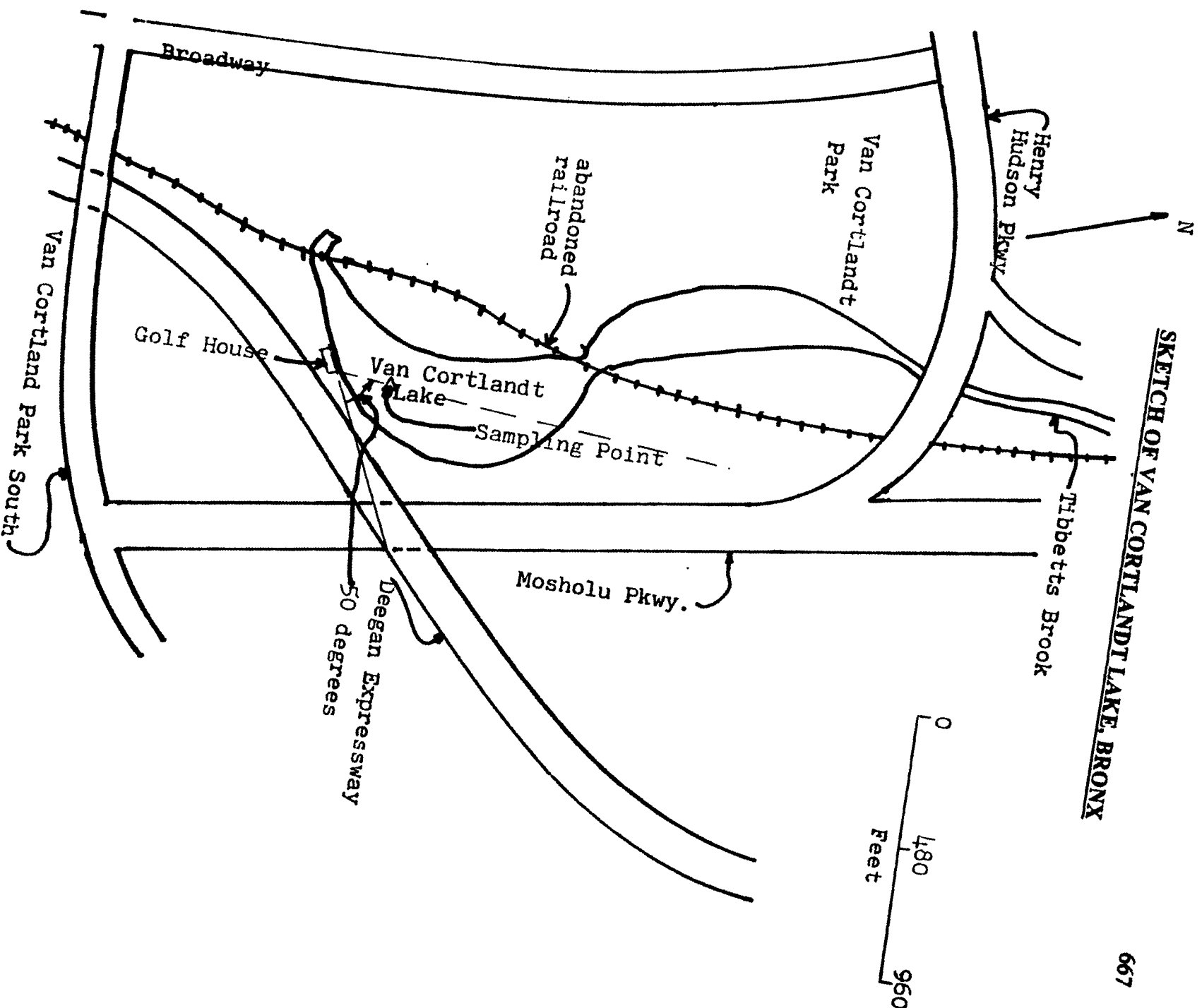


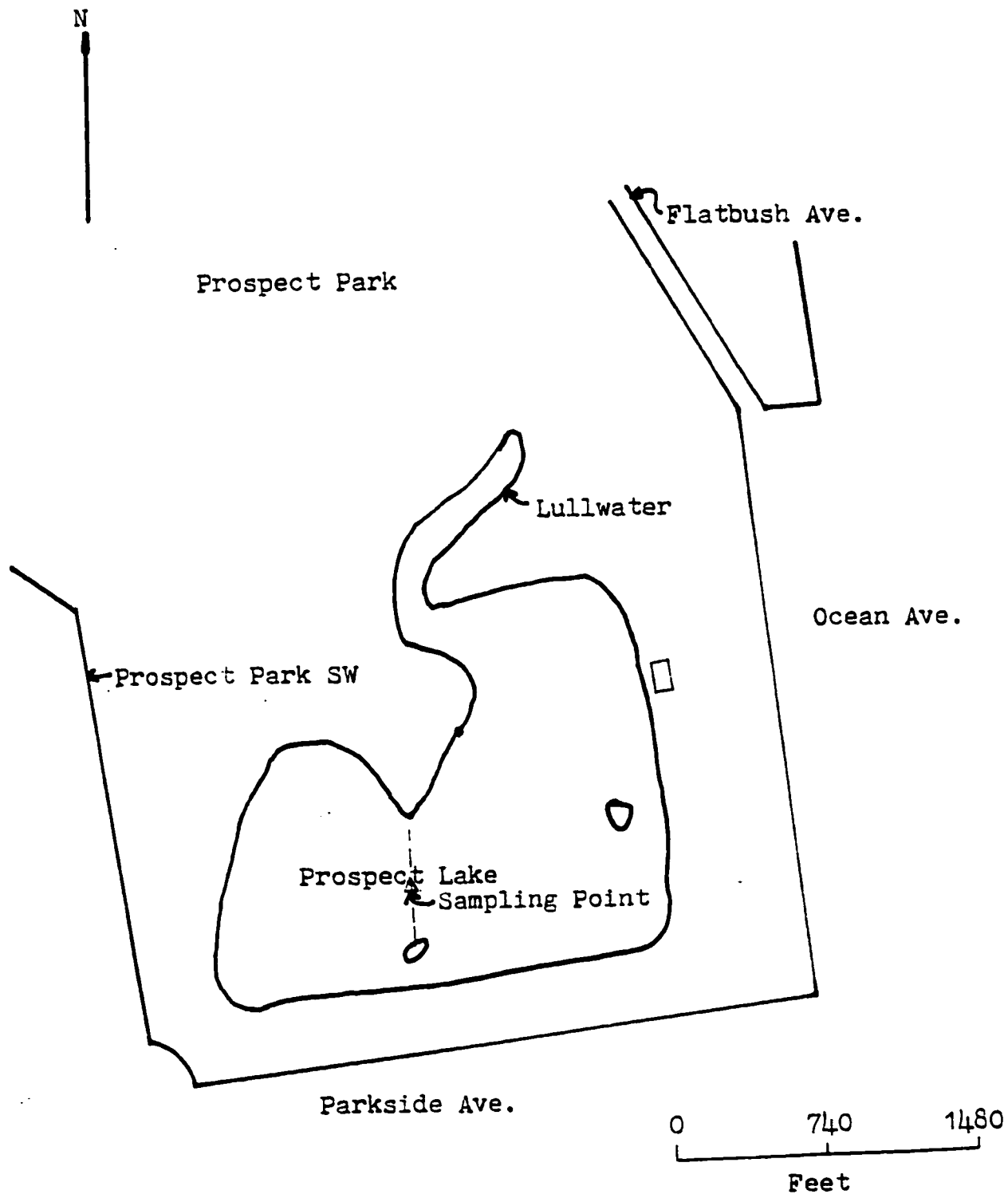
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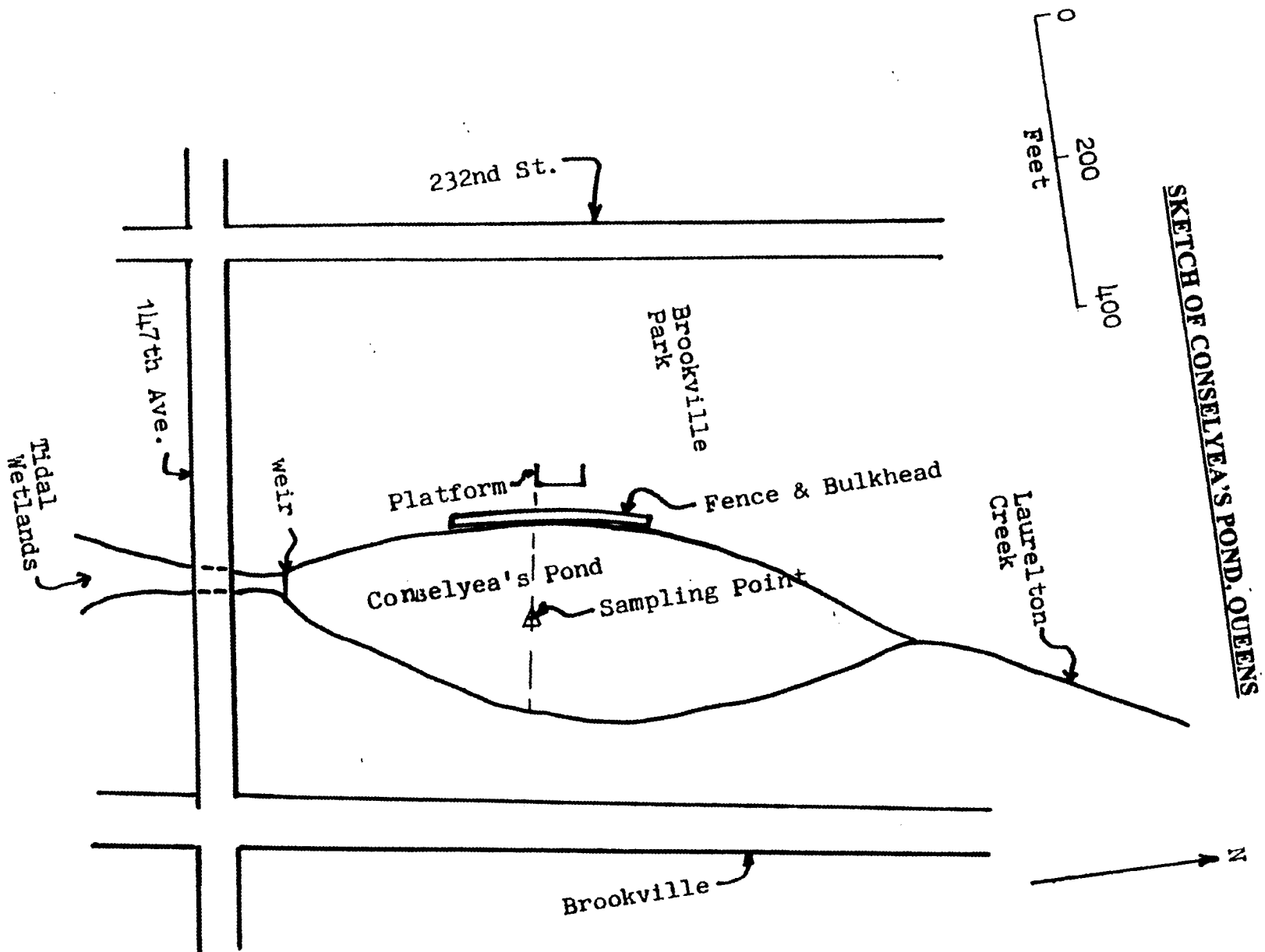
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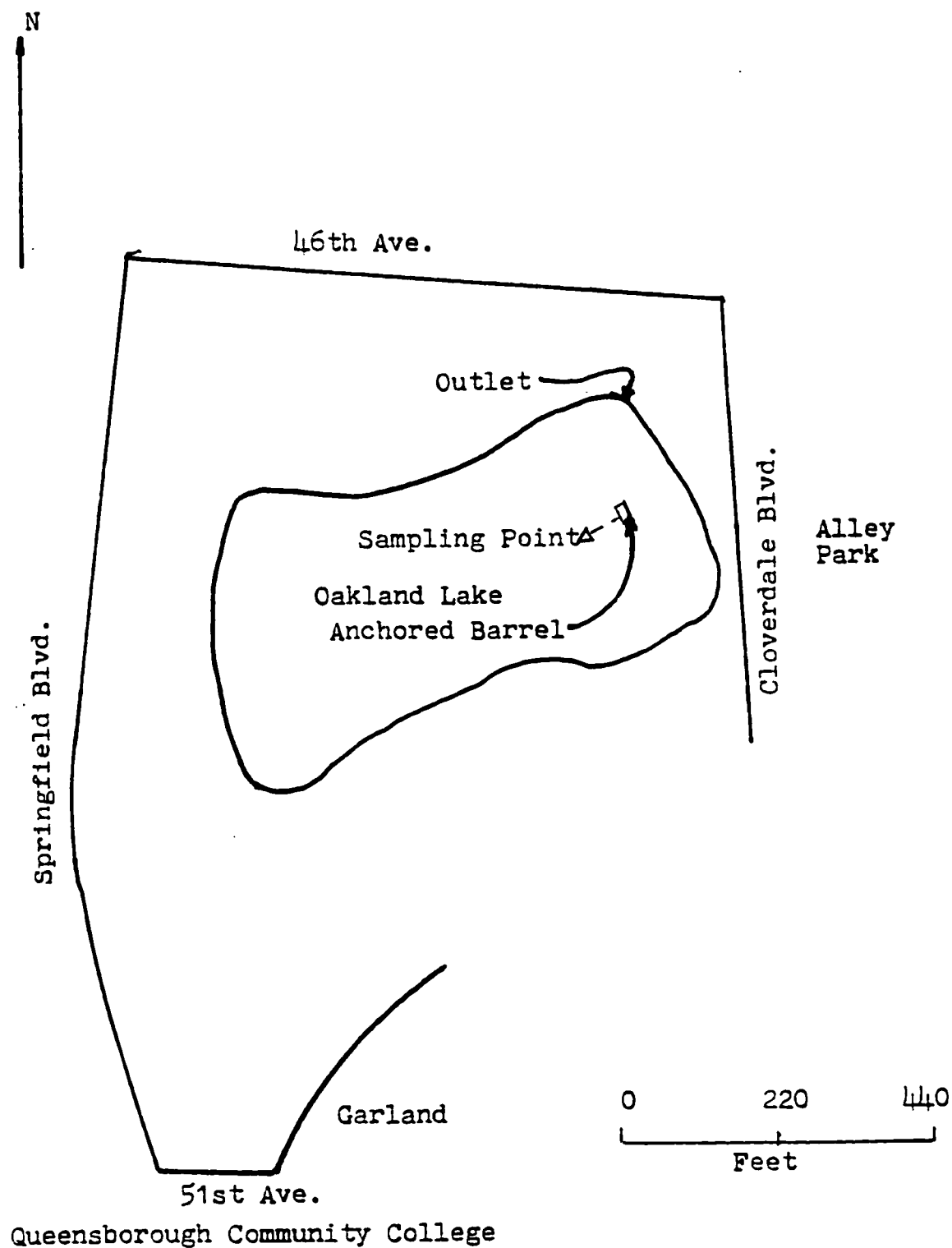
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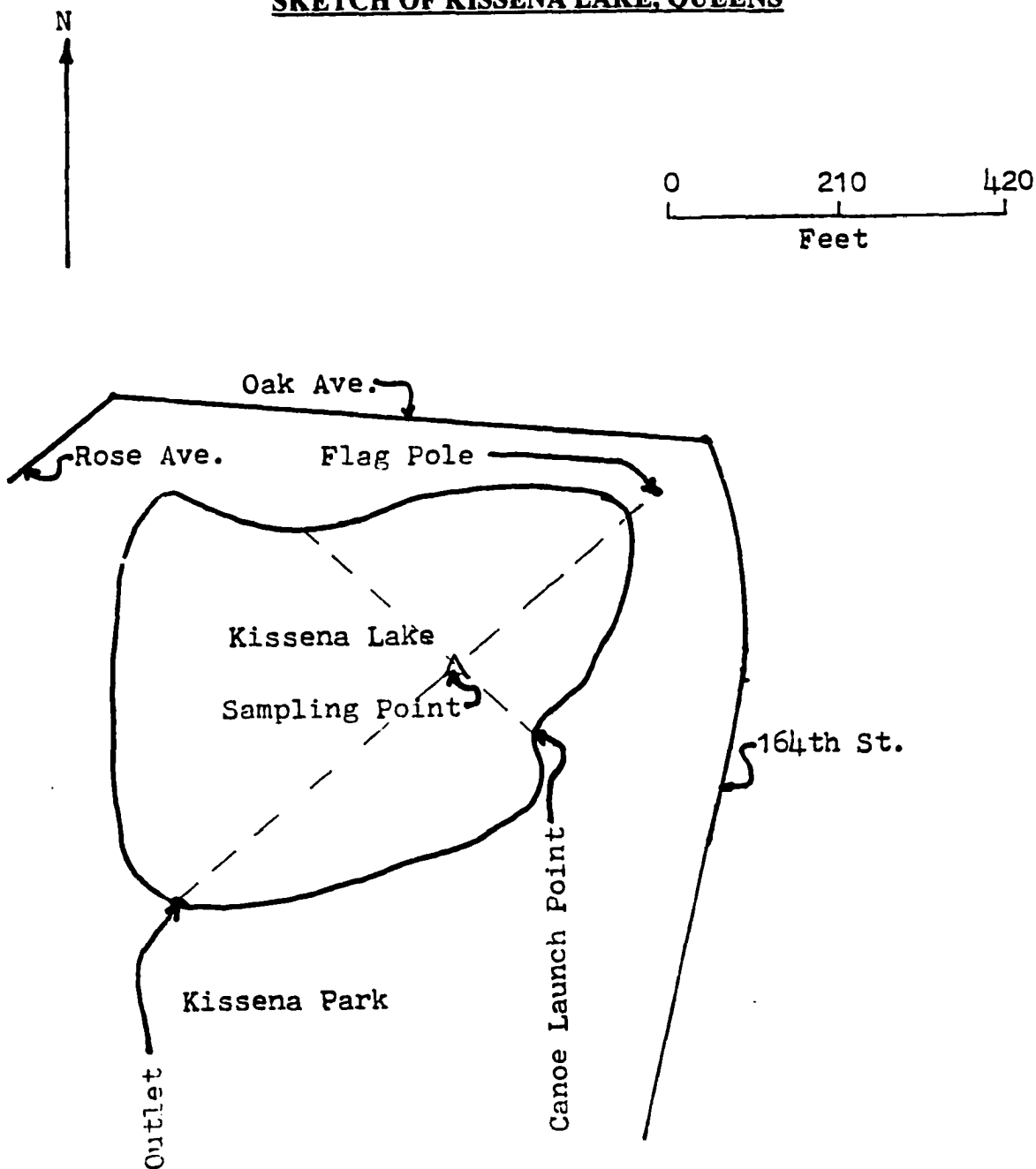
SKETCH OF VAN CORTLANDT LAKE, BRONX



SKETCH OF PROSPECT LAKE, BROOKLYN

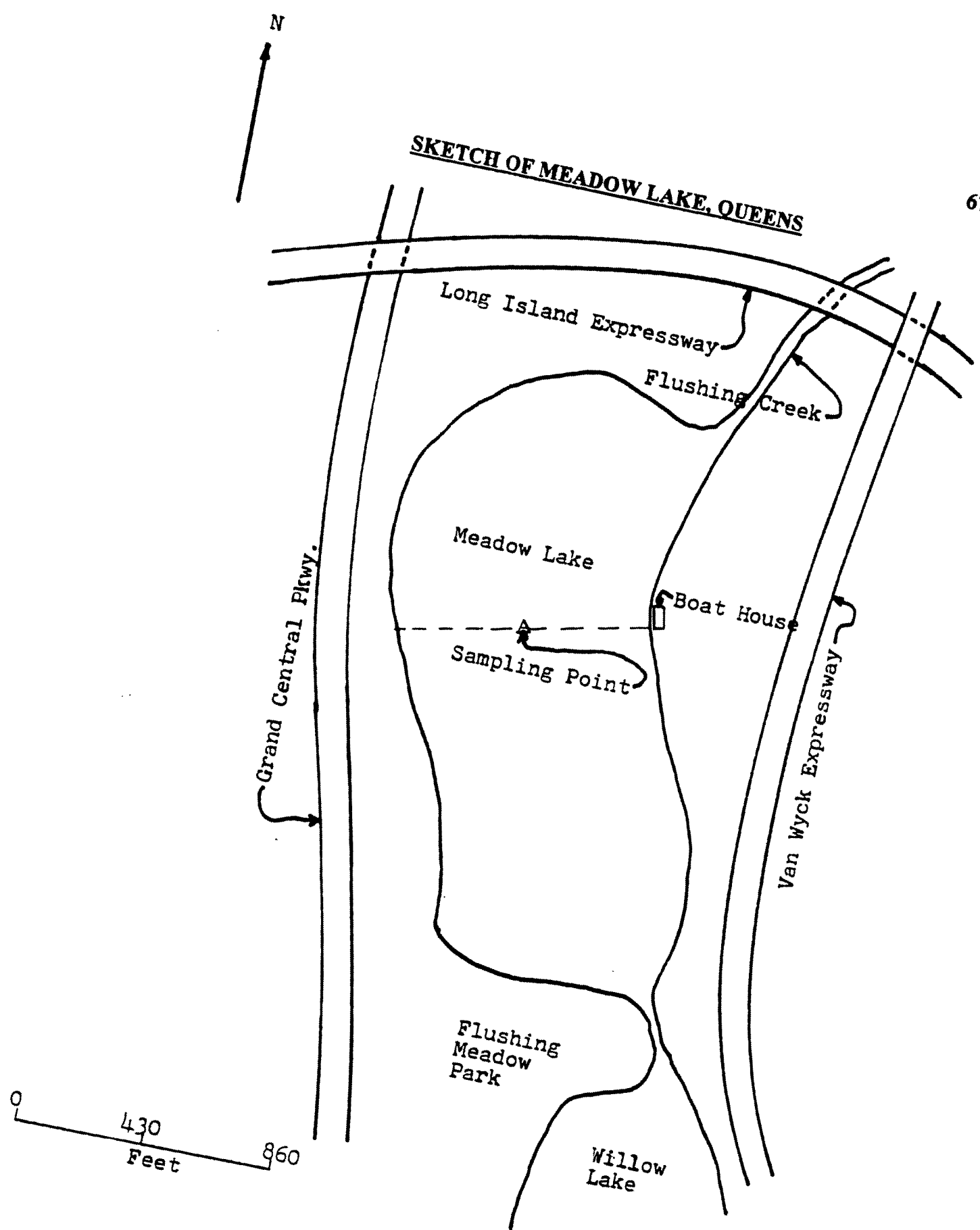


SKETCH OF OAKLAND LAKE, QUEENS

SKETCH OF KISSENA LAKE, QUEENS

SKETCH OF MEADOW LAKE, QUEENS

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INTERSTATE SANITATION COMMISSION

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
PROJECT: Richard Newman, NYDEC

	11/10/97			11/12/97				11/25/97				12/04/97					
	1A	1B	2	3A	3B	4A	4B	19 5A	5B	22 6A	6B	25 7A	7B	29 8A	8B	33 9A	9B
Turbidity, NTU	7.5	-	7.5	6.1	-	4.3	-	5.0	-	8.0	-	7.0	-	9.0	-	17.0	-
Hardness, mg/L	58	-	161	71	-	110	-	28	-	1360	-	211	-	26	-	293	-
Chloride, mg/L	22.1	-	66.3	90.0	-	69.2	-	8.68	-	3761	-	91.1	-	1.5	-	254.7	-
Chlorophyll a, mg/m ³	13.0	-	3.60	3.90	-	6.61	-	12.8	-	77.9	-	9.07	-	68.4	-	87.4	-
Chlorophyll b, mg/m ³	14.6	-	6.24	5.40	-	10.3	-	14.2	-	110.1	-	12.2	-	75.3	-	95.1	-
Chlorophyll c, mg/m ³	2.47	-	2.09	1.38	-	6.16	-	3.15	-	22.8	-	2.29	-	11.3	-	11.7	-
Oxidation Reduction Potential, mv	461	458	446	472	467	458	454	454	450	394	383	432	431	447	447	401	391
Lead, µg/L	6.1	-	11.5	9.9	-	20.2	-	8.2	-	7.3	-	<1	-	1.6	-	8.8	-
Copper, µg/L	7.8	-	14.3	9.5	-	13.1	-	2.0	-	1.7	-	<1	-	<1	-	1.8	-
Zinc, µg/L	6.0	-	10.2	3.6	-	5.8	-	12.0	-	9.6	-	1.0	-	1.3	-	2.2	-
Cadmium, µg/L	<1	-	<1	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-
Color, cu	80	80	80	80	80	80	80	60	60	60	(4)	30	40	30	30	180	120
Nitrate Nitrogen, mg/L	0.144	0.126	0.288	0.317	0.359	<0.05	<0.05	<0.05	<0.05	0.38	0.27	1.52	1.52	0.082	0.082	0.202	0.202
Nitrite Nitrogen, mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ammonia Nitrogen, mg/L	0.201	0.207	0.123	0.141	0.201	<0.1	<0.1	<0.1	<0.1	0.14	<0.1	<0.1	<0.1	<0.1	<0.1	0.116	0.13

200 567 6.569 1.16 6.13

	21	1.54	1.4	2.52	1.26	1.4	1.68	1.4	1.54	2.8	1.26	1.4	1.54	1.12	<10	2.66	2.8
Total Kjeldahl Nitrogen, mg/l.	<0.1	<0.1	0.247	0.127	<0.1	<0.1	0.128	<0.1	<0.1	0.13	0.138	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ortho-Phosphate, mg/l.	0.189	0.173	0.274	0.155	0.182	0.139	0.145	<0.1	<0.1	0.156	0.177	0.149	0.234	0.282	0.231	0.173	0.168
Total Phosphorus, mg/l.	1800	-	2500	400	-	800	-	<1	-	200	-	<1	-	<1	-	<1	-
Fecal Coliform, cfu/100ml	-	-	-	46	-	31	-	33	-	49	-	920	-	5	-	2	-
Fecal Streptococci, cfu/100ml	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total Organic Carbon mg/l																	

INTERSTATE SANITATION COMMISSION

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION

PROJECT: Richard Newman, NYDEC

	05/26/98				06/04/98				06/08/98				06/09/98				
	1A	1B	2	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B
Turbidity, NTU	6.0	-	4.0	3.4	-	5.6	-	15.0	-	14.0	-	2.4	-	5.1	-	30.0	-
Hardness, mg/L	58	-	183	95	-	155	-	35	-	1060	-	189	-	34	-	742	-
Chloride, mg/L	106	-	82.5	33.6	-	107.1	-	8.4	-	5691	-	83.9	-	12.8	-	186.5	-
Chlorophyll a, mg/m ³	11.3	-	1	1.81	-	1.31	-	59.2	-	63.3	-	7.56	-	22.2	-	70.4	-
Chlorophyll b, mg/m ³	22.0	-	3.05	6.90	-	1.46	-	71.8	-	85.9	-	9.83	-	26.3	-	70.2	-
Chlorophyll c, mg/m ³	4.21	-	<1	1.49	-	<1	-	<1	-	7.66	-	6.81	-	1.60	-	<1	-
Oxidation Reduction Potential, mv	403.3	403	412	388	421	431	452	375	398	429	442	398	307	309	297	336	328
Lead, µg/L	7.6	-	6.3	16.6	-	20.2	-	17.1	-	<1	-	6.7	-	3.0	-	22.1	-
Copper, µg/L	4.2	-	9.8	<1	-	1.3	-	<1	-	11.9	-	5.0	-	13.9	-	6.6	-
Zinc, µg/L	3.3	-	4.4	5.7	-	3.9	-	<1	-	23.9	-	2.1	-	1.9	-	3.0	-
Cadmium, µg/L	<1	-	<1	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-
Color, cu	70	80	25	25	25	40	40	40	30	40	25	<5.0	<5.0	10	20	30	25
Nitrate Nitrogen, mg/L	0.116	0.129	0.85	<0.05	<0.05	0.295	0.301	<0.05	<0.05	<0.05	<0.05	0.496	<0.05	<0.05	0.069	<0.05	<0.05
Nitrite Nitrogen, mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.052	<0.05	<0.05	<0.05	<0.05
Ammonia Nitrogen, mg/L	0.137	0.126	0.176	0.111	0.100	<0.1	0.166	0.139	0.106	0.155	0.441	0.229	0.649	<0.1	<0.1	0.223	0.205

1A 1B 2 3A 3B 4A 4B 5A 5B 6A 6B 7A 7B 8A 8B 9A 9B

Total Kjeldahl Nitrogen, mg/L	6.86	3.50	7.98	3.22	3.08	4.20	3.50	5.46	10.8	8.26	9.66	3.22	3.36	3.50	3.64	3.36	3.50
Ortho-Phosphate, mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.543	<0.1	<0.1	0.228	0.257	<0.1	<0.1
Total Phosphorus, mg/L	<0.1	<0.1	0.110	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.131	0.571	<0.1	<0.1	0.238	0.301	<0.1	<0.1
Fecal Coliform, col/100ml	32	-	IND	12	-	16	-	8	-	100	-	3	-	1	-	18	-
Fecal Streptococci, col/100ml	<1	-	<1	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-
Total Organic Carbon mg/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

INTERSTATE SANITATION COMMISSION

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION PROJECT: Richard Newman, NYDEC

	07/29/98			08/03/98				08/05/98				08/10/98					
	1A	1B	2	3A	3B	4A	4B	5A	5B	6A	6B	7A	7B	8A	8B	9A	9B
Turbidity, NTU	16.0	-	15.0	4.3	-	8.0	-	25.0	-	10.0	-	3.5	-	17.0	-	17.0	-
Hardness, as mg CaCO ₃ /L	63	-	242	76	-	135	-	32	-	3100	-	226	-	23	-	1140	-
Chloride, mg/L	19.3	-	109.8	57.4	-	137.5	-	11.9	-	9099	-	100.4	-	10.4	-	3373	-
Chlorophyll a, mg/m ³	32.3	-	1.36	11.2	-	69.6	-	46.1	-	19.6	-	10.7	-	152.8	-	240.5	-
Chlorophyll b, mg/m ³	30.2	-	129.0	11.0	-	64.5	-	39.0	-	19.5	-	7.64	-	126.6	-	209.7	-
Chlorophyll c, mg/m ³	10.4	-	<1	6.57	-	16.5	-	7.35	-	<1	-	3.23	-	<1	-	43.3	-
Oxidation Reduction Potential, mv	404 34	397	405	391	371	373	393	351	439	431	-146*	439	236	306	308	325	307
Lead, µg/L	11.4	-	8.5	5.8	-	6.4	-	1.5	-	<1	-	3.4	-	3.1	-	<1	-
Copper, µg/L	1.8	-	5.4	6.4	-	2.6	-	1.1	-	2.7	-	1.8	-	<1	-	3.0	-
Zinc, µg/L	3.4	-	9.1	6.8	-	5.2	-	2.6	-	7.1	-	3.6	-	<1	-	<1	-
Cadmium, µg/L	<1	-	<1	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-	<1	-
Color, cu	160	180	80	40		120		240		90		40		280		250	
Nitrate Nitrogen, mg/L	<0.05	<0.05	2.14	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.242	<0.05	<0.05	<0.05	0.310	0.280
Nitrite Nitrogen, mg/L	<0.05	<0.05	0.112	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.091	0.085	<0.05

Ammonia Nitrogen, <i>mg/L</i>	0.140	0.120	0.200	0.280	0.280	0.420	0.420	0.140	0.280	<0.1	1.03	<0.1	3.22	<0.1	0.560	0.420	0.280
Total Kjeldahl Nitrogen, <i>mg/L</i>	0.28	0.28	0.42	0.42	0.42	0.588	0.588	1.54	1.68	2.94	1.40	0.14	3.92	0.42	0.84	0.28	0.56
Ortho-Phosphate, <i>mg/L</i>	0.123	0.109	0.110	<0.1	0.114	<0.1	0.109	<0.1	<0.1	0.118	1.51	<0.1	<0.1	0.245	0.411	<0.1	<0.1
Total Phosphorus, <i>mg/L</i>	0.504	0.130	0.127	<0.1	0.163	0.123	0.194	<0.1	<0.1	0.138	1.67	0.208	<0.1	0.294	0.429	<0.1	<0.1
Fecal Coliform, <i>col/100ml</i>	<1	-	<1	1	-	30	-	<1	-	TNTC	-	68	-	41	-	12	-
Fecal Streptococci, <i>col/100ml</i>	<1	-	<1	<1	-	3	-	3	-	68	-	4	-	<1	-	<1	-
Total Organic Carbon <i>mg/l</i>	<10	14.2	13.2	<10		<10		<10		26.6		<10		<10		<10	

pH:	1A	7.72	1B	7.47
	2	7.18	C	7.93
	3A	9.77	3B	9.35
	4A	9.47	4B	9.25
	5A	10.22	5B	7.06
	6A	7.69	6B	7.20
	7A	7.64	7B	6.72
	8A	10.44	8B	7.57
	9A	10.07	9B	10.13
			3C	9.77
			5C	10.05
			7C	6.87
			8C	10.41

* strong interference effect from some unknown substance present in the sample, the sample had a perceptible odor.