REPORT

ASSESSMENT OF HYDROGEOLOGIC CONDITIONS TOWN OF NORTH CASTLE

Town of North Castle Conservation Board

Armonk, New York

March 1990

BLASLAND & BOUCK ENGINEERS, P.C.
BLASLAND, BOUCK & LEE
ENGINEERS & GEOSCIENTISTS

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1.0 INTRODUCTION

In September 1989, Blasland & Bouck Engineers, P.C. (Blasland & Bouck) was retained by the Conservation Board of the Town of North Castle to perform a comprehensive evaluation of ground-water conditions in the Town, and to prepare a report on this work. The study was to be completed within a limited budget of approximately $12,000, which the Conservation Board understood would cover the costs of performing a detailed literature review; evaluating information obtained from this review concerning the sources and availability of ground water within the Town; developing a general water budget; identifying real and potential sources of ground-water contamination and describing their effects on the ground-water system; and devising sound ground-water management recommendations. Although the broad nature of the scope and the limited budget of this project restricted our approach to the study, the extensive volume of past work completed in Westchester County enabled us to assemble enough basic data concerning the geology, hydrogeology, and ground-water chemistry to satisfy the requirements of the project.

By way of background, members of this firm have been involved in similar studies in this region for a number of years, including projects conducted in Westchester County. In fact, the North Castle study is a scaled-down version of the type of work completed in 1972 under Section 208 of the Federal Water Pollution Control Act. Many of the 208 studies conducted in this region include information on land-use control for ground-water protection. A 208 study was conducted in the northern part of Westchester County, which included only the northern-most parts of the Town of North Castle. Some information developed in that study was used in the preparation of this report.

1.1 Purpose and Scope

Over the course of this study, we have met several times with the Conservation Board, and we have had a number of discussions with Mrs. Elizabeth Sluder and other Board members concerning the purpose and the scope of our work. It was agreed by all that the purpose of this investigation was to provide a comprehensive overview of ground-water conditions in the Town of North Castle. As part of this overview, information would be included that concerned the areal distribution and availability of ground water in the Town; how best to develop these ground-water supplies, the effects of certain land-use practices on the availability or quantity of ground water; and changes in ground-water quality that may likely occur under current land-use practices. The Board should note that there are a number of issues that were beyond the scope of this study, such as identifying specific locations of productive ground-water supplies, identifying remedial engineering steps required for areas that have been impacted by contaminants, and characterizing remedial investigations and actions taken to resolve contamination problems in specific areas such as Armonk.

As intended, this report will serve as a primer or as a guidance manual on the ground-water resources of the Town of North Castle. This report should set the stage in providing basic information to assist the Board in making planning and management decisions concerning the Town's ground-water resources as complex development issues arise in the future.

2.0 STUDY AREA DESCRIPTION

The Town of North Castle is located in east-central Westchester County along the New York and Connecticut State borders (Figure 1). North Castle encompasses approximately 26.3 mi^2 (16,833 acres); about 90% of this total area is designated for residential uses and the remaining 10% for office, commercial, and other business uses. The percentage of total land designated for residential purposes includes the following categories of land use: 38% vacant land; 26% residential; 18% open space; and 8% interior surface-water bodies. The percentage of land used for business purposes includes 3% commercial, 3% transportation, and 3% institutional. The residential area in the vicinity of the business area of the Hamlet of Armonk comprises about one quarter of the Town's population, and land usage in this area varies slightly. About 62% of the land is used for residential and commercial purposes, 16% is used for transportation, 11% is open space, and about 10% is vacant land.

The reader should note that although Armonk proper encompasses both the Wampus and Byram watersheds, when discussing Armonk in the text, we are referring to the business area of Armonk. Additionally, the name Armonk shown on the maps in this report is located in the general vicinity of the Hamlet, and is not meant as a specific location.

According to the Westchester County Department of Planning, the estimated population of North Castle was 9,963 in January 1989, and the greatest number of individuals fell into the 25 to 44 year-old age category. From 1900 to 1989, North Castle experienced an overall population growth of about

14%, except from 1970 to 1980 when there was a slight decrease of about 0.1%. From 1980 to 1989, there was an increase in population growth of about 5%. The greatest increase in population growth (6%) occurred from 1950 to 1970.

2.1 Physiography

The Town of North Castle is situated on the Manhattan Prong of the New England physiographic province. The area is characterized by rolling hills, and land surface altitudes that range from about 300 feet to almost 700 feet above mean sea level. North Castle is in an area typified by numerous parallel ridges and valleys. As a result, highways and railways generally follow along the trend of the valleys.

Numerous lakes, ponds, and wetlands are found throughout the North Castle area. A number of these lakes serve as water reservoirs. The most prominent surface-water body in the study area is the Kensico Reservoir, which is found along the western border of the Town. Other prominent surface-water bodies are the Byram Lake Reservoir and Wampus Lake, which are found along the northern border of North Castle.

2.2 Drainage

The Town of North Castle is separated by two major drainage basins (Figure 2). Surface water in the western part of North Castle and west of Armonk drains into the Bronx River basin. The one sub-basin found within this major basin and within the Town's borders is the Kensico-Armonk sub-basin.

Surface water in the east-central and eastern part of North Castle (from Armonk eastward) drains into the Upper Long Island Sound basin. Three sub-basins found within this major basin and partly within the Town's borders are the Wampus River sub-basin, the Byram River sub-basin, and the Mianus River sub-basin.

The United States Geological Survey (USGS) maintains surface-water gaging stations throughout Westchester County. In North Castle, the USGS maintains two gaging stations on the Wampus River and the Byram River. Based on USGS data records, the estimated surface-water runoff for Westchester County is 485 million gallons per day (mgd). The estimated surface-water runoff for the Town of North Castle is about 29.1 mgd.

2.3 Climate

The climate of the Town of North Castle is governed by weather systems to the northeast of the Town and by the Atlantic Ocean, which is about 20 miles south of the Town. The climate of the region is characterized by mild winters and relatively cool summers. Extreme air temperatures commonly are moderated by local sea breezes.

The average daily air temperature in the area is 51°F. The average annual low air temperature is 31°F, which generally occurs during January. The average annual high air temperature is 74°F, which generally occurs during July.

The average annual precipitation that falls in Westchester County ranges from 45 to 52 inches per year. The average annual precipitation falling in the Town of North Castle is about 48 inches per year. Data concerning average monthly precipitation and air temperature collected over an 8-year period at the Westchester County Airport by the National Oceanic and Atmospheric Administration are presented in Figure 3a, b.

2.4 Previous Investigations

Numerous geologic and hydrogeologic investigations have been conducted in and around the Town of North Castle, Westchester County, New York. Information found in the reports of these investigations include geologic descriptions, evaluations of the ground-water resources, inventories of the quantity and quality of ground water, and discussions of real and potential ground-water contamination problems. These reports, many of which were used in the preparation of this report, are listed in the Reference section at the back of this report.

3.0 GEOLOGY

To understand the occurrence of ground water in rocks that underlie the Town of North Castle, it is first necessary to familiarize the reader with the major types of rocks and sediments found in the area. A glossary of geologic and hydrologic terms appears at the end of this report to provide the reader with definitions of terms that are used throughout the report.

The Town of North Castle is situated on fractured crystalline rocks that are overlain by glacial deposits. These crystalline rocks primarily consist of metamorphosed sedimentary rocks. Sedimentary rocks are layered rocks formed by the deposition of sediments by means of water, ice, or air. At the time of their formation, most sedimentary rocks are unconsolidated (consisting of loose grains). If, over time, the rocks are buried deeply and are compressed, or if they undergo certain chemical changes, the loose grains will become cemented to form a consolidated sedimentary rock. If over the course of geologic time these sedimentary rocks are buried to a depth at which they are subjected to high temperatures and pressures, then both their structural characteristics and mineralogic composition are changed and the rocks are changed or metamorphosed into metamorphic rocks. Consolidated rocks in general are referred to collectively as bedrock.

The metamorphosed sedimentary bedrock underlying North Castle consists of gneiss, schist, quartzite, and marble. Most of the rocks underlying North Castle have been intensely folded and they have been cut by numerous faults. Figure 4 is a block diagram that shows the general nature of the topography and geologic features and rocks underlying the Town of North Castle.

A formation is the basic geologic unit for naming rocks. The bedrock formations underlying the Town of North Castle are the Fordham Gneiss, the Manhattan Formation, the Inwood Marble, the Bedford Gneiss, the Yonkers Gneiss, and the Hartland Formation. The areal distribution of these rocks is shown on the map in Figure 5. The distribution of the bedrock units and the contacts shown between rock formations in Figure 5 are based upon the compilation of several geologic maps, including those prepared by van der Leeden (1962), Fisher, Isachsen, and Rickard (1970), and Maslansky (1985).

A geologic cross section through the western part of North Castle has been included to provide the reader with a picture of the vertical extent of the bedrock units (Figure 6). The geologic cross section, which is based on work completed by Geraghty & Miller (1977) for the 208 areawide study for Westchester County, extends eastward across the Kensico Reservoir and continues northeastward to just west of Byram Lake Reservoir (see Figure 5 for the line of section A-A').

Bedrock in the area is overlain by unconsolidated deposits of glacial debris called drift. These glacial deposits were laid down by ice sheets that covered the area during Pleistocene times. Glacial deposits consisting of sand, gravel, silt, and clay were laid down by meltwater streams and in lakes that were formed as the glacial ice sheets melted. These unconsolidated deposits overlie the bedrock everywhere in the Town, except on steep slopes.

Glacial drift that consists of unsorted mixtures of unconsolidated sediments that range in size from boulders to clay is referred to as glacial till or unstratified drift. Glacial drift that consists of sorted sediments of gravel, sand, silt, and clay laid down in glacial streams and lakes is referred to as stratified drift or glacial outwash.

The thickness of the glacial drift in the North Castle area ranges from a few feet on steep slopes where great expanses of barren rock are exposed to several hundred feet in some low-lying valleys. The most areally extensive glacial deposit is till.

In most valleys and low-lying areas, glacial till is covered by glacial outwash that consists primarily of sand and gravel. The thickness of these outwash deposits ranges from a few feet to more than 60 feet in some valleys. The most areally extensive deposits of sand and gravel are shown on the map in Figure 7. Maslansky (1985) mapped extensive deposits of sand and gravel along both the Wampus and Byram River valleys. Based on shallow well-log records, sand and gravel deposits also are inferred around the Windmill Farm area, along the upper reaches of the Mianus River, in the Banksville area, and along the Bronx River in North White Plains. The exact areal extent of these deposits is uncertain.

Bedrock underlying the Town of North Castle has been deformed by fault movement and by folding. The movement of glacial ice sheets across this area also has caused the rocks to undergo stress, strain, and compaction. As a result, numerous major and minor joints and fractures have developed in the bedrock. Fluhr (1941) described numerous faults along the Delaware aqueduct in the western part of North Castle. Many of the faults and major fractures are difficult to recognize in the metamorphic rocks. Many of the fracture zones have been crushed and decayed, and they have been filled in by impervious mixtures of finely pulverized rock flour called gouge and by coarser rock fragments referred to as fault breccia. As a result, this material has been more deeply weathered and decayed thereby increasing the overlying thickness of the soil cover.

Figure 8 is a map that shows the traces of major fractures (lineaments) underlying the Town of North Castle. The map in Figure 8 is a compilation of data obtained from work completed by Frederick P. Clark Associates (1966), Geraghty & Miller (1977), and Maslansky (1985). Although not entirely predictable, the patterns of fault and fracture zones in the area underlying North Castle commonly tend to follow along the course of major streams and valleys. The reader should note that the fracture traces shown in Figure 8 represent only the trends of major lineaments found in the bedrock underlying North Castle. There literally are thousands of minor fractures and joints that extend both horizontally and vertically outward from these major fractures, and separate sets of minor fracture patterns that trend between these major fractures.

4.0 HYDROGEOLOGIC FRAMEWORK

To assist the Town of North Castle in understanding and protecting the Town's ground-water supplies and ensuring the quality of ground water, we first will discuss some of the basic elements of the hydrologic cycle as related to ground water, and then describe more specific aspects of ground-water conditions in the Town. Definitions of ground-water terms are presented in the text where the terms are first introduced; definitions also are provided in the Glossary at the end of this report.

4.1 Hydrologic Cycle

The hydrologic cycle refers to the constant cyclic movement of water from the oceans to the atmosphere, onto and through the Earth's surface, to streams, and finally back to the oceans. That part of the hydrologic cycle in which we are interested is the ground-water flow system.

Precipitation that falls on the land surface first wets the land surface and vegetation, and then infiltrates into the ground. Water found below the land surface occurs in two distinctly different zones: the unsaturated zone and the saturated zone.

The unsaturated zone extends from the land surface downward to depths that can range from less than a foot in humid regions to more than several hundred feet in arid regions. Openings or void spaces between soil or rock particles in the unsaturated zone are filled partially with water and partially with air.

Below the unsaturated zone is the saturated zone where all of the interconnected openings in the rock are filled with water. The upper surface of the saturated zone is referred to as the water table, and water occurs here under a pressure that is equal to atmospheric pressure. If one were to drill a shallow well into the saturated zone, the level of the water in the well would be equal to the position of the water table. The term ground water actually refers to the water found in the saturated zone. This also is the water that discharges to wells, to streams, and to springs and seeps.

The zone that lies between the water table and the unsaturated zone is the capillary fringe. Water that occurs in the capillary fringe is held above the water table by the strong surface tension of the water.

Figure 9 is a simple diagram that shows the occurrence of water below the land surface. This diagram is a generalization of the different zones through which water migrates. In the real environment the positions and thicknesses of these zones are quite dynamic and constantly changing. For instance, the thickness of the unsaturated zone fluctuates up and down in response to seasonal changes in precipitation, to changes in recharge, or to human-related activities such as pumping.

That part of the precipitation that infiltrates the land surface and percolates through the unsaturated zone and down into the saturated zone is referred to as recharge. The areas in which recharge occurs are termed recharge areas. In recharge areas, water is added to or replenishes the ground-water system. Once water reaches the saturated zone, it continues to move both vertically and laterally downgradient to areas where the ground water is discharged to streams, springs, seeps, or even the ocean. These areas where water leaves the ground-water system (or saturated zone) are referred to as discharge areas (Figure 10).

Several hydraulic terms that are important in describing the ability of a rock to transmit and store water are hydraulic conductivity, transmissivity, and porosity. Hydraulic conductivity is a measure of the water-transmitting capacity of different types of rocks. A saturated rock in which the hydraulic conductivity is large enough to supply a usable quantity of water to a well or spring is referred to as an aquifer.

The aquifer acts as the means by which ground water is transmitted downgradient from points of recharge to points of discharge. A rock or layer of rocks in which the hydraulic conductivity is significantly low is referred to as a confining bed. In contrast to hydraulic conductivity, transmissivity is a measure of the water-transmitting capacity of an aquifer. Transmissivity is equal to the hydraulic conductivity of the rocks times the aquifer thickness.

Porosity refers to the volume of open space in a rock. Generally, the higher the percentage of openings in a rock, the greater the volume of water that can be stored in that rock. One exception to this is clay, which exhibits a high porosity owing to the large volume of open space between clay particles; however, the open spaces within a clay are extremely small and they are not well connected. Consequently, some water is held within the clay, but movement through the clay is extremely slow, and in some cases almost negligible.

4.2 Aquifers

The two basic types of aquifers that can be designated based on rock type and hydraulic characteristics are unconfined and confined aquifers. An unconfined aquifer occurs wherever the top or upper surface of the aquifer is coincident with the water table (Figure 10). Water in an unconfined aquifer rises and falls freely in response to changes in the volume of water stored in the aquifer. The volume of water stored in an unconfined aquifer is related directly to seasonal changes in precipitation and evaporation, to changes in recharge, to conditions of drought (or flood), and to human-related activities such as pumping. Thus, water-level fluctuations can be expected to occur seasonally; in the Eastern United States, water levels in unconfined aquifers generally are highest in late spring and lowest in fall.

Confined aquifers occur wherever water infiltrates downward through a confining bed and completely saturates the underlying permeable rocks (Figure 10). Water in a confined aquifer is under pressure because the rocks (confining beds) that bound the saturated rocks have substantially lower hydraulic conductivities than the saturated rocks themselves. As a result of this pressure, the water level in a well that taps a confined aquifer will rise above the top of the aquifer. In some cases where there is sufficient pressure, the water level in a well will rise above the land surface. The result is a flowing well and the confined aquifer is defined as an artesian aquifer.

It is important to note that the water level in a confined aquifer is not directly affected by seasonal climatic changes. Rather, the water level fluctuates in response to tidal affects (near the coast), to barometric changes, and to changes in the rate of recharge. In many instances where the aquifer is completely confined (the bedrock is completely covered), recharge to the aquifer from precipitation will occur only where the bedrock crops out (is exposed) at the land surface at higher altitudes.

4.3 Aquifers in North Castle

Ground-water supplies in the Town of North Castle are obtained from both unconsolidated glacial deposits of sand and gravel (unconfined aquifers) and consolidated fractured bedrock (confined aquifers). For purposes of simplifying our discussion, unconfined aquifers comprised of glacially deposited sand and gravel will be referred to hereafter as "sand and gravel aquifers;" and confined aquifers comprised of fractured metamorphic bedrock will be referred to hereafter as "bedrock aquifers."

In the Town of North Castle, sand and gravel aquifers constitute important local supplies of ground water. The largest yields of ground water come from sand and gravel aquifers (Figure 11). However, the areal extent of sand and gravel deposits in North Castle is limited to areas in the valleys of large streams such as the Bronx, Byram, and Wampus Rivers in the western part of North Castle and to the Mianus River and low-lying wetlands in the eastern part of North Castle (Figure 11). Other sand and gravel deposits that occur locally in many of the valleys and lowland areas of the Town are not very thick, and they are not productive enough to serve as important sources of ground water.

In lowland areas and in the Bronx, Wampus, Byram, and Mianus River valleys where sand and gravel deposits are thick (greater than 50 feet), these deposits serve as storage reservoirs of water for the fractures in the underlying bedrock. In this sense, the sand and gravel aquifers are hydraulically connected to the underlying bedrock aquifers. In upland areas and on hills where the sand and gravel deposits are relatively thin, the capacity of the sediments to store ground water is low.

Where sand and gravel deposits are sufficiently thick and saturated and where the porosity of the sediments is relatively high (20-30% open space), moderate to high yields of ground water can obtained. For instance, four public-supply wells that tap a sand and gravel aquifer in Water District 2 (Windmill Farms) have reported yields that range from 85-220 gallons per minute (gpm) and a median yield of 183 gpm. The median reported depth of these wells is 57 feet below land surface. The median reported yield for 90 wells that tap sand and gravel aquifers in Westchester County is 44 gpm. The most productive sand and gravel aquifers in North Castle are found in and along major stream valleys and directly overlie the Inwood Marble, which occurs in narrow bands along the Wampus, Byram, and Mianus Rivers.

Sands and gravels associated with the Inwood Marble commonly contain large volumes of water in storage. As a result, these sand and gravel aquifers act not only as storage reservoirs for fractures in the underlying Inwood

Marble, but they also can be pumped for relatively long periods of time if sufficient recharge is available.

Other glacial deposits do occur in valleys and lowland areas, but these deposits commonly consist of fine sands, silt, and clay that are not very porous or permeable, and therefore, are not considered as aquifers. Where these types of deposits cover glacial material in the valleys, recharge to the underlying bedrock aquifers occurs by means of precipitation falling on the outcrop area; by surface water that is in hydraulic connection with the aquifers; or by ground water that migrates laterally from surrounding bedrock.

The sand and gravel aquifers in North Castle are unconfined, and therefore, these aquifers are under water-table conditions. The shape of the water table generally is a subdued replica of the land surface topography. In valley areas, the depth to water commonly is 10 feet or less; a static water level of 8 feet was measured in one public-supply well after the well was drilled to a depth of 85 feet into the sand and gravel aquifer in Water District 2 (Windmill Farms). In upland areas and along hills and ridges, the water table lies at greater depths below land surface.

Very few wells in the Town of North Castle are drilled into the sand and gravel aquifers. Consequently, no specific information currently is available to accurately map the flow direction of the water table and to describe water-level fluctuations in the sand and gravel aquifers. However, we can say that sand and gravel aquifers (water table) are affected directly by variations in climatic factors and by changes in precipitation. For example, where the aquifer lies near land surface in the Byram and Wampus River valleys, seasonal changes in evapotranspiration, which is the loss of water from the soil both by evaporation and by transpiration from the plants growing, will affect to a certain extent the level of the water table.

The second type of aquifer that underlies the Town of North Castle is the bedrock aquifer, which is comprised of consolidated fractured metamorphic bedrock. The bedrock forming these aquifers include marble, gneiss, and schist. The hydraulic characteristics of these consolidated rocks differ substantially from the previously described unconsolidated deposits of sand and gravel. Perhaps the most important difference is the porosity of the bedrock. Whereas sands and gravels are relatively porous (porosity = 20 to 30%) because of the large volume of open space between the sand and gravel particles, bedrock particles have been cemented and fused, which greatly reduces the porosity. As a result, the water-transmitting capacity of these consolidated metamorphic rocks is reduced to the extent that they yield very low volumes of water. In fact, water yielded from bedrock aquifers actually occurs in the fractures and joints within the rocks and along faults.

Although the water-yielding capacity of the bedrock aquifers is low, approximately 90% of all wells in North Castle tap the bedrock, and only 10% of the wells tap the sand and gravel aquifers. The high percentage of wells that tap bedrock is most likely owed to the fact that the bedrock underlying North Castle is nearly everywhere at or near land surface. For instance, in Water District 2 near Windmill Farms, the depth to bedrock ranges from 1 to 26 feet below land surface; and the median depth to bedrock in Water District 2 near Windmill Farms (in this case the Fordham Gneiss) is about 15 feet below land surface. The public-supply wells that tap the Fordham Gneiss in Water District 2, however, range in depth from 175 to 250 feet below land surface; the median depth of the public-supply wells is 217 feet. Although the depth to bedrock is much shallower than the depths to which the public-supply wells extend, the depths of these wells are dependent on the amount of overburden through which the wells must be drilled; the well yield required to supply water to a certain size population; and the depth at which the bedrock aquifer is capable of producing water at the required yield. In the case of the public-supply wells near Windmill Farms, the yield ranges from 8 to 25 gallons per minute (gpm), and the median yield is 16 gpm. In most instances, the yield required for domestic purposes ranges from 5 to 10 gpm, and the capacity of the bedrock aquifer to produce a sufficient quantity of water to meet these needs can be found in the upper 100 feet of bedrock.

The volume of water yielded to wells that tap bedrock can vary depending on the occurrence, the number, and the degree of connection of water-bearing fractures. In general for North Castle, the median yields of the major bedrock formations are as follows: Fordham Gneiss 10 gpm; Manhattan Formation (schist) 12 gpm; and Inwood Marble 15 gpm (Figure 11). Although these are median yields, some higher yields have been observed in wells drilled into the Inwood Marble, the Manhattan Formation, and the Fordham Gneiss.

The reported yield of a well can be misleading because the yield often is based on the capacity of the pump rather than the sustained quantity of water that can be withdrawn from the well. A much better indicator of the actual yield that can be obtained from an aquifer is the specific capacity of a well. Specific capacity is the yield of water obtained from an aquifer per foot of drawdown of the water level in the aquifer. Specific capacity is measured as gallon per minute per foot (gpm/ft). In general, the average specific capacities of wells drilled into the bedrock aquifers are as follows: Fordham Gneiss 0.57 gpm/ft; Manhattan Formation 0.67 gpm/ft; and Inwood Marble 0.78 gpm/ft. The Inwood Marble is by far the most productive bedrock aquifer (median yield = 15 gpm; average specific capacity = 0.78 gpm/ft), and yet, when compared to the sand and gravel aquifers (median yield = 44 gpm; average specific capacity = 6.18 gpm/ft) one can see that the bedrock aquifer yields much less water.

As mentioned previously, the water stored and transmitted in the bedrock aquifers is found in the interconnected water-bearing fractures in the bedrock. In the Town of North Castle, the bedrock surface has been broken into large blocks, which indicates intense deformation of the rock. Additionally, the fractures in the rocks, which are zones of weakness, have been eroded over time and the fracture openings have been widened. Thus, the map of major lineaments (fractures) shown in Figure 8 indicates the general areas where water yields probably will be highest.

5.0 LIMITATIONS TO GROUND-WATER DEVELOPMENT

As we have carefully outlined up to this point, the sub-basin drainage areas in North Castle differ in size; and the topography and hydrogeologic environment in the sub-basins are variable. Consequently, the availability of ground water that can be withdrawn and used consumptively on an annual basis from each of these sub-basins also is variable. For instance, in high altitude areas of the Town where the soil cover is minimal and there are few fractures in the underlying bedrock, domestic well yields typically range from 0-5 gallons per minute (gpm). In mid-altitude areas where the soil cover is moderate and there are some fractures in the underlying bedrock, domestic well yields typically range from 3-12 gpm. And, in low-lying areas where thick unconsolidated sediments cover numerous major and minor fractures and joints, domestic well yields typically range from 10-50 gpm (Geoenvironmental Consultants, Inc., 1985).

The best way to estimate the availability of ground water to produce safe sustained yields to wells is by estimating a water budget for the Town of North Castle. For the water budget, we assume that there is an overall net balance between water that enters the ground-water system through recharge and water that leaves the system through discharge. Recharge to the ground-water system in North Castle primarily is derived from precipitation (rain and snow). Ground-water is discharged from both sand and gravel aquifers and bedrock aquifers to streams and low-lying wetland areas. Ground water also is lost to evaporation and transpiration, to centers of pumping, and to the disposal of water beyond the Town's boundaries.

In this study, we calculated that an average annual precipitation of 48 inches over a 26 mi^2 area (Town area) is equivalent to about 61 million gallons of water per day (mgd). This seems to be a enormous volume of water, and it is; however, not all of this water infiltrates the land surface to become ground water. In fact, we conservatively estimated that only about 5 inches (or about 10%) of the total annual precipitation reaches the ground-water system. As a result, we estimated a total recharge of about 6.3 mgd to the ground-water system over the entire area of the Town. Recharge to the entire Town area actually is directed into one of the three drainage areas: the Kensico-Armonk, Bryam-Wampus, or Mianus River sub-basins.

Although the rate of ground-water recharge for all three sub-basins is nearly the same, the actual amount of recharge to each basin varies depending on the topographic, geologic, and soil conditions that characterize each basin. Unfortunately, ground-water recharge to specific sub-basins cannot be measured directly; however, we can make qualitative assumptions about recharge to the sub-basins. In general, we would expect recharge to a sub-basin to be low where the bedrock is exposed at the land surface and the slopes are steep, and therefore, surface runoff would be high (such as the Wampus sub-basin). On the other hand, in a sub-basin extensively underlain by porous sand and gravel deposits (such as the Byram sub-basin), we would expect the infiltration of precipitation into the subsurface to be high, surface runoff would be low, and thus, recharge to the underlying aquifers would be high. Consequently, future development should focus on determining specific water budgets and availability for each of the individual sub-basins. In this way, the individual sub-basins could be protected against overdevelopment, which could ultimately stress the ground-water systems that comprise these individual sub-basins.

In light of all these facts, we must ask ourselves what are the major limitations to further ground-water development in the Town of North Castle given that there is a finite volume of water available to recharge the ground-water system? In other words, what considerations must be made in planning the development of ground-water resources in the above referenced sub-basins to ensure safe sustained yields of water to wells without producing negative impacts on the ground-water system. Negative impacts would include problems of ground-water quality, the lowering of ground-water levels, and reductions in streamflow.

5.1 Ground-Water Usage

Based on a 1989 population of 9,963 the total water used for domestic purposes is 860,000 gallons per day (gpd). For this study, we have assumed that the typical household uses an average of 200 gpd; the typical household usage excludes water used for outside irrigation. The reader should note that the domestic usage excludes water used for industrial or commercial purposes. Of the 860,000 gpm used in the Town, 66% of the water is obtained from private wells and 34% is obtained from two major public water-supply systems (Water Districts 1 and 2) and from one small water-supply system (Two Castle System) located in the northern part of North Castle. The Two Castle System operated by the Whippoorwill Water Company is a community water system that diverts water from the Catskill aqueduct and serves approximately 40 families. Based on data from 1974, we found that the demand for water on the North Castle Water District 1 in North White Plains was about 300,000 gpd, and the demand on the North Castle Water District 2 at Windmill Farms was about 115,000 gpd. Although the total usage has increased over the last 15 years owing to a slight increase in population, the availability of ground water from existing sources still is more than adequate to meet the current needs of the Town.

5.2 Limitations

The primary areas that should be considered as limiting the future development of ground-water sources concern: 1) the availability of ground water; 2) the lowering of ground-water levels in aquifers; 3) the reduction of streamflows in streams that are hydraulically connected to the underlying aquifers; and 4) the induced infiltration of contaminants into the ground-water system.

As pointed out earlier in our discussion, topographic and geologic conditions vary throughout North Castle. Some areas in North Castle are underlain by massive bedrock and the soil cover is thin, whereas other areas are underlain by highly fractured bedrock and the unconsolidated materials overlying the bedrock are porous. Consequently, it should come as no surprise that the availability of ground water and the volume of water yielded from these different geologic areas also differ from place to place in North Castle.

Based on statistical information available concerning well yields from bedrock aquifers in Westchester County, we found that there is not a substantial difference in the availability of ground water obtained from the Inwood Marble, the Manhattan Formation, and the Fordham Gneiss. Well yields from bedrock aquifers are highly dependent on the locations of local structural features such as fractures, the depth of the fractures, and, the degree of connection between water-bearing fractures. There is no doubt that where fractures are most pronounced, small water-supply systems could be developed. Even more favorable would be areas where the fractured bedrock is overlain by porous saturated sand and gravel deposits, because recharge through the sand and gravel and into the underlying fractured bedrock would be relatively high. An example of this type of situation is where the highly fractured Inwood Marble is overlain by saturated sands and gravels along the Byram River in west-central North Castle. On the other hand, there are areas in North Castle where the bedrock is massive and not extensively fractured. In these areas, wells may have to be drilled to several hundred feet simply to penetrate a sufficient number of fractures at depth to obtain a minimum supply of water (2 gpm). Drilling deeper in areas where the bedrock is massive not only increases the drilling cost, but also decreases the likelihood of finding highly productive zones of water because commonly, the bedrock is more massive and less fractured as the depth increases.

Highly productive deposits of sand and gravel found in the stream valleys of the Wampus, Byram, and Mianus Rivers most likely could yield from 0.5 to 1 million gallons per day (mgd). Unlike the bedrock aquifers where the amount of recharge per unit area is about 5 inches per year, the amount of recharge to the sand and gravel aquifers can range as high as 8 inches per year. Consequently, wells that tap the sand and gravel aquifers are easily capable of yielding 100 to 300 gpm. As a point of fact, two wells drilled into saturated sand and gravel deposits west of the Wampus River near

Armonk each produce 500 gpm for IBM. If one assumes that about 5% of the total area is underlain by saturated sand and gravel deposits, and one conservatively estimates the recharge to be about 0.5 mgd per square mile, then approximately 0.65 million gallons of ground water could be obtained solely from the sand and gravel aquifers on a daily basis.

From a water management and development perspective, we regard the entire land surface that is underlain by saturated sand and gravel deposits as primary recharge areas (see Figure 11 for the distribution of these areas). Thus, any further development and/or land use should be undertaken with the view of protecting these shallow ground-water supplies.

Additionally, while there is no evidence to suggest that water availability from either the sand and gravel or the bedrock aquifers is diminishing on a Town-wide scale, there may be areas of local concern. One specific example would be smaller sub-basin drainage areas (such as the Wampus sub-basin) that primarily are underlain by bedrock and that have limited areal extent. It is possible that in this type of scenario, the volume of water available to recharge the bedrock aquifers would be quite low. In fact, if the volume of water withdrawn through pumping were left unchecked, then the amount of water withdrawn could exceed the amount of recharge, and thereby lower ground-water levels and perhaps dewater the aquifer.

The volume of water in storage commonly is much greater than the volume of water available through recharge. Of course the volume of water stored in the fractures of the bedrock aquifers is much smaller than the volume stored in the sand and gravel aquifers. For example, if one assumes a storage coefficient of 0.20 for the sand and gravel deposits, and the water table over a 1-mi^2 area is lowered by 1 foot, then approximately 41.7 million gallons of water could be released from storage (Geraghty & Miller, 1977). This is extremely important because the water table declines seasonally when little to no recharge is available; and the water table can be lowered artificially by pumping shallow wells that tap the sand and gravel aquifers. Consequently, the volume of water held in storage could be used as a resource if it is managed properly, and thus, the sand and gravel aquifers could be used to regulate water levels. That is to say, during those times of high water demand or during dry periods when the sand and gravel aquifers may be overpumped, water held in storage could act to overcome the effects of pumping and prevent water levels from declining to seriously low levels. The water that was removed from storage would then be replaced or replenished the following season when recharge to the system occurred.

Where sand and gravel aquifers are hydraulically connected to streambeds, there always should be concern that overpumping wells that tap these aquifers may reverse the hydraulic gradient, thus reducing streamflow. In other words, pumping too much water from the underlying sand and gravel deposits could induce surface water to infiltrate downward into the aquifer. This would be detrimental not only in terms of reducing streamflow, but also in terms of increasing the likelihood of introducing into the shallow ground-water system contaminants that may be in the stream water. The possibility of reversing the hydraulic gradient because of nearby ground-water pumping is very much dependent on the degree of hydraulic connection between the aquifer and the streambed. Where the degree of connection is low owing to the presence of low permeability materials in the stream bottom, surface-water infiltration would be nearly nonexistent. However, in areas where the degree of connection between the streambed and the underlying aquifer is high because no confining bed is present, induced leakage of surface water through the bottom of the streambed and into the underlying aquifer could occur. We do know from our review of the literature that a certain amount of water flowing in the streams in North Castle is derived from ground water rather than from precipitation and runoff. Streams in North Castle both lose water to and gain water from the ground-water system, but this is a natural occurrence that depends on seasonal changes and the altitude of the water table. Currently, there are no sufficient data available to determine whether induced surface-water infiltration is occurring.

To determine whether induced infiltration is occurring requires performing controlled aquifer (pumping) tests by using observation wells and by monitoring variations in water quality and water temperature during these tests. However, because we know that a certain amount of streamflow actually is derived from ground-water flow, it perhaps would be prudent to monitor pumping in shallow wells in those areas nearby to adjacent streams to ensure against possible overpumping that could lead to induced infiltration.

Perhaps the greatest limitation to further development of ground-water sources in North Castle is the potential degradation of the ground-water quality. The chemical quality of ground water commonly tends to be uniform and somewhat stable within a given sub-basin. Ground-water naturally consists of dissolved solids and chemical constituents derived from rock and mineral matter. In the natural environment, there is a delicate balance maintained which keeps the chemical quality of ground water in equilibrium. However, when human-related activities introduce natural or synthetic contaminants to the ground-water system, this balance can be upset quickly.

Previous investigations such as the Northern Westchester County 208 Study, which was completed in 1977, have clearly shown an upward trend in the levels of some natural chemical constituents such as nitrate and chloride. Excessive loadings of these constituents in an aquifer eventually can exceed the capacity of the local ground-water system to dissipate these chemicals; and over time, the concentrations of these constituents can increase to the point where they exceed public health and Federal drinking water standards.

Fortunately in the North Castle area, the number of potential and real sources of contamination are limited. The two contaminant sources that we should be most concerned about are septic tank systems and roadway deicing salts; although, there are other nonpoint contaminant sources such as leaky sewers and underground storage tanks, and point sources such as accidental spills of which we should be aware.

In unsewered parts of North Castle, septic tank systems are used to dispose of domestic liquid wastes, which are discharged directly to the ground-water system. Although onsite disposal and discharge of liquid wastes are confined to relatively small areas such as individual homes or subdivisions, the septic wastes can affect the quality of ground water obtained from individual private wells and potentially could affect the overall ground-water quality of an aquifer.

Under normal conditions, chloride and nitrate that are derived from sewage will migrate with percolating water and eventually enter the ground-water system. In the 208 study (Geraghty & Miller, 1977), it was shown that in the North Castle Water District 2, chloride and nitrate levels found in ground water have increased with time (Figures 12a, b; 13a, b), and thus, some degradation of the water quality has occurred already. It was further pointed out that where local problems of contamination exist owing to a high density of individual septic systems, an entire aquifer that is used to supply potable water for that area can become contaminated. The problem can be further complicated in areas where the density of many septic systems is high. In this case, several aquifers can become contaminated, and result not only in the degradation of the quality of potable ground water used to supply an entire sub-basin or river drainage basin, but also degrade surface-water quality.

A U.S. Geological Survey (USGS) investigation performed in Massachusetts by Morrill and Toler (1973) showed that there was a direct relation between housing and septic tank density and surface-water quality. This particular study is pertinent to the North Castle area because the small drainage basins investigated in eastern Massachusetts are similar geologically to the Wampus, Byram, and Mianus River sub-basins in North Castle. The USGS study indicated that the concentration of dissolved solids found in the stream water base flow was dependent on the density of housing, and that most dissolved solids derived from septic tank systems eventually reached the streams. Morrill and Toler (1973) further estimated that the concentration of dissolved solids in stream water base flow could be expected to increase 10-15 milligrams per liter (mg/L=parts per million) per 100 houses per square mile

(Figure 14). As the graph indicates, where housing densities are no more than one to two dwellings per acre, the accretion rate of dissolved solids is essentially negligible. These housing densities in Figure 14 are nearly equivalent to 6- and 3-acre zoning, respectively. However, where the housing density exceeds two dwellings per acre, the rate of accretion of total dissolved solids increases linearly. These development density limitations cannot be transposed directly to North Castle. However, it is important to note that surface-water quality can be used as an indicator of the capability of the land area to accommodate future development; and perhaps more importantly, both surface-water and ground-water quality can be affected by over development if not properly managed.

The second major source of potential contamination that affects ground-water (and eventually surface-water) quality is the application and the stockpiling of roadway deicing salts. Where deicing salt is stockpiled outdoors in unsheltered areas, salt will leach into the subsurface and locally contaminate the underlying aquifer; we would refer to this as a point-source contaminant. Where deicing salt is applied to the roadways during winter months, salt also will leach into the subsurface and regionally degrade the chemical quality of the ground-water system; this is referred as a nonpoint source contaminant. Deicing salt is applied at a rate of about 1 cubic yard per lane mile to the 75 miles of paved roadways maintained by the Town, and the 25 miles of paved roadways maintained by the County and State.

Leachate produced from an unsheltered salt stockpile will most readily migrate downward through the unsaturated zone and contaminate the ground water in areas underlain by saturated sand and gravel deposits. Once the ground water has been degraded, the leachate can continue to migrate downgradient in the direction of ground-water flow to points of natural discharge (streams) or migrate in the direction of a pumped well. Additionally, where a sand and gravel aquifer is in hydraulic connection with an underlying bedrock aquifer (i.e. sand and gravel deposits underlain by Inwood Marble), the salt leachate can migrate through the fractures in the bedrock and either discharge to pumping wells or to streams in hydraulic connection with the bedrock.

One known salt storage facility, which is operated by the Town of North Castle, is located in the Hamlet of Armonk. At this facility, stockpiled salt was at one time left unsheltered outdoors. The stockpiled salt is now stored in a sheltered area, however, had the salt been left unsheltered any salt leached from the stockpile most likely would have entered and degraded the quality of the Wampus River, which flows just south of the facility. Salt leachate could have entered the Wampus either by surface runoff from the site or by downward leaching to the local aquifer, which eventually would have discharged naturally to the river.

Leached deicing salts contribute chloride to the ground-water system. Although chloride generally is not harmful to humans, when high concentrations are reached, chloride ingestion can be harmful to those who suffer from kidney or heart disease. The Federal drinking water standard has established an upper limit on the concentration of chloride in drinking water as 250 mg/L. Concentrations above 250 mg/L make the water unpalatable for human consumption, and at very high levels, chloride may be injurious to human health for those who suffer from the diseases mentioned above.

Obviously, future subdivisions and housing developments would require additional roadways, which would increase the areal application of deicing salts. As more of the Town land area is paved, the likelihood of contributing more salt leachate and increasing the concentration of chloride in both ground-water and surface-water supplies increases. And, as mentioned before, chloride concentration trends have been increasing over the last 20 years (Figure 13a, b). If development is left unchecked, the potential exists to degrade the ground-water system beyond its ability to recover.

In addition to the concern that septic tank systems and roadway deicing salts are potential sources of ground-water contamination, there are other potential sources of contamination that could affect the Town's ground-water quality. Although these sources are not considered to be serious, nevertheless, they include:

- o Leaky sewers.
- o Leaky underground storage tanks used for fuel and for chemicals.
- o Nonpoint-source contaminants such as agricultural chemicals (pesticides, herbicides, and fertilizers).
- o Accidental spills.
- o Surface runoff from urbanized areas.

- Brine water resulting from water softening devices.

- Product storage areas.

Although none of the above sources are considered as serious problems at this time, future development in the Town likely will increase the prospects of contamination occurring as a result of all of these potential sources.

On a local level, North Castle already has experienced several contamination problems. For example, gasoline in an underground storage tank was found to be leaking from the tank and into the local ground-water supply in Armonk. The problem has been resolved, but not without first contributing hydrocarbons to the ground water, and thus, affecting the quality of ground water in the vicinity of the leaky storage tank. It should be noted that there are Federal standards and guidelines in place that govern the handling of leaky underground storage tanks.

Another contamination problem found in Armonk, which is a relatively developed area, was the detection of volatile organic compounds (VOCs) in nine out of 36 private supply wells that provide water to residences and businesses in Armonk. Water sampled and analyzed from these nine wells from 1979 to 1987 showed the presence of three halogenated solvents: tetrachloroethene (PCE), trichloroethene (TCE), and 1,2-dichloroethene (DCE). Additionally, some water samples also contained various concentrations of other VOCs, carbon tetrachloride, phenols, and priority pollutant metals. The concentrations of these organic compounds, metals, and the halogenated solvents all were found to exceed New York State Department of Health water quality standards. A remedial investigation identified the potential source of the halogenated solvents as three different dry cleaning establishments in Armonk. Although VOCs have been detected in the wells since 1979, their concentrations have decreased with time owing to dispersion and dilution by the ground-water system.

Unfortunately, these volatile organics (PCE, TCE, and DCE) not only were found in the local ground-water supply, but also in surface-water samples collected from the Wampus River. The river is a natural point of discharge for the local sand and gravel aquifer. Consequently, contaminants that percolate with precipitation into the subsurface migrate into the sand and gravel aquifer and into the underlying fractured Inwood Marble, and eventually are discharged with ground-water outflow to the Wampus River. Contaminants in the Wampus River also may have arrived there via overland flow (surface runoff) and/or via the storm sewer system. More detailed information concerning the remedial investigation and assessment of hydrocarbon and volatile organic contamination in the Armonk area can be obtained from the 1989 report prepared by Goldberg-Zoino Associates of New York, P.C.

While not currently defined as problems, additional sites in the Armonk area that may be appropriate for monitoring include:

- The Westchester Garden Landfill; although no ground-water contamination has been detected, nursery wastes, car and truck bodies, and urban renewal wastes have been found.

- The Labriola Mini-Executive Park Landfill; although no contamination has been detected at the landfill, which was closed in the 1970's, nursery wastes have been found.

- The Texaco gas station on Route 128 where the underground storage tank leaked gasoline into the subsurface sometime prior to 1980. This site and other petroleum storage facilities may be the source of petroleum compounds and therefore, should be monitored.

Overall, the quality of water in North Castle is considered to be good to excellent. All constituents were found to be well below State and Federal drinking water standards.

As already discussed, chloride and nitrate concentrations in the North Castle Water District 2 have increased slightly from 1960 to 1976. Chloride concentrations increased from 5 mg/L in 1960 to 24 mg/L in 1976 (U.S. Public Health Service acceptable level is 250 mg/L). Nitrate concentrations increased from 0.13 mg/L in 1960 to 6.0 mg/L in 1976 (U.S. Public Health Service acceptable level is 10 mg/L). Although concentrations of both these constituents are well within the limits that are acceptable for drinking water, these increasing trends reflect the increase in development in North Castle during this time period. Therefore, one can speculate that as development continues to grow, these trends will likely continue to increase, and at some point in time, the levels of these constituents could exceed acceptable limits for drinking water.

6.0 MANAGEMENT CONCEPTS

There is no doubt that development in the Town of North Castle will continue to grow, and no doubt that ground water will continue to play an important role. However, given the limitations discussed in the previous section, it is essential that development planning consider the aforementioned limitations to ensure that small drainage sub-basins are not allowed to develop to the point where they exceed water availability; and to ensure that the water quality of the aquifers comprising these sub-basins is not degraded.

6.1 Ground-Water Availability

Most of the ground water in the Town is withdrawn from deep wells that penetrate the bedrock aquifers, however, the most productive aquifers are the unconsolidated sand gravel deposits found along the major streams. In fact, the sand and gravel aquifers are nearly ten times more productive than the bedrock aquifers. Although these unconsolidated deposits are areally limited, small water supply systems could easily be developed where the sand and gravel deposits are saturated and where recharge to the deposits is favorable. These water supply systems probably could provide up to 1 million gallons per day.

Additional smaller water supply systems that could yield up to 0.5 million gallons per day could be developed in the bedrock aquifers, primarily in those areas where the fracture density in the bedrock is high and/or in areas where major fracture lineaments have been identified.

A large volume of geologic data collected in previous investigations provides a sound basis to begin preliminary assessments of ground-water conditions in particular areas of North Castle. However, to pinpoint specifically those locations where favorable hydrogeologic conditions exist for future development of ground-water supplies would require the implementation of an extensive and costly drilling and testing program. Inasmuch as the Town probably is not in a position to invest and implement such a comprehensive ground-water exploration program, other alternatives are available.

One sound alternative is to conduct a well inventory of all available hydrogeologic data collected for existing wells and for new water wells that will be drilled in the future. The well inventory data collected from 1965 to 1984 and supplied by the Westchester County Environmental Management Council (EMC) provides a solid basis upon which to expand the well inventory data base for North Castle. Valuable information concerning the subsurface environment can be obtained from accurately recorded driller's logs when they are properly prepared. By reviewing well records, one can begin to put together a three dimensional picture of the subsurface hydrogeologic environment. In other words, one can view this as putting together a jigsaw puzzle of the subsurface hydrogeologic framework; and each new piece of well-drilling information that is added to the puzzle fills in a gap where no specific data were previously available. Over a period of time as data are added, the picture will begin to take shape. Geologic cross sections similar to that shown in Figure 6 could be constructed to give one a sense of the vertical extent of sand and gravel deposits and the extent of major and minor fractures in the underlying bedrock. Geologic maps similar to those shown in Figures 5 and 7, also could be constructed for site-specific areas of interest in order to delineate the exact areal extent of unconsolidated deposits and bedrock. As more and more pieces of data are added to the puzzle, one can begin to more accurately pinpoint those areas in the Town where subsurface hydrogeologic conditions are favorable for the development of ground-water supplies.

Presently, in order to obtain a well drilling permit, drillers are required to supply a minimum amount of data concerning the construction and the yield of the well, and the bacteriological quality of the water obtained from the well.

In addition to the EMC well inventory data, existing well records on file in the Westchester County Health Department, although not always complete, also provides a sound basis to begin a well inventory. These existing drilling records will at least provide data concerning depths to bedrock and lengths of well casings, which are valuable in the preparation of geologic maps. Some drilling records may also include data concerning specific geologic formations and the yield of the drilled well. What may be missing or inaccurately recorded is the exact location of the well. The accurate construction of any geologic map or cross section is dependent on the accurate placement of data points (in this case, well locations) used to prepare the map or cross section. Obviously, if well locations submitted by the driller are inaccurately located, then the overall picture that one is constructing will not be a true representation of subsurface conditions. In fact, this type of simple inaccuracy could eventually lead to a costly mistake (i.e., wells drilled into poorly producing massive bedrock).

To give a more complete picture of hydrogeologic conditions at specific sites, additional information can easily be collected at the time of drilling, which would improve the overall quality of the well-completion data reported by the driller. The types of data that the Town should ensure that drillers provide and additional data that the Town could require drillers to report are as follows.

o Sketch maps of the drilling sites that accurately show the locations of newly drilled wells.

o Well construction data that specify the total depth of the well; the casing and screen depths; land surface altitude (where available); record of drilling times; record of mud losses or other circulation problems; and data related to the final pump installation (depth, size, rate of pumping).

o Depth, thickness, and character of each rock type or soil type that is penetrated during drilling. Depths of fractures, openings, or other unusual features found during drilling. Drillers familiar with the North Castle area probably are familiar with rock types and formation names, and therefore, should provide them in their drilling records wherever possible.

o Depths at which water is first encountered during drilling; the amounts and depths at which water-level changes occur during drilling; and the final depth to water upon completion of the well.

- Specific capacity of the well; as discussed previously, specific capacity is an expression of the productivity of a well that can be obtained upon completion of the well by measuring the rate of discharge of water from the well and the amount of drawdown that occurs at that rate. The driller should record by which method water was removed (pumping, bailing, etc.) and the rate of withdrawal.

- Chemical analysis of a water sample collected from the completed well. The analysis, which could be prepared at the owner's expense, should include tests for chloride, nitrate, sulfate, sodium, hardness, total dissolved solids, and a full suite of metals. Chemical data obtained from newly constructed wells would broaden the data base of chemical-quality data available for North Castle.

Some drillers who work in North Castle may in fact record and submit all of the above-mentioned data; however, we assume that not all well records are complete. Therefore, the list above could be used as a basis for improving the overall quality and uniformity of well-completion records filed by drillers in North Castle.

Specific-capacity data may perhaps be one of the most important pieces of data that should be reported for newly completed wells. Again, specific capacity is the actual yield that can be obtained from a well per foot of drawdown of the water level. Drawdown refers to the amount the water level is lowered during pumping. Drawdown varies with the rate of pumping, therefore, it is important to specify the rate of pumping for any measured drawdown. Specific-capacity data are important because they are good indicators of the actual yield or amount of water that can be withdrawn from an aquifer. Thus, specific capacity provides one with an indication of the sustained quantity of water that can be withdrawn from the aquifer without causing detrimental effects on ground-water levels.

Specific-capacity data also can provide useful information when planning the linear spacing between a number of wells that will be producing from the same formation. The drawdown that is produced around a pumping well creates a "cone of depression" in the water level. The size of the cone will depend on the hydraulic characteristics of the water-bearing formation, the rate of pumping, and the duration of pumping. If wells pumping from the same formation are spaced too closely together, the cones of depression surrounding the wells will overlap and interference will occur between wells. As a result, the water level in nearby nonpumping wells will be lowered, and when all of the wells are pumping, the production from each well will be decreased. This could have an extremely serious effect on production in those areas where well yields are only a few gallons per minute.

In addition to knowing where and how much water is available, the Town also should know where and how much water is being withdrawn from the ground-water system. Identifying the distribution of pumping centers (where water is withdrawn) is important where one is attempting to determine the direction and rate of ground-water flow. Withdrawal data also are important in evaluating the ability of a sub-basin to withstand increased development. As we have discussed in the previous section on limitations, recharge is variable between sub-basins and recharge is limited in smaller sub-basins. Increased development in those sub-basins where recharge is limited would undoubtedly lead to increased withdrawal, which eventually could exceed the natural recharge capacity of those sub-basins. Consequently, we recommend establishing a series of monitoring wells that could be used to measure changes in ground-water levels over a period of time. As a result, should a clear downward trend in water levels be detected owing to increased withdrawals, action then could be taken to reduce withdrawals. Additionally, since withdrawals by public water-supply wells probably are known, we would recommend that withdrawals by industrial or commercial wells also be reported on a yearly basis. Because ground-water withdrawals by industrial or commercial businesses probably are at least equal to or perhaps more than withdrawals by public supply systems, an inventory of reported yearly withdrawals could be useful in determining and controlling large diversions of ground water. Monitoring ground-water levels and inventorying withdrawals in the sand and gravel aquifers found adjacent to the larger river valleys also would be extremely beneficial to ensure against overpumping the shallow aquifers, which could result in reduced streamflow and induced surface-water infiltration to the shallow aquifers.

As stated previously in this report, we also regard the entire land surface area that is underlain by saturated sand and gravel deposits as primary recharge areas. Future development owing to population growth in these highly sensitive and vulnerable areas would undoubtedly result in an overall decrease in the surface area available for recharge to the shallow aquifers. In other words, where development was allowed to increase, buildings and paved roadways also would increase thereby eliminating those developed surface areas as recharge areas and reducing the overall recharge to the sand and gravel aquifers. Additionally, if the volume of water available to recharge the aquifers is decreased, and the volume of water withdrawn through pumping is allowed to increase without monitoring withdrawals, then at some point in time it is possible that the amount of water pumped from the aquifers could exceed the amount of recharge. As a result, ground-water levels would decline, and eventually the aquifers could be dewatered. Overdevelopment in prime recharge areas could be particularly detrimental in small sub-basins such as the Wampus that have limited areal extent and limited recharge areas. For these reasons, we also recommend focusing future efforts on determining rates of recharge and specific water budgets for individual sub-basins which could then be used to protect these vulnerable recharge areas against overdevelopment. It also would be prudent to acquire and set aside these sensitive recharge areas in order to control future development in these area.

6.2 Ground-Water Quality

Presently, with the exception of some local degradation in Armonk, the quality of ground water in North Castle is good. To ensure the continued good quality of ground water in the Town, there are some steps that can be taken to initiate sound ground-water management planning for the future.

Septic tank systems and roadway deicing salts have been identified as major potential sources of ground-water contamination. Evidence already exists to suggest that the quality of ground water gradually is changing, and that chloride and nitrate concentrations are increasing. Although concentrations of these constituents are well within the safe limits established for drinking water, these upward trends indicate that if left unchecked, the levels of chloride and nitrate in ground water could exceed the capacity of the aquifers to accommodate the loading effects of these constituents. We recommend that steps be taken at this time to begin monitoring changes in the concentrations of chloride, nitrate, and total dissolved solids in ground water.

Ground-water quality monitoring should begin by establishing a series of observation wells where water samples could be collected and analyzed on a routine basis. In this way, the observation wells could be used as early warning devices to signal changes in the stability of the ground-water quality in the aquifers that are being monitored. In the early stages of monitoring, water-quality analyses also could provide basic data to establish baseline water-quality conditions that could be used to compare gradual changes in the ground-water chemistry over time. Observation wells used for monitoring should be located strategically in those areas where ground-water systems, such as sand and gravel aquifers, would be most susceptible to contamination. High susceptibility areas would include highly urbanized areas where the water table lies close to the land surface; areas where shallow aquifers are in hydraulic connection with surface-water bodies; areas where population densities are expected to increase; and areas where ground-water withdrawals may exceed the recharge capacity of a small sub-basin.

A water-quality sampling program should be scheduled on a semi-annual basis. Water samples should be collected and analyzed during periods of high flow in late spring and during low flow in late fall. Water samples should be analyzed for pH, specific conductance, and water temperature, and a full suite of basic inorganic chemical constituents including total dissolved solids, chloride, fluoride, iron, manganese, nitrate, sodium, and sulfate. Additionally, metals that can infiltrate into the ground-water system from septic tank systems should also be added to the list of chemical analyses. In more urbanized areas where the potential may be high for the introduction of organic chemicals and specifically volatile organic compounds, it would be appropriate to include these chemicals in the suite of constituents to be analyzed. In those areas where it may be suspected that fertilizer, pesticide, and/or herbicide usage is high such as nurseries or small tracts of land under agricultural production, it would be appropriate to analyze for commonly used agricultural chemicals.

Water-quality monitoring could be further enhanced by requiring that water samples be collected and analyzed for basic chemical constituents including chloride, nitrate, and total dissolved solids when new water-supply wells are drilled. These analyses, which could be performed at relatively low costs to the well owners, would provide invaluable information to supplement the data base established to monitor baseline ground-water quality conditions.

Shallow aquifers comprised of saturated sand and gravel deposits underlie the Byram, Wampus, and Mianus River valleys. These shallow aquifers contain large volumes of water, and therefore, they have the potential to provide enough water for public supply purposes. Because these aquifers are shallow and the water table in these low-lying areas lies near the land surface, the potential for contaminants to migrate into the ground-water system is high. As a result, thoughtful consideration should be given to monitoring and protecting these vulnerable areas, possibly by identifying and acquiring areas of potential development for public water-supply use, and then setting these areas aside for future development.

Septic tank systems will continue to be the dominant method in which domestic wastes are disposed in North Castle. Proper planning and management practices can be implemented that will reduce the rate at which nitrates and other undesirable chemicals are added to the ground-water system. For instance, soil groupings developed by the Soil Conservation Service can be used to determine the suitability of soils in areas where new septic systems are planned.

In planning new septic tank systems, one should also consider the minimum acreage of land that could successfully absorb the disposal of septic tank effluent. The larger the lot size, the greater the quantity of precipitation that will infiltrate into the subsurface and the smaller the percentage of water that will be recirculated. Consequently, it would be less difficult to maintain ground-water quality on a larger lot size. A larger lot size also allows for additional suitable space for the installation of a new disposal system should the old system fail. In Westchester County for instance, a minimum usable area of 5,000 square feet or an area that is equal to twice the size of the proposed system is required (Div. Environmental Health Services, 1966).

Finally, routine maintenance of existing septic tank systems will help in the effective operation of existing systems, and help minimize the degradation of absorption fields, which if ruined, would require replacement of an entire system. Many homeowners do not realize the importance of performing regular maintenance on their septic systems. Thus, educating homeowners about the necessity of periodic septic system maintenance would be one simple way of protecting ground-water systems against possible degradation from septic tank effluent. Education could simply be in the form of mailing notices to homeowners with septic tank systems, and requiring the homeowners to return signed forms certifying that proper maintenance had been handled by licensed septage pumpers.

In order to keep roadways open during winter months, deicing salts must be used; however, increased usage has contributed to increased concentrations of chloride in ground water. Point sources of chloride leachate produced from any unsheltered stockpiles of deicing salts can be easily remedied simply by requiring that all stockpiled salts be covered. Nonpoint sources of chloride leachate that result from the application of deicing salts to roadways can be minimized by applying only the minimum required quantity to road surfaces. Guidelines for the correct calibration and application of roadway salts can be obtained from the Salt Institute in Alexandria, Virginia. Bruce Bertram, Technical Director of the Institute, and other Institute members are available to answer questions and assist communities in developing safe salting programs. Mr. Bertram and his staff can be reached at (703) 549-4648.

Perhaps the most pressing ground-water issue that could affect the future quality of water in North Castle is the increase in population densities that exceed either the recharge capacity of small sub-basins or the capacity of these small sub-basins to accommodate discharges from septic tank systems. Further work remains to be done to establish actual baseline conditions with respect to development densities and ground-water quality in North Castle.

Results from the study performed in eastern Massachusetts, however, indicate the potential exists in North Castle for development of ground-water sources beyond the actual recharge potential of individual sub-basins, thus increasing the likelihood of ground-water contamination. We suggest that small sub-basins that are potentially vulnerable to the effects of development densities be identified and monitored closely. Efforts also should be made to pinpoint potential contaminant sources other than septic tank systems. Monitoring would require collecting ground-water samples on a semi-annual basis, analyzing the samples for total dissolved solids, and tracking the trends in the concentrations of total dissolved solids found in ground water. Besides collecting ground-water samples for analysis of total dissolved solids, we also would suggest collecting and analyzing surface-water samples for total dissolved solids from the Byram, Wampus, and Mianus Rivers, which are underlain by shallow aquifers.

7.0 CONCLUSIONS

The intent of this report is to provide the Conservation Board with basic information concerning the present conditions of ground-water resources as related to the availability, quantity, and quality of ground water in North Castle. We believe that we have provided the Board with sound, basic recommendations that can be implemented to plan future development, and at the same time, protect the quantity and quality of ground-water resources in North Castle.

Presently, the quantity of ground water available in North Castle is more than adequate to meet the needs of the Town. And in actuality, there are still large reservoirs of ground water that have yet to be tapped. Likewise, the overall quality of the ground-water resources presently is considered to be good to excellent. This, however, is not to say that these current conditions will remain as such with any future development in the Town.

In this report, we have outlined a number of recommendations that can be implemented by the Board on a both short-term and long-term basis. The types of work elements that could be implemented within the next year or so include the following. Note that page numbers are shown in parentheses next to each summarized recommendation to refer the reader to the appropriate discussion in the text.

- Perform a well inventory of all available data for existing wells in North Castle (p.38, 39).

- Standardize the well-completion records that drillers must submit for all new wells drilled in North Castle (p. 39, 40, 41).

- Require drillers to report specific-capacity data for newly completed wells (p. 19, 20, 41, 42).

- Establish a network of monitoring wells (these could be both private wells and commercial business wells) to measure water-level fluctuations (p. 43).

- Establish a semi-annual water-quality sampling program that would include the collection of both ground-water and surface-water samples (p. 45,46).

- Educate homeowners about the importance of performing regular maintenance on their septic systems (p. 47).

On a long-term basis, the types of recommendations that could be implemented within perhaps the next 5 years would include the following.

- Identify and acquire sensitive recharge areas (sand and gravel deposits), and set them aside for future development (p. 25, 26, 37, 43, 44).

- Monitor the quality of ground water in the shallow sand and gravel aquifers, which appear to be promising future sources of ground water (p. 28, 45, 46).

- Establish baseline ground-water quality data, compare the relation to population densities, and monitor the trends in chemical constituents, specifically total dissolved solids (p. 30, 31, 48, 49).

- Monitor the withdrawal of ground water in small sub-basins where the amount of available recharge is limited (p. 22, 26, 28, 42, 43, 44).

- Monitor the quality of ground water in suspected areas of contamination such as Armonk (p. 34, 35, 36).

- Require routine maintenance of existing septic systems (p. 47, 48).

- Investigate possible control methods for the distribution and application of roadway deicing salts (p. 48).

By implementing these types of recommendations, the Town of North Castle will be able to better ensure the future availability and quality of their ground-water resources.

B&B ENGINEERING
MARCH 1990

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9.0 GLOSSARY[1]

Aquifer. A saturated formation or part of a formation that yields significant quantities of water to wells and springs.

Artesian aquifer. A confined aquifer in which the water is under sufficient pressure to rise higher than the aquifer surface in a well tapping the aquifer.

Base flow. Sustained or fair-weather stream discharge, composed primarily of ground water; the flow of a stream without runoff from precipitation.

Bedrock. General term for rock, generally solid, that underlies soil or other unconsolidated sediments.

Brine. A solution containing appreciable amounts of sodium chloride and other salts.

Capillary fringe. The zone above the water table in which water is held by surface tension. Water in the capillary fringe is under a pressure less than atmospheric.

Chloride concentrations. A measure of the salt in water, expressed in milligrams per liter.

Cone of depression. A low in the potentiometric surface, centered in an area of concentrated pumping.

Confined aquifer. An aquifer bounded above and below by relatively impermeable beds and containing confined ground water. (See "artesian aquifer").

Confined ground water. Ground water under pressure significantly greater than that of the atmosphere. its upper surface is bounded by a relatively impermeable layer.

Confining bed. A layer of earth material, generally clay or other fine-gradient sediment, that retards the movement of water.

Consolidated material. A sediment or rock composed of firm and coherent particles that are cemented together.

Discharge area. The location at which water leaves an aquifer, such as a stream.

Dissolved solids. The total amount of dissolved material, organic and inorganic, contained in water or wastes.

Drainage basins. The area drained by a river system through a valley system comprised of streams and their tributaries.

Drainage divide. The boundary between drainage basins; a topographic divide.

Drawdown. The distance by which a water table is lowered as a result of pumping.

Evapotranspiration. Loss of water from a land area through transpiration by plants and evaporation from the soil.

Fault. A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Fault breccia. Angular fragments resulting from the crushing, shattering, or shearing of rocks during movement of a fault or from friction between the walls of the fault.

Formation. The primary unit of formal geologic mapping or description.

Fracture. Breaks in rocks due to intense folding or faulting.

Glacial drift. Rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by the ice or water emanating from it. Includes

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[1]Most definitions are quoted or paraphrased from Bates, R.L., and Jackson, J.A. edgs. 1980. Glossary of Geology, second edition: Falls Church, VA, American Geological Institute, 749 p.

both stratified and unsorted material.

Gneiss. A coarse-grained rock in which bands rich in granular minerals alternate with bands in which schistose minerals predominate.

Gouge. Finely abraded material occurring between the walls of a fault, the result of grinding movement.

Ground water. Water saturating a geologic stratum beneath land surface; all water below the water table.

Ground-water flow. That portion of the precipitation which has been absorbed by the ground and has become part of the ground-water, alternately being discharged as spring and seepage water into the stream channels.

Ground-water level. Ground-water surface.

Head, static. The height of the surface of a water column that could be supported by the pressure of ground water at a given point.

Hydraulic conductivity. A measure of the ability of soil rock material to transmit water.

Hydraulic gradient. The change in static head per unit of distance in a given direction. If not specified, the direction is generally understood to be that of the maximum rate of decreases in head.

Hydrologic cycle. The complete cycle through which water passes, commencing as atmospheric water vapor, passing into liquid and solid form as precipitation, passing into the ground surface, and finally returning to the form of atmospheric water vapor by means of evaporation and transpiration.

Infiltration. The flow of a fluid into a substance through pores or small openings.

Joint. Fracture in rock, generally more or less vertical or transverse to bedding, along which no appreciable movement has occurred.

Leachate. A solution obtained by leaching, as in the downward percolation of meteoric water through soil or solid waste and containing soluble substances, such as a landfill.

Lineament. Straight or gently curved, lengthy features of the Earth's surface, frequently expressed topographically as depressions or lines of depressions.

Marble. A metamorphic rock composed essentially of calcite and/or dolomite.

Metamorphic rock. A rock formed at depth in the Earth's crust from preexisting rocks by mineralogical, chemical, and structural changes caused by high temperature, pressure, and other factors.

Milligrams per liter. A unit for expressing the concentration of a chemical constituent in solution, that is, the weight of constituent (thousandths of a gram) per unit volume (liter) or water.

Outcrop. An area where a given rock unit is exposed at land surface.

Outwash deposits. Stratified drift deposited by meltwater streams beyond active glacier ice.

Percolation. Flow through a porous substance; to pass through fine interstices.

Permeability. Property or capacity of a porous rock, sediment, or soil for transmitting a fluid; a measure of the relative ease of fluid flow under unequal pressure.

Porosity. The volume of openings in a rock. When expressed as a fraction, porosity is the ratio of the volume of openings in the rock to the total volume of the rock.

Quartzite. A granulose metamorphic rock consisting essentially of quartz.

Recharge area. The location at which water can enter an aquifer

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directly or indirectly; generally an area consisting of a permeable soil zone and underlying rock material that allows precipitation or surface water to reach the water table.

Runoff. The discharge of water through surface streams.

Saturated zone. Part of the water-bearing material in which all voids are ideally filled with water.

Schist. A medium or coarse-grained metamorphic rock with subparallel orientation of the micaceous minerals that dominate its composition.

Sedimentary rock. A layered rock formed at or near the Earth's surface from fragments of older rocks, by precipitation from solution, or from the remains of living organisms.

Specific capacity. The discharge of a well expressed as a rate of yield per unit of drawdown.

Specific conductance. A measure of the ability of water to carry an electric current. A high value indicates a high concentration of dissolved minerals.

Specific retention. The ratio of the volume of water retained in a rock after gravity drainage to the volume of the rock.

Specific yield. Ratio of volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of the mass, stated as a percentage.

Storage coefficient. The volume of water released from storage in a unit prism of an aquifer when the head is lowered a unit distance.

Stratified drift. Drift exhibiting both sorting and stratification, implying deposition from a fluid medium such as water or air.

Till. Nonsorted, nonstratified sediment carried or deposited by a glacier.

Transmissivity. The capacity of an aquifer to transmit water; equal to the hydraulic conductivity times the aquifer thickness.

Unconfined aquifer. An aquifer having a water table and containing unconfined water.

Unconfined ground water. Ground water having a free water table, not confined under pressure, beneath a relatively impermeable layer.

Unconsolidated material. A sediment or rock composed of particles that are not cemented together.

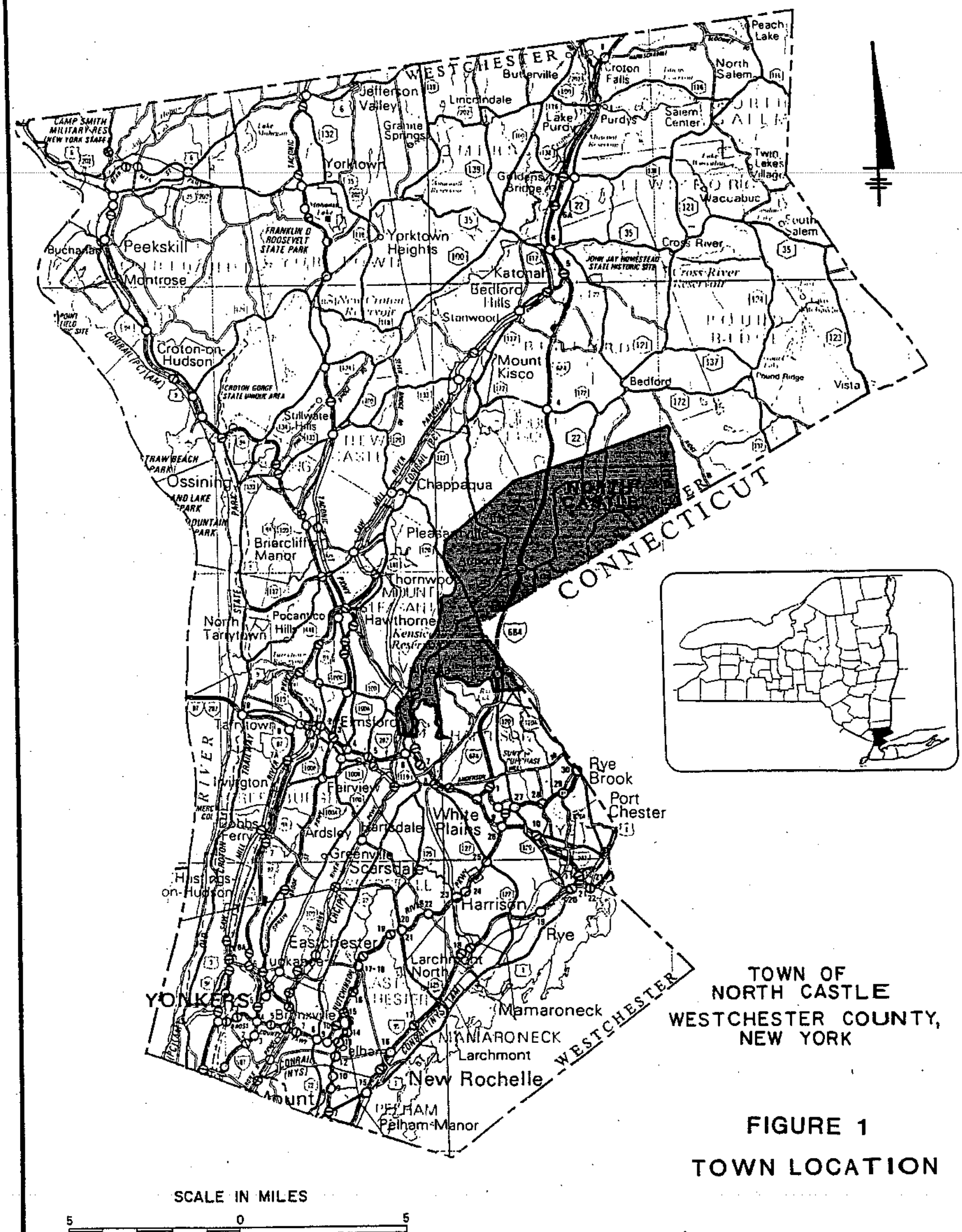
Unsaturated zone. The zone between the land surface and the water table, containing water held by capillarity, and containing air or gases generally under atmospheric pressure.

Unstratified drift. Drift not formed or deposited in beds or strata.

Water table. top of the zone of saturation.

Well log. Record of a well, generally a lithologic record of the strata penetrated.

Yield. The amount of water that can be taken continuously from a well for any economic purpose.



TOWN OF
NORTH CASTLE
WESTCHESTER COUNTY,
NEW YORK

FIGURE 1

TOWN LOCATION

SOURCE: NYSDOT NEW YORK STATE ATLAS, 1983

BLASLAND & BOUCK ENGINEERS, P.C.
ENGINEERS & GEOSCIENTISTS

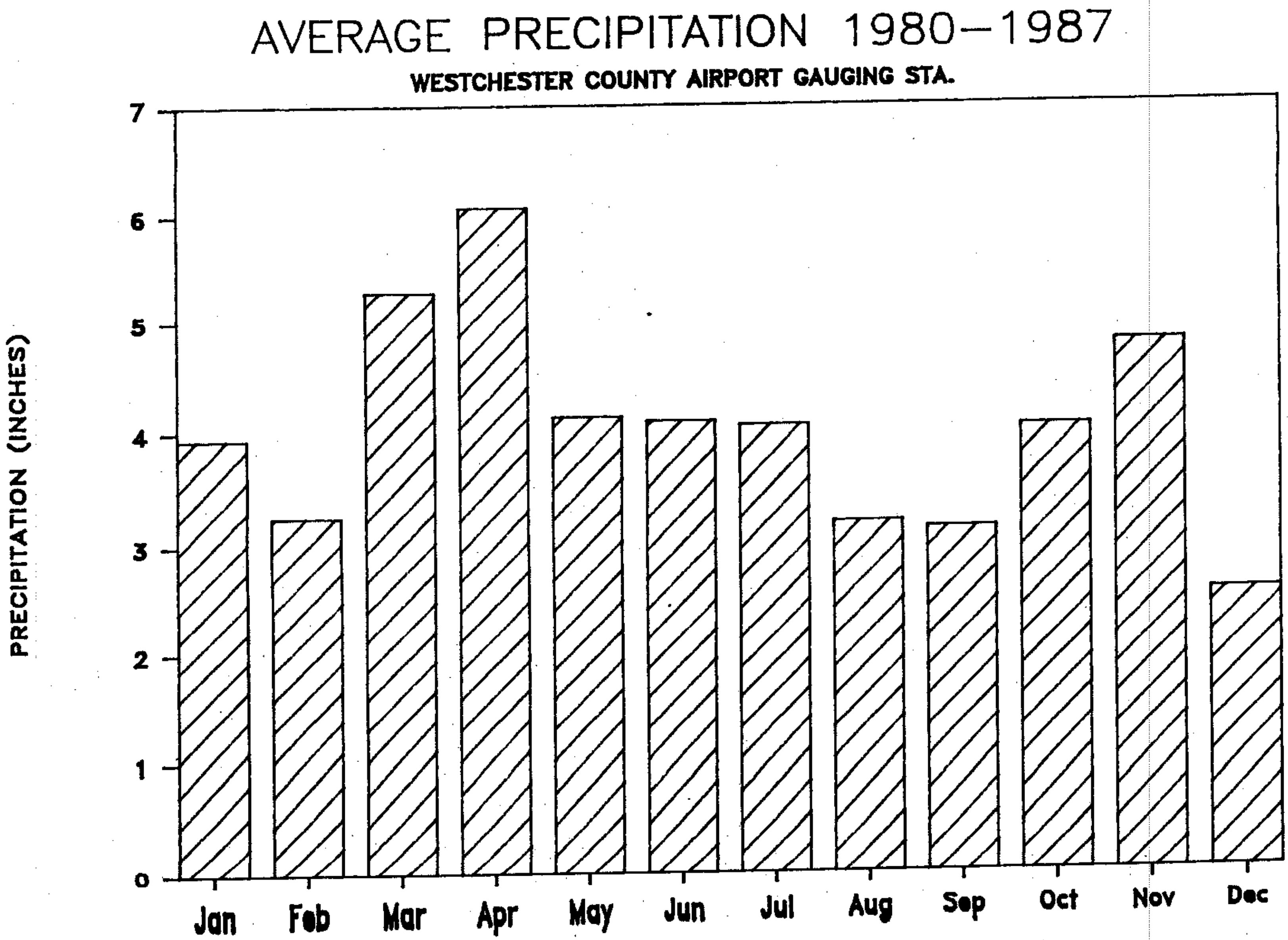

AVERAGE PRECIPITATION 1980—1987
WESTCHESTER COUNTY AIRPORT GAUGING STA.
PRECIPITATION (INCHES)
7
6
5
4
3
2
1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

FIGURE 3A

AVERAGE TEMPERATURES 1980–1987

WESTCHESTER COUNTY AIRPORT GAUGING STA.

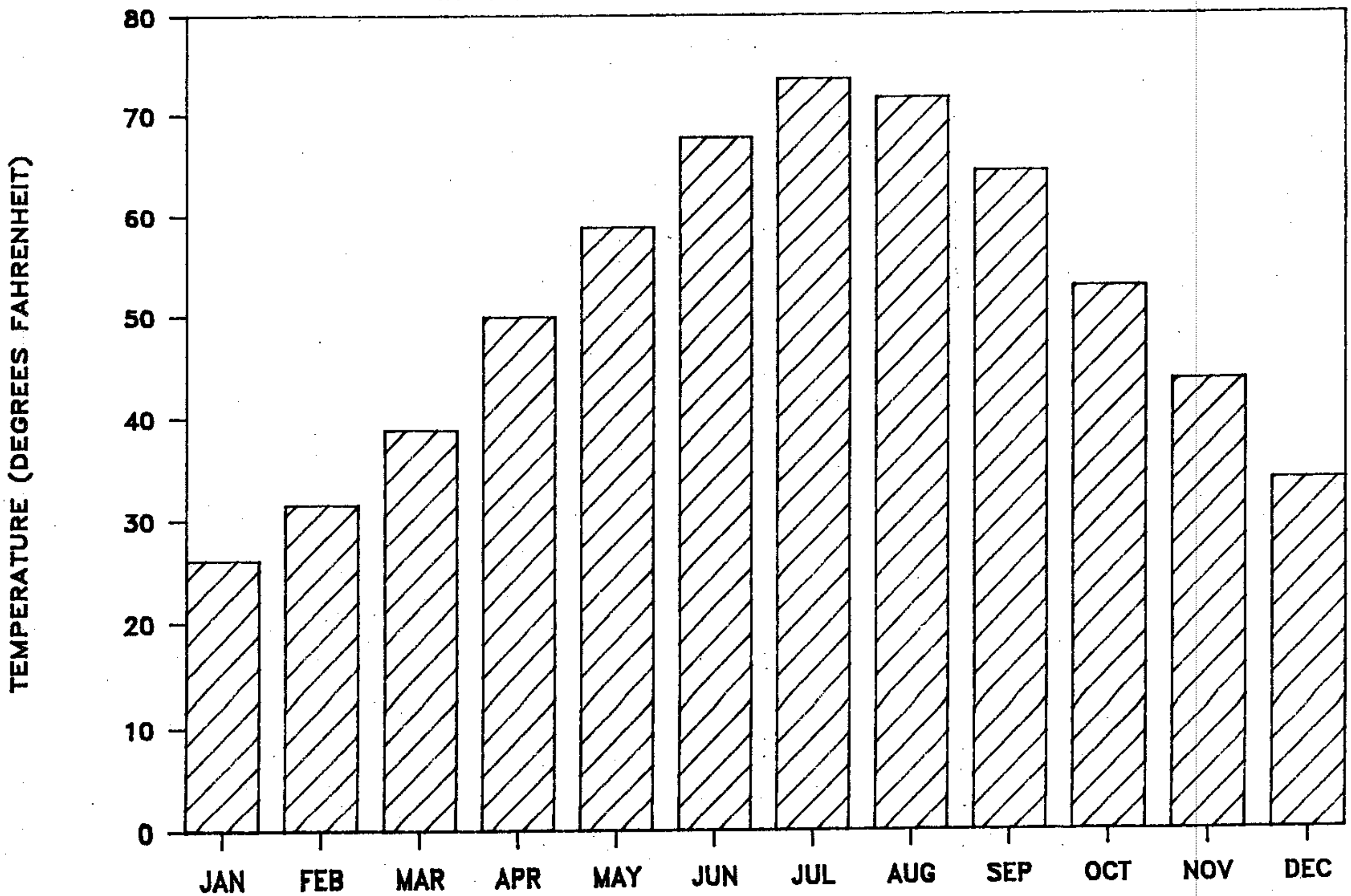


FIGURE 3B

BLASLAND & BOUCK ENGINEERS, P.C.

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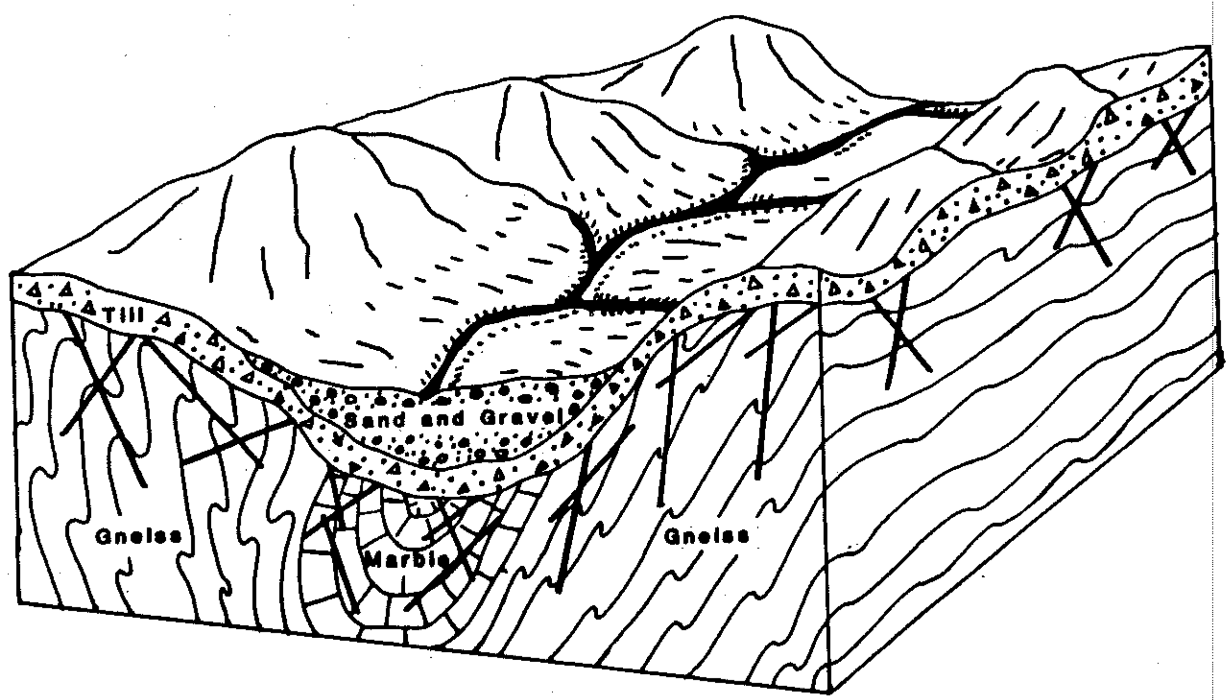

FIGURE 4 BLOCK DIAGRAM OF GEOLOGY AND TOPOGRAPHY IN NORTH CASTLE (MODIFIED FROM HEATH, 1984)

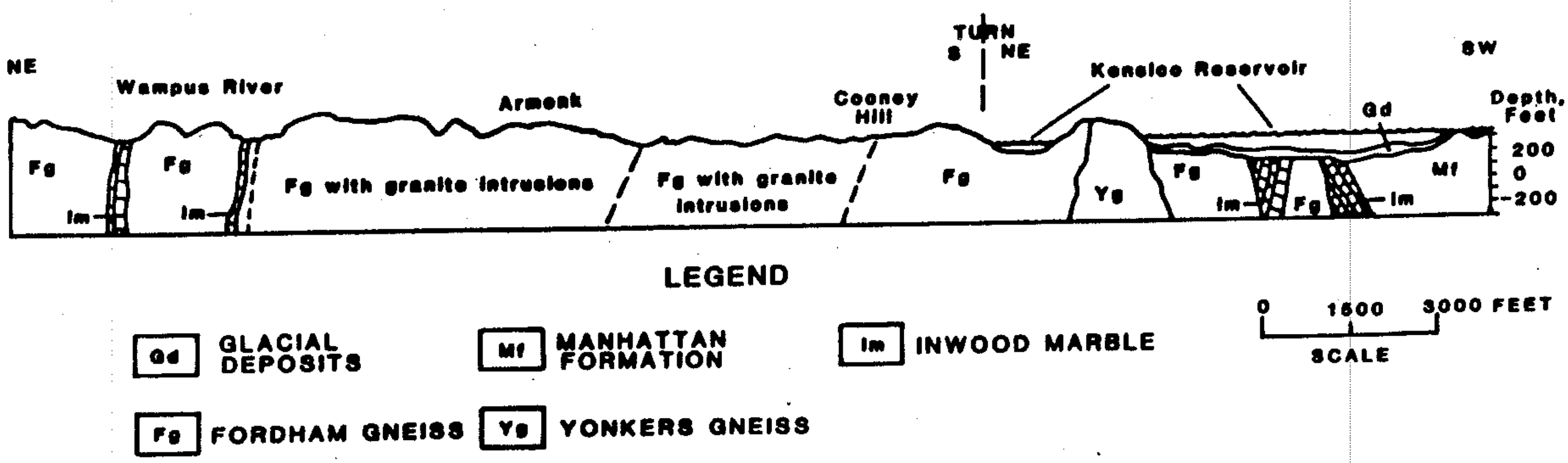

FIGURE 6 GEOLOGIC CROSS SECTION (MODIFIED FROM GERAGHTY & MILLER, 1977)

BLASLAND & BOUCK ENGINEERS, P.C.

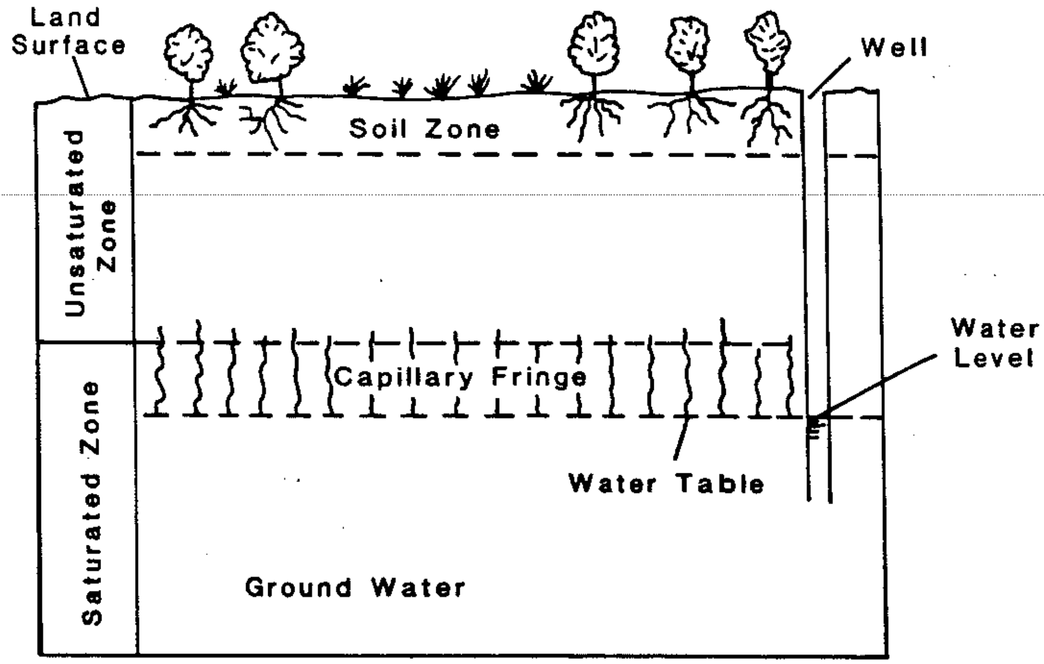

FIGURE 9 SCHEMATIC DIAGRAM OF UNSATURATED AND SATURATED ZONES (MODIFIED FROM HEATH, 1984)

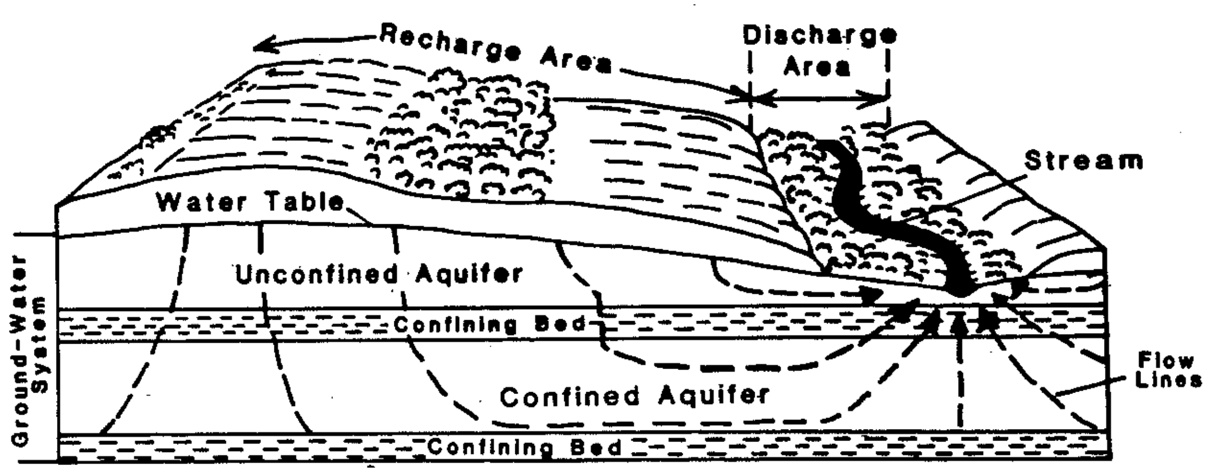

FIGURE 10 SCHEMATIC DIAGRAM OF RECHARGE AND DISCHARGE AREAS (MODIFIED FROM HEATH, 1984)

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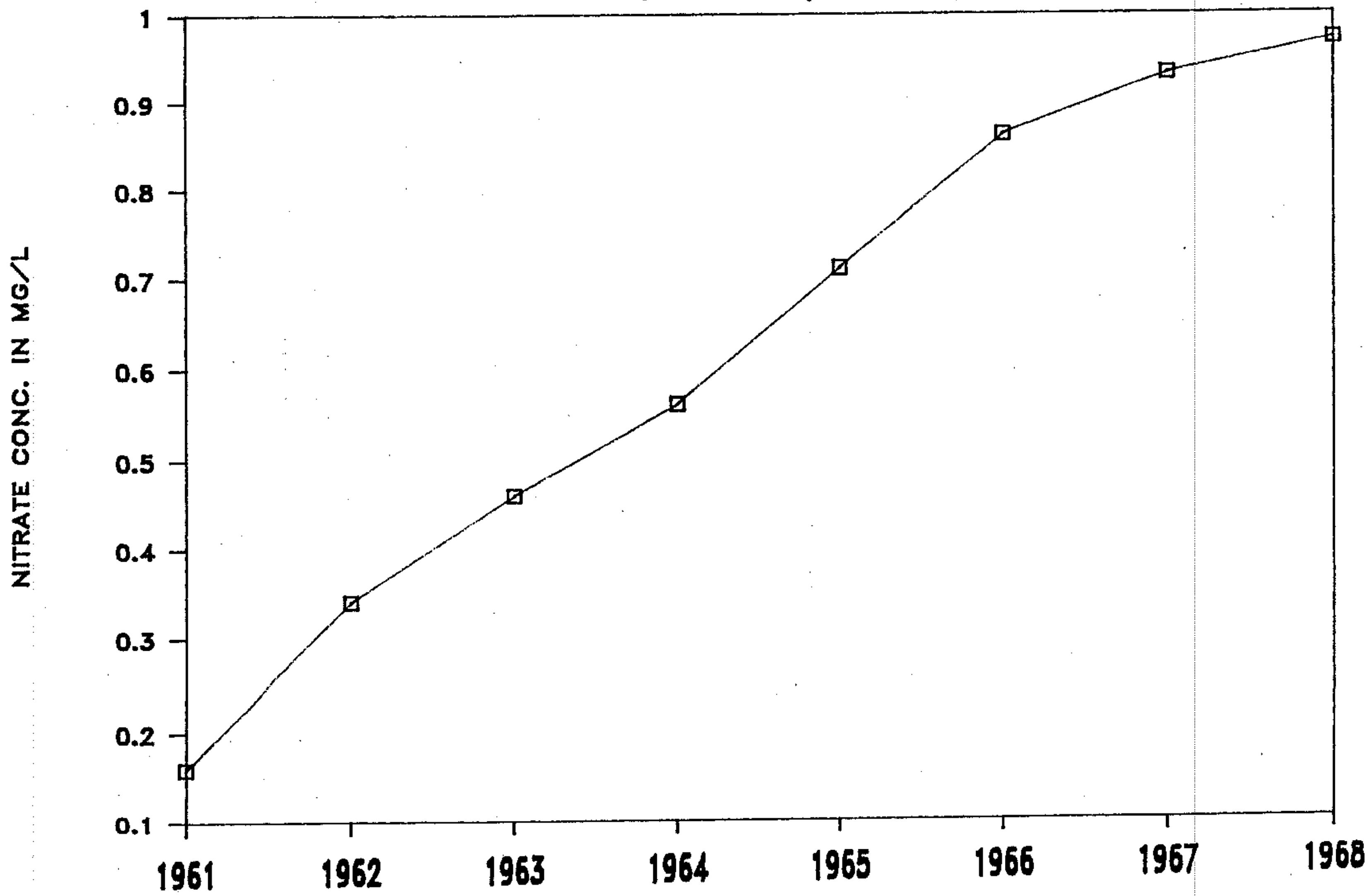
NITRATE CONCENTRATIONS IN GROUND WATER

NORTH CASTLE, NEW YORK (1961–1968)



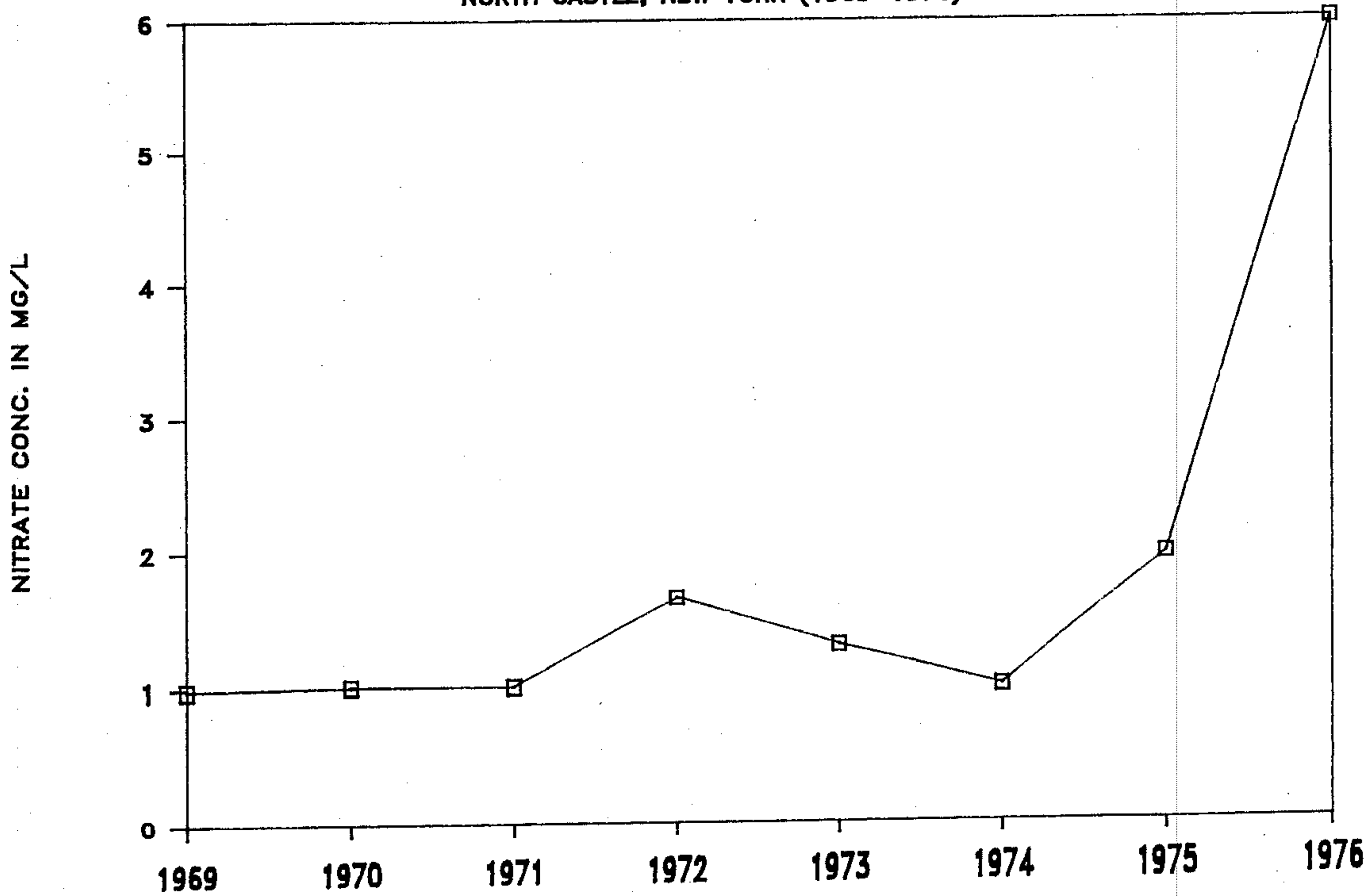
* The USPHS RECOMMENDED LIMIT = 10 mg/l

FIGURE 12A

BLASLAND & BOUCK ENGINEERS, P.C.

NITRATE CONCENTRATIONS IN GROUND WATER

NORTH CASTLE, NEW YORK (1969–1976)



• The USPHS RECOMMENDED LIMIT = 10 mg/l

FIGURE 12B

BLASLAND & BOUCK ENGINEERS, P.C.

CHLORIDE CONCENTRATIONS IN GROUND WATER

NORTH CASTLE, NEW YORK (1961–1968)

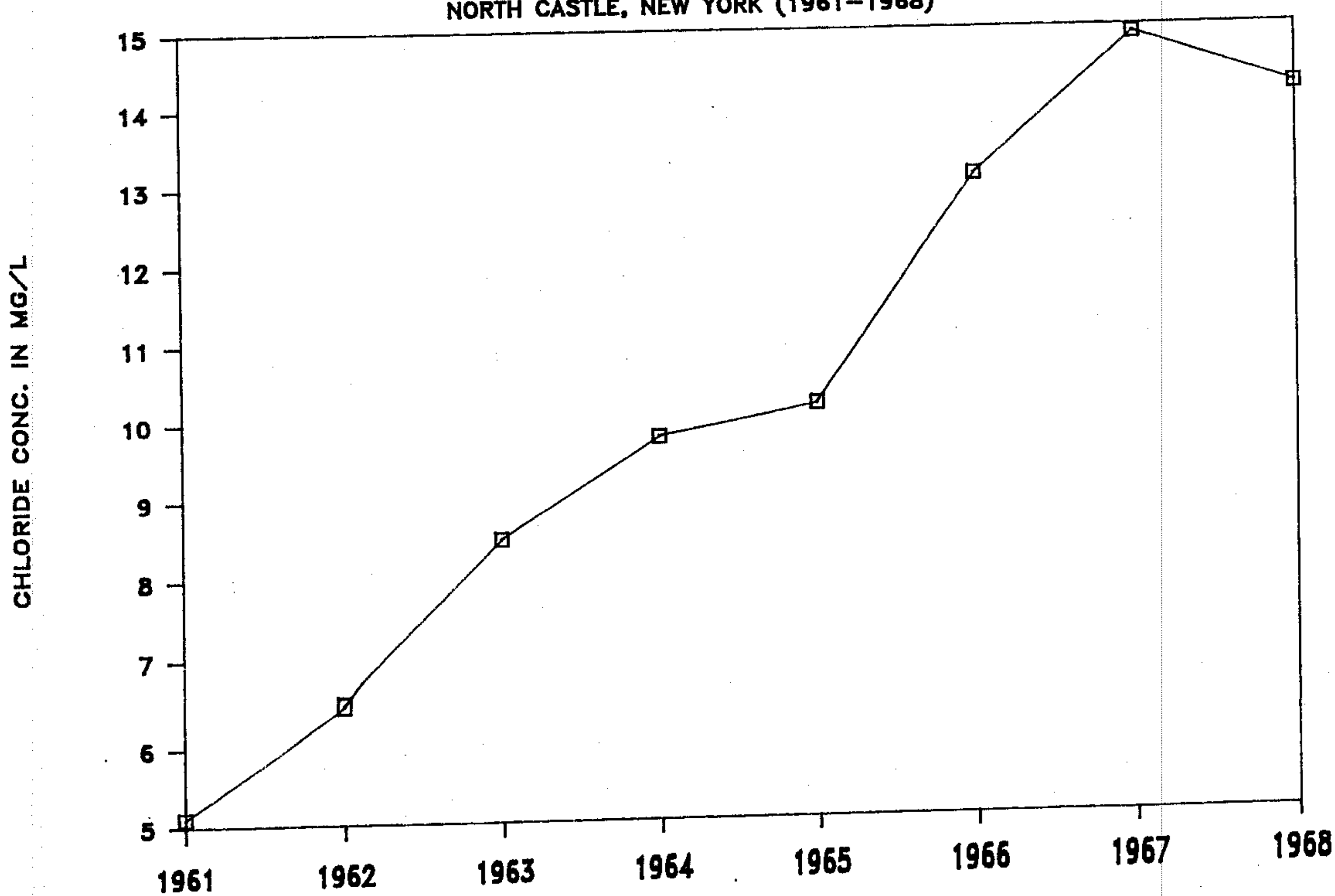


FIGURE 13A

BLASLAND & BOUCK ENGINEERS, P.C.

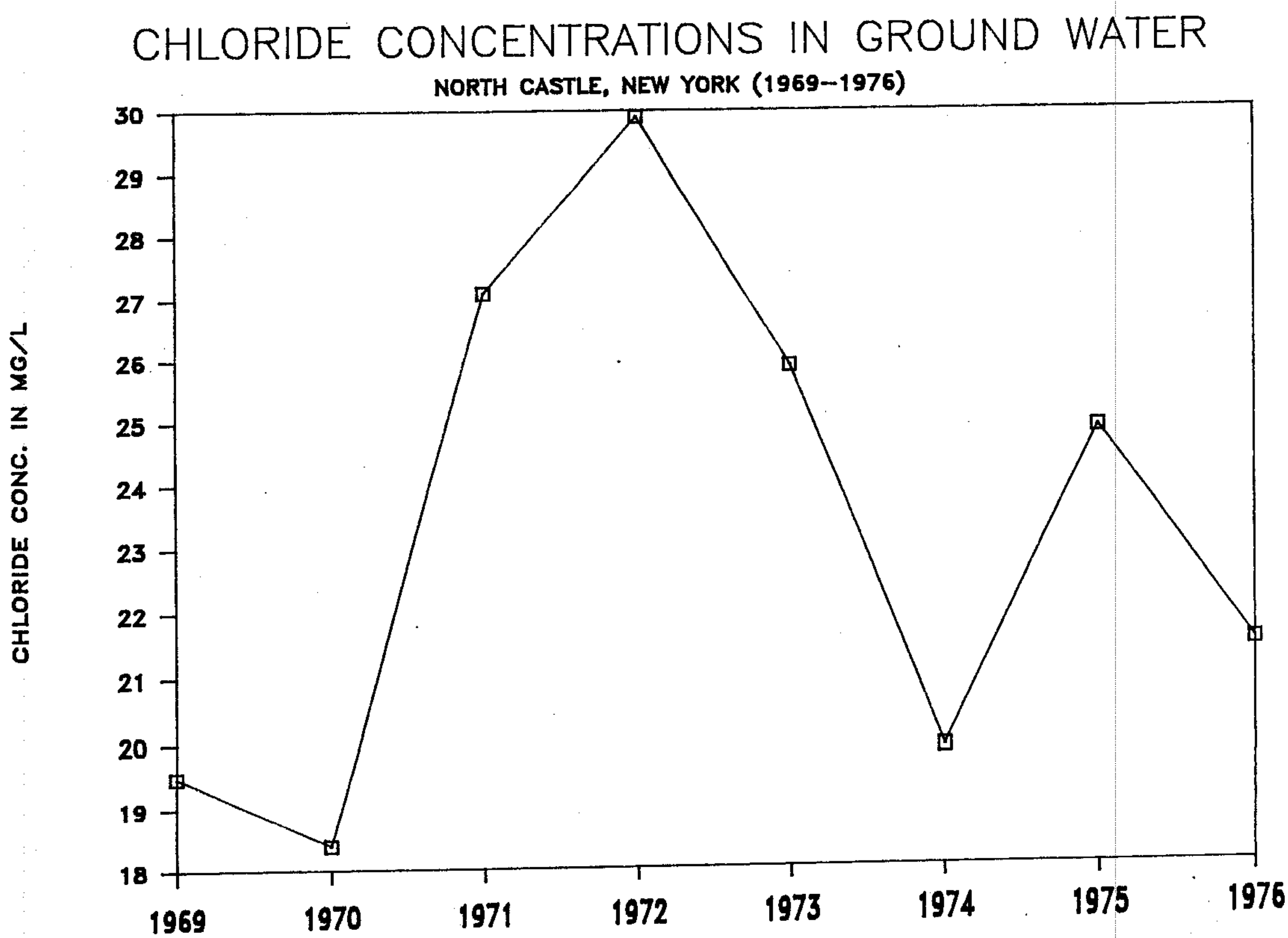


FIGURE 13B

BLASLAND & BOUCK ENGINEERS, P.C.

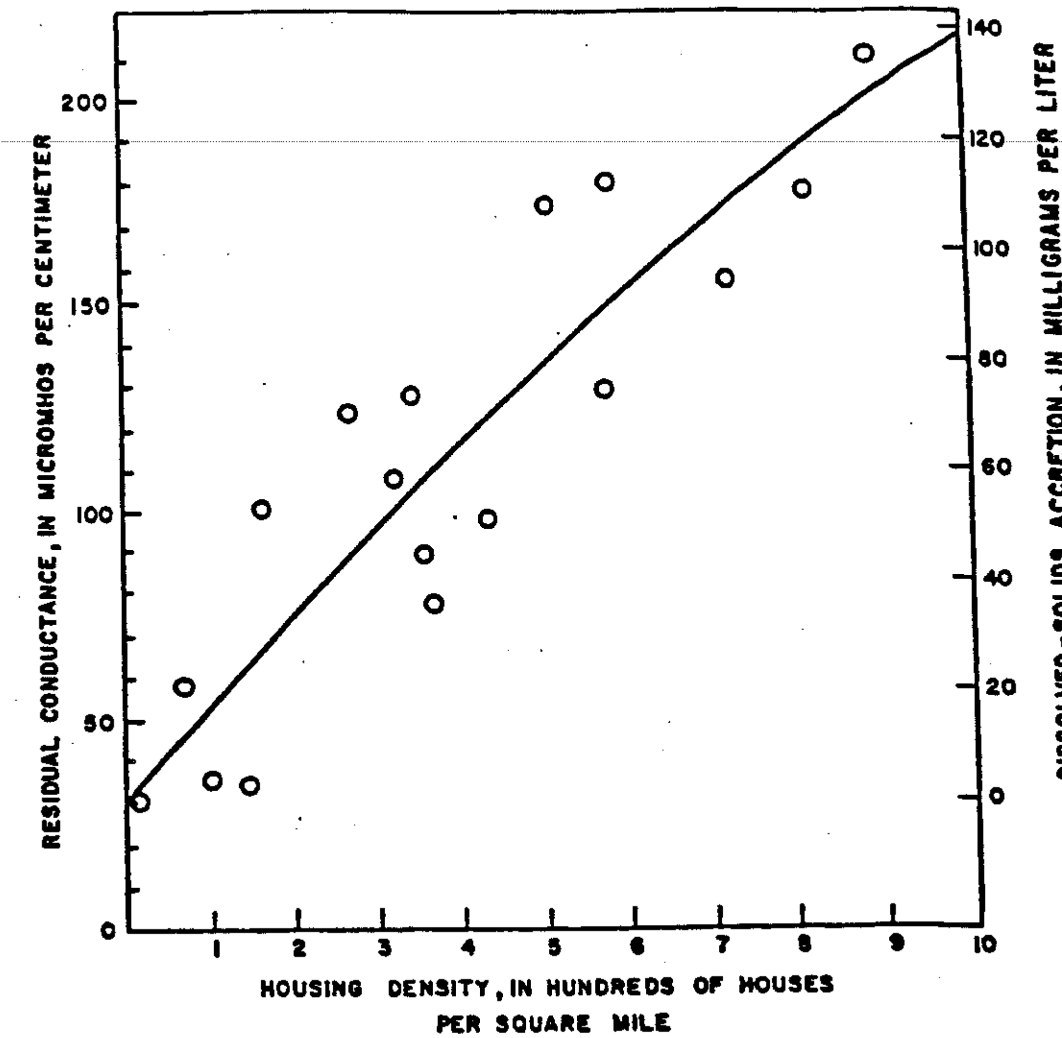


FIGURE 14 RELATION OF HOUSING DENSITY AND ACCRETION OF DISSOLVED SOLIDS IN STREAM BASE FLOW (FROM MORRILL AND TOLER, 1973)

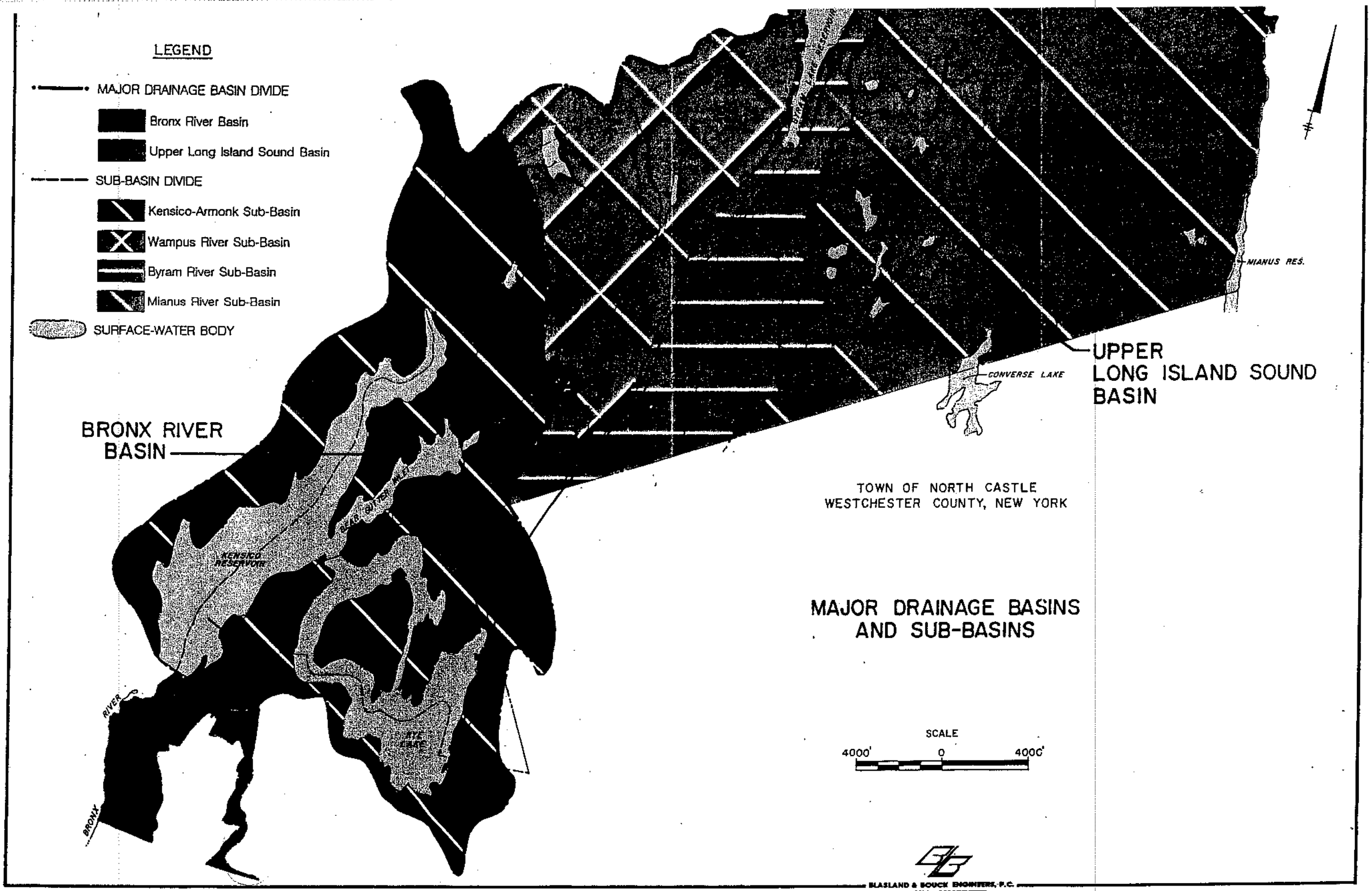
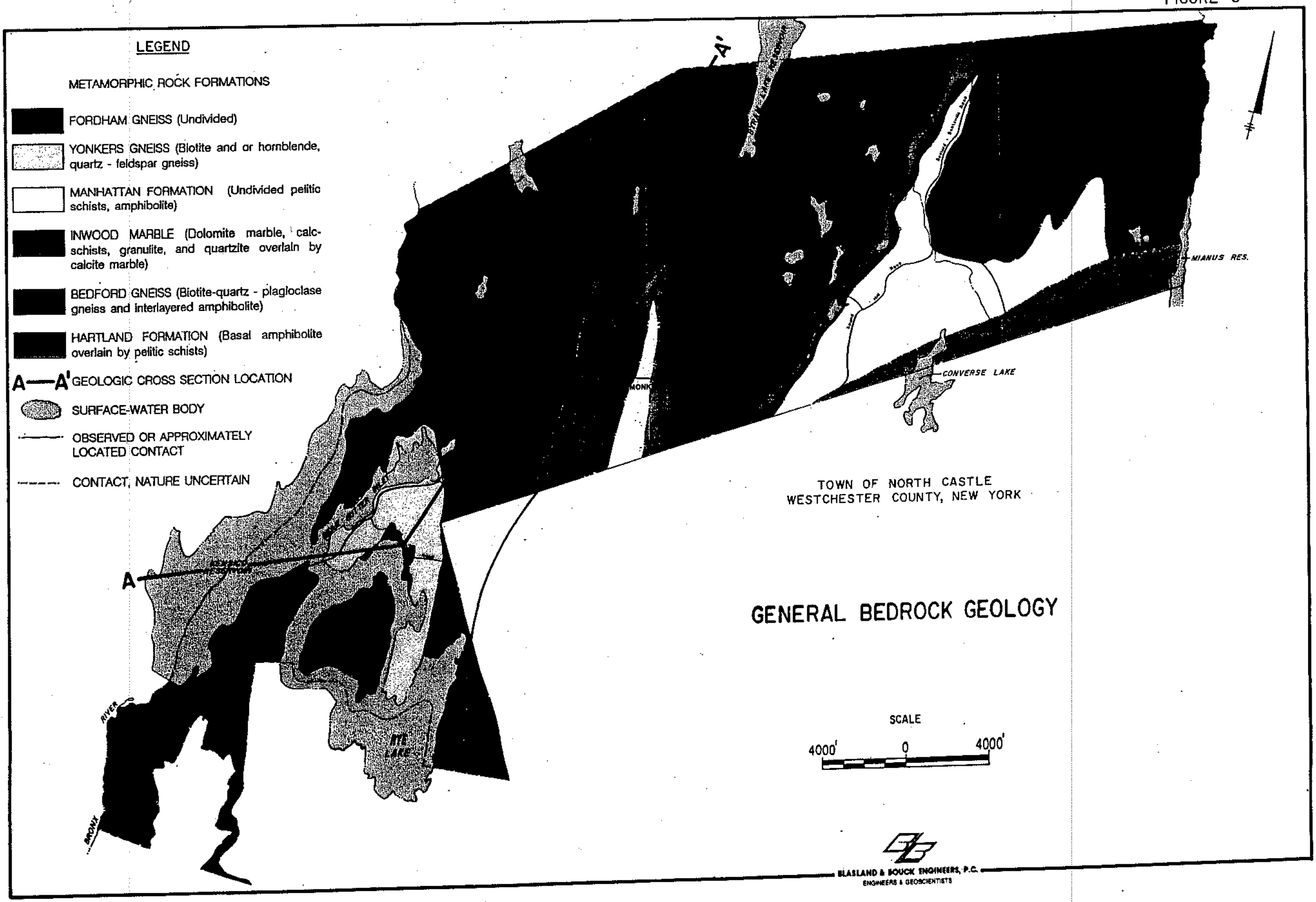

LEGEND
MAJOR DRAINAGE BASIN DIVIDE
Bronx River Basin
Upper Long Island Sound Basin
SUB-BASIN DIVIDE
Kensico-Armonk Sub-Basin
Wampus River Sub-Basin
Byram River Sub-Basin
Mianus River Sub-Basin
SURFACE-WATER BODY
BRONX RIVER BASIN
UPPER LONG ISLAND SOUND BASIN
MIANUS RES.
CONVERSE LAKE
KENSICO RESERVOIR
BRONX
RIVER
TOWN OF NORTH CASTLE
WESTCHESTER COUNTY, NEW YORK
MAJOR DRAINAGE BASINS AND SUB-BASINS
SCALE
4000'
0
4000'
BLASLAND & BOUCK ENGINEERS, P.C.

FIGURE 5



TOWN OF NORTH CASTLE
WESTCHESTER COUNTY, NEW YORK

GENERAL BEDROCK GEOLOGY

BLASLAND & BOUCK ENGINEERS, P.C.
ENGINEERS & GEOSCIENTISTS

FIGURE 7

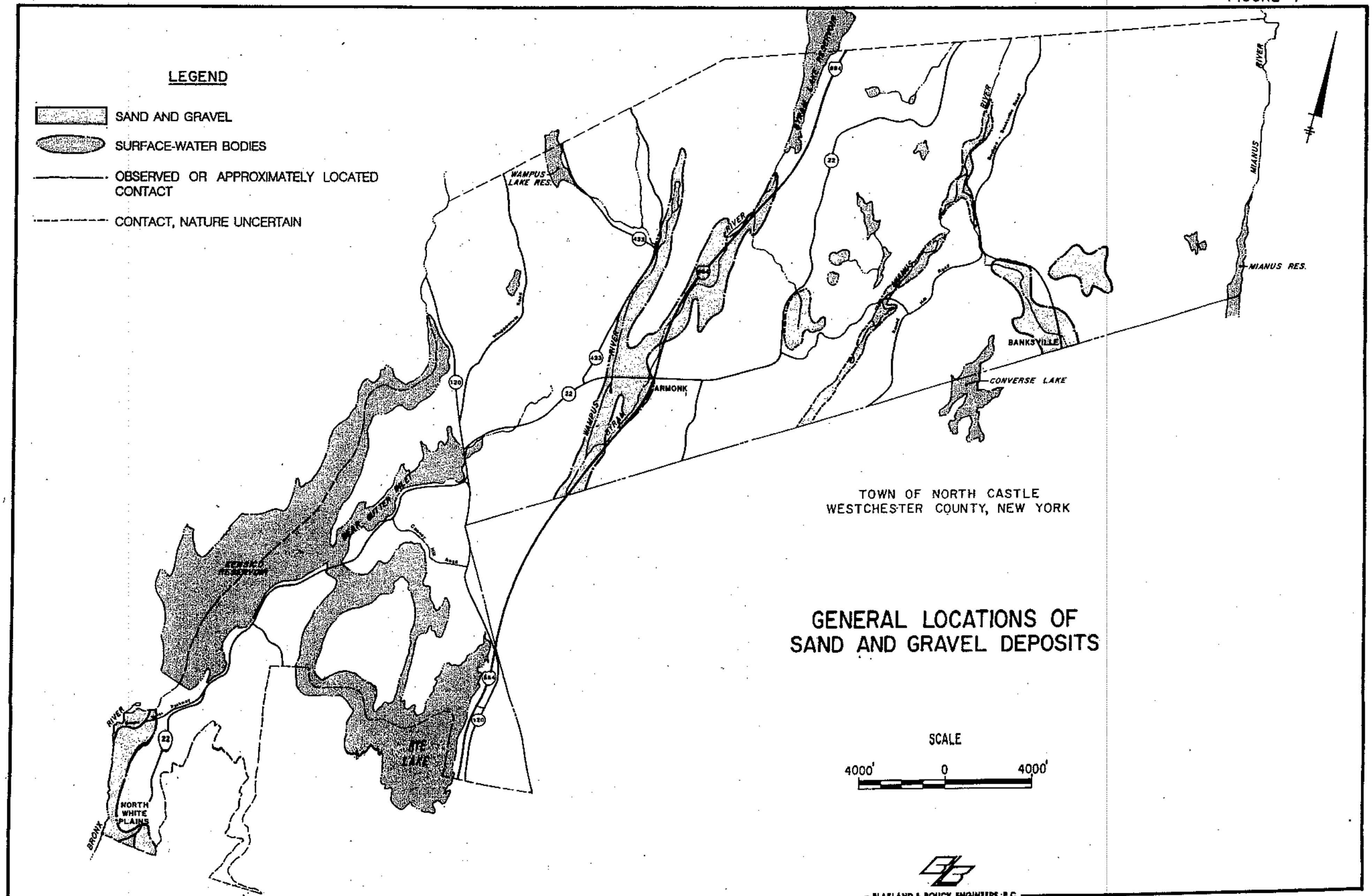
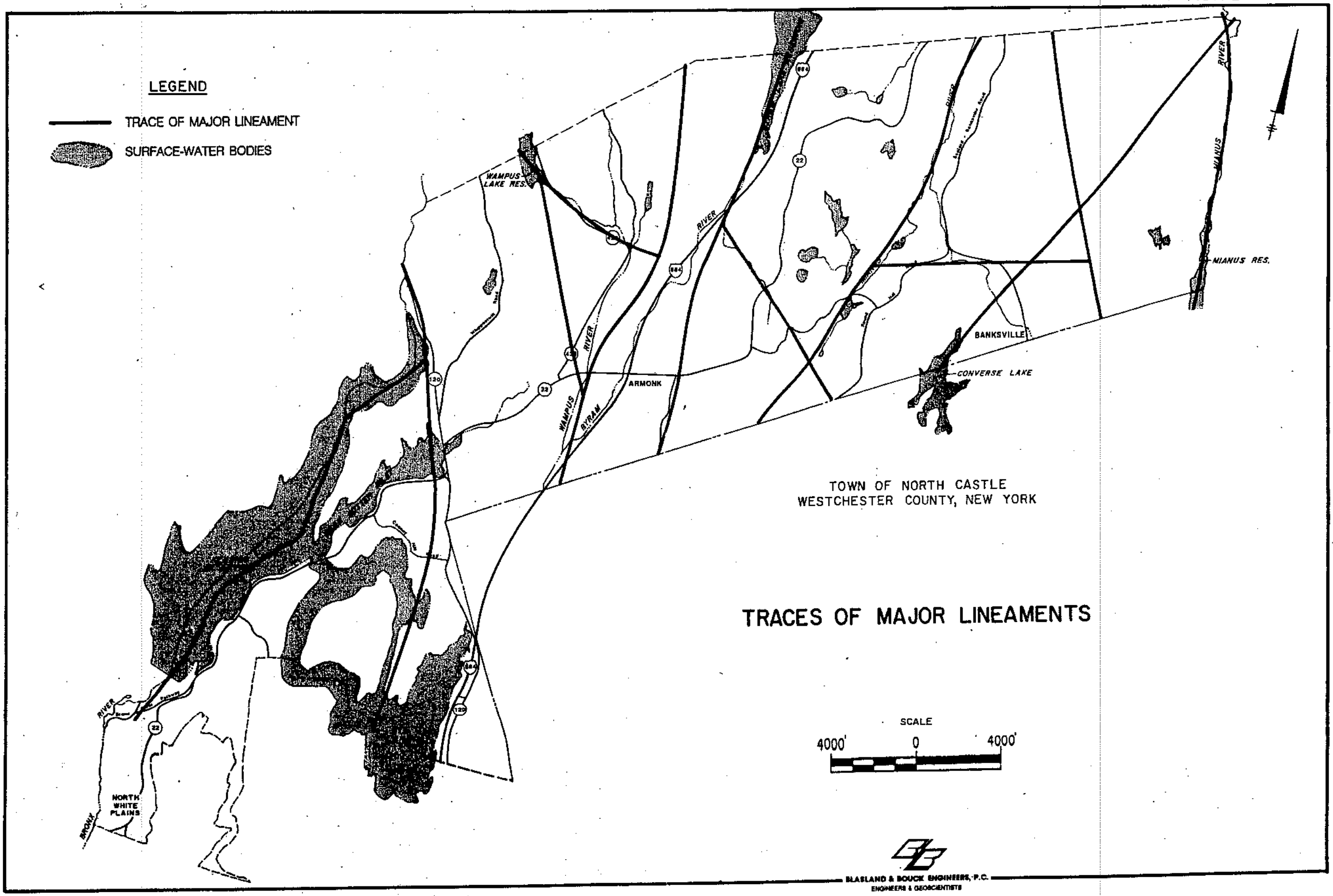
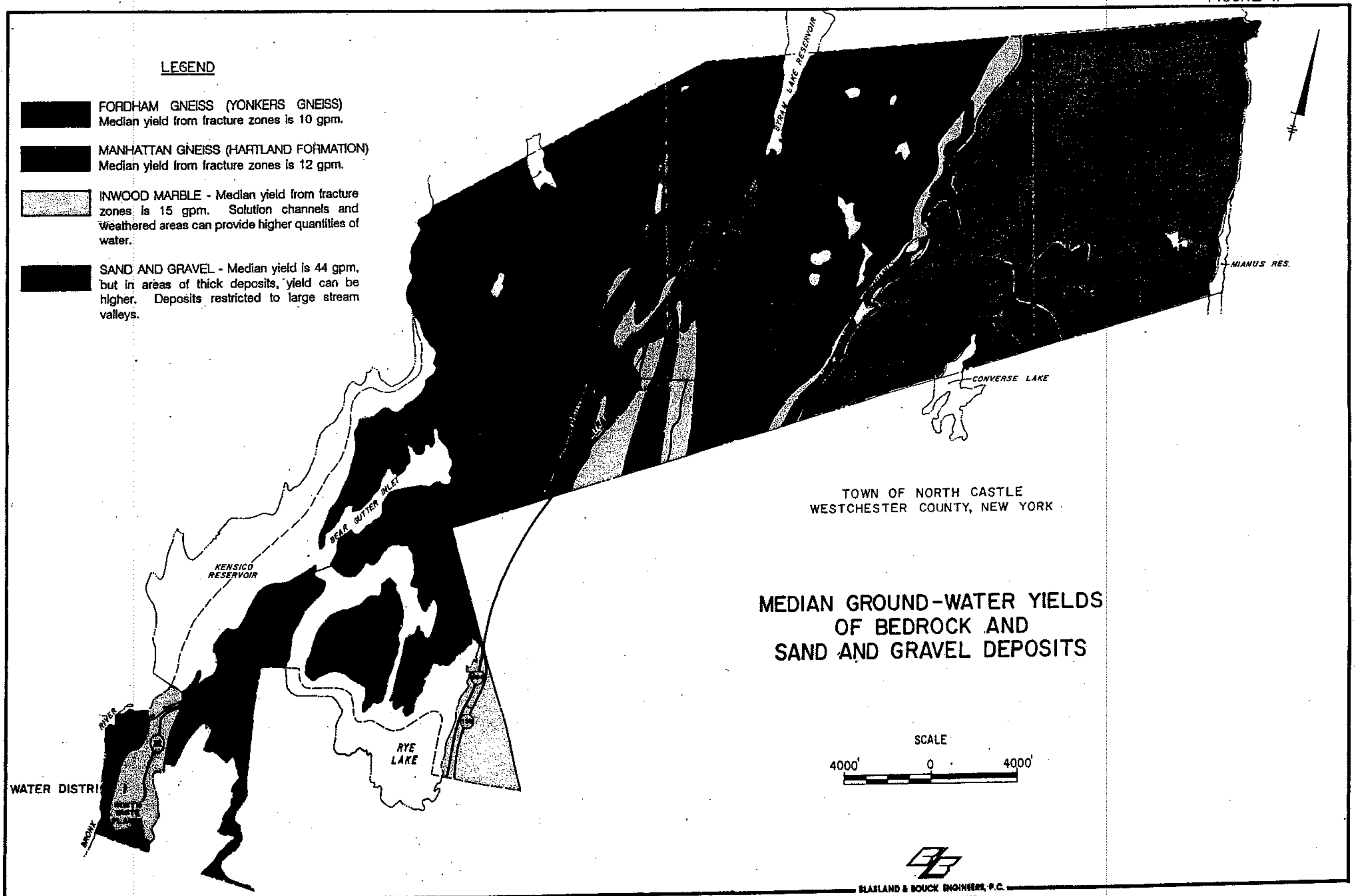

LEGEND
SAND AND GRAVEL
SURFACE-WATER BODIES
OBSERVED OR APPROXIMATELY LOCATED CONTACT
CONTACT, NATURE UNCERTAIN
WAMPUS LAKE RES.
ARMONK
BANKSVILLE
CONVERSE LAKE
MIANUS RES.
MIANUS RIVER
WAMPUS RIVER
NORTH WHITE PLAINS
BRONX RIVER
TOWN OF NORTH CASTLE
WESTCHESTER COUNTY, NEW YORK
GENERAL LOCATIONS OF
SAND AND GRAVEL DEPOSITS
SCALE
4000' 0 4000'
BLASLAND & BOUCK ENGINEERS, P.C.
ENGINEERS & GEOSCIENTISTS

FIGURE 8



TRACES OF MAJOR LINEAMENTS

FIGURE II


LEGEND
FORDHAM GNEISS (YONKERS GNEISS) Median yield from fracture zones is 10 gpm.
MANHATTAN GNEISS (HARTLAND FORMATION) Median yield from fracture zones is 12 gpm.
INWOOD MARBLE - Median yield from fracture zones is 15 gpm. Solution channels and weathered areas can provide higher quantities of water.
SAND AND GRAVEL - Median yield is 44 gpm, but in areas of thick deposits, yield can be higher. Deposits restricted to large stream valleys.
BYRAM LAKE RESERVOIR
MIANUS RES.
CONVERSE LAKE
BEAR GUTTER INLET
KENSICO RESERVOIR
RYE LAKE
BRONX RIVER
WATER DISTRI
TOWN OF NORTH CASTLE
WESTCHESTER COUNTY, NEW YORK
MEDIAN GROUND-WATER YIELDS OF BEDROCK AND SAND AND GRAVEL DEPOSITS
SCALE
4000' 0 4000'
BLASLAND & BOUCK ENGINEERS, P.C.
ENGINEERS & GEOSCIENTISTS