## TABLE OF CONTENTS

## TABLE OF CONTENTS
**(continued)**

### LIST OF TABLES
**(at end of report)**



### LIST OF FIGURES
**(at end of report)**

# GROUND-WATER RESOURCES OF ORANGE COUNTY, NEW YORK
# ORANGE COUNTY WATER AUTHORITY
# GOSHEN, NEW YORK

## INTRODUCTION

The Orange County Water Authority (OCWA) retained Leggette, Brashears & Graham, Inc. (LBG) to conduct a Ground-Water Resources Study (GWRS) to update ground-water information and maps for the County. The purpose of the GWRS is to provide a basis for planning present and future water-supply needs of the County and provide guidance for future development of high-yielding ground-water supplies. The GWRS indicates areas with inadequate or marginal water supplies and makes recommendations for development of additional ground-water supplies.

The GWRS inventories existing ground-water supplies and potential areas for development of future supplies. Based on quantitative knowledge of the water resources that are available, local and County planners will be involved in setting development guidelines to safeguard existing ground-water supplies and protect favorable undeveloped areas for future development of ground-water supplies. This information will also be used to conduct future wellhead and aquifer protection programs.

The previous plan to develop a large-scale water supply for the County considered the development of a large surface-water supply and distribution of the water throughout the Orange County Water Loop. The OCWA does not consider this plan to be a viable alternative for development of water supply for the present and foreseeable future demands for the County. The water-supply questions addressed by this report are whether ground water can be considered a feasible and favorable alternative for water-supply development and whether the development of additional ground-water supplies will be sufficient for meeting future water demands of the County.

## PURPOSE AND SCOPE

The GWRS updates two previous published reports, "Ground-Water Basic Data, Orange and Ulster Counties, New York" by Frimpter (1970) and "Ground-Water Resources of Orange and Ulster Counties, New York" by Frimpter (1972). The hydrogeologic data utilized by Frimpter in the two above-mentioned studies pre-date 1970. The GWRS is specific to Orange County and utilizes the most current hydrogeologic data summarized in the "Regional Ground-Water Study, Existing Conditions Report", prepared by LBG and the Community Consultants and dated January 1995 (Existing Conditions Report). The GWRS inventories significant ground-water supplies developed in Orange County into the 1990s. From 1970 to date, Orange County has experienced a significant increase in both residential and commercial/industrial development. The growing development in the County has resulted in a significant increase in ground-water supply development. This report presents the results of available ground-water data to date.

As with the 1972 Frimpter report, the aquifers discussed in this report were mapped and their potential yields were estimated from currently-available hydrogeologic data. Emphasis was placed on municipal water-supply systems in the County and on evaluating present and future water-supply demands of these systems. The GWRS also emphasizes the potential development of the bedrock aquifers in Orange County, which were not considered "dependable" sources of water supply by Frimpter (1972).

The work on which this report is based consists of the following:

- Inventory of available well data and related hydrogeologic data from 439 selected wells in the County. The wells were inventoried for the Existing Conditions Report.
- Estimated present and future water demands to the year 2020.
- Mapping of the following layers created in AutoCAD files:
  - New York State Department of Transportation (NYSDOT) base maps (roads, municipal boundaries and names);
  - wells inventoried in this Study;
  - State and Federal wetlands;
  - hydrology;
  - Soil Survey (Olsson, 1981);
  - topography;
  - watershed areas;
  - sand and gravel aquifers;
  - bedrock aquifer units;
  - fracture traces and faults;
  - land use (Space Track, 1993);
  - existing and potential contamination sites; and
  - designated locations for likely development of high-yielding bedrock wells.
- Inventory of water-quality data from 84 wells in the County to determine water quality developed from the respective aquifer types.

## PREVIOUS INVESTIGATIONS

The following is an inventory of the significant geologic and water resource reports and mapping conducted prior to this Study in Orange County or including Orange County:

- Frimpter, Michael H., 1970, "Ground-Water Basic Data, Orange and Ulster Counties, New York", State of New York Conservation Department, Water Resources Commission, Bulletin 65.
- Frimpter, Michael H., 1972, "Ground-Water Resources of Orange and Ulster Counties, New

York", U. S. Geological Survey Water-Supply Paper 1985.

- Offield, Terry W., 1967, "Geology of Goshen - Greenwood Lake Area, New York", New York State Museum and Science Service, Map and Chart Series No. 9.

- Fisher, Donald, Y. W. Isachsen, and L. V. Richard, 1970, "Geologic Map of New York, Lower Hudson Sheet", New York State Museum and Science Service Map and Chart Series No. 15.

- Jaffe, Howard W. and Elizabeth B. Jaffe, 1973, "Bedrock Geology of the Monroe Quadrangle, New York", Map and Chart Series Number 20, New York State Museum and Science Service.

- Leggette, Brashears & Graham, Inc., January 1995, "Regional Ground-Water Study, Existing Conditions, Orange County, New York", Orange County Water Authority.

The town-wide regional ground-water studies included in the Existing Conditions Report inventoried the municipal, private, commercial and individual systems and proposed systems with well yields or water demands greater than 50,000 gpd (gallons per day). Consequently, the data from wells inventoried tend to provide the results of ground-water exploration for higher-yielding wells.

## MAP PREPARATION

The maps included in the report were prepared on NYSDOT base maps on AutoCAD files. The following are the NYSDOT quadrangle base maps that cover Orange County:

| | | |
|---|---|---|
| Cornwall | Peekskill | Unionville |
| Goshen | Pine Bush | Walden |
| Greenwood Lake | Pine Island | Wappingers Falls |
| Maybrook | Pond Eddy | Warwick |
| Middletown | Popolopen Lake | Wawayanda |
| Monroe | Port Jervis-North | West Point |
| Napanach | Port Jervis-South | Wurtsboro |
| Newburgh | Sloatsburg | Yankee Lake |
| Otisville | Thiells | |

The mapping by LBG and OCWA personnel was produced using NYSDOT quadrangle base maps, and new layers of information were created in AutoCAD files and produced at 1:24,000 scale. Minimal study was directed at the Peekskill and West Point quadrangle base maps considering that most of the area on these two maps includes Harriman State Park and the United States Military Academy at West Point.

Figure 1 is the index map for the map sets located in the Appendix. The map sets and layers included on the respective maps are as follows:

**Set 1 - Sand and Gravel Aquifer Maps**

- roads, including names;
- hydrology (streams, lakes, etc.);
- sand and gravel aquifer units;
- wells completed in sand and gravel aquifers;
- topographic contours;
- watershed boundaries;
- soil survey (sand and gravel deposits at land surface, vertical thickness unknown);
- potential and existing contamination sites; and
- municipal water-system sites.

**Set 2 - Bedrock Aquifer Maps**

The bedrock aquifer maps include the following layers:

- roads and names;
- hydrology;
- wells completed in bedrock aquifers;
- bedrock aquifer units;
- bedrock contact lines;
- topographic contours;
- fracture traces, faults and significant structure features; and
- watershed boundaries.

**Set 3 - Bedrock Aquifer Maps**

The following layers have been added to Set 2 (Bedrock Aquifer Map) to assist in targeting of proposed locations for developing high-yielding bedrock wells:

- State and Federal wetlands;
- sand and gravel aquifer units;
- existing and potential contamination sites;
- municipal water sites; and
- proposed locations for possible development of high-yielding bedrock wells.

The legend for the maps includes the respective references utilized in the Study and mapping work.

**Well Location System**

Wells are identified on the maps with an alphanumeric label and a symbol. All data about the wells are presented in the Existing Conditions Report. The well label next to the well symbol indicates the respective town section of the Existing Conditions Report in which well data are presented. The data on the wells inventoried are presented on table 1 in each of the respective town sections. Legend symbols differentiate bedrock supply wells and sand and gravel supply wells, both in service and not in service.

As an example, available data on Well BG-25 (Map 2-34) would be located on table 1 in the Town of Blooming Grove section of the Existing Conditions Report. The well symbol indicates the well is a bedrock supply well not in service.

## ACKNOWLEDGEMENTS

This report was prepared for and funded by the Orange County Water Authority under the supervision of

James A. Beaumont, P.E., Executive Director, who provided valuable guidance and encouragement.

Special thanks are given to the individual residents, developers, private water companies and municipalities who supplied data to this Study. Additional thanks are given to the Orange County Department of Health (OCDOH) and New York State Department of Environmental Conservation (NYSDEC) for providing available information on public water supplies in Orange County.

The "Regional Ground-Water Study, Existing Conditions Report" prepared by LBG includes town-wide regional ground-water studies conducted by the following firms:

- Chumard and Associates
- EA Engineering Science & Technology
- Eustance and Horowitz, P.C.
- Hudson Engineering Associates
- Lanc and Tully Engineering & Surveying, P.C.
- Lawler, Matusky and Skelly Engineers
- Leggette, Brashears & Graham, Inc.
- Malcolm Pirnie, Inc.
- McGoey, Hauser and Edsall, Consulting Engineers, P.C.
- Raimondi Associates, P.C.
- Tectonic Engineering Consultants, P.C.

In addition, William A. Grazier of Computer Graphic Systems and David Washburn of R.E.I.S., Inc. assisted in the formatting and preparation of the maps for this report.

## LOCATION AND PHYSICAL FEATURES OF THE AREA

Orange County is located in southeastern New York (figure 2) and is bounded by the Hudson River to the east and by the States of Pennsylvania and New Jersey to the south and west. Sullivan and Ulster Counties lie immediately to the north of Orange County. Orange County is 834 square miles and has been divided into three physiographic provinces (figure 3); New England, Valley and Ridge and Appalachian Plateau (Frimpter, 1972). The bedrock geology distinguishes the provinces.

The southeastern sector of Orange County lies in the New England Province and is regionally known as the Hudson Highlands. This area is largely state-owned park land and federal military lands at the West Point Reservation. The elevations rise rapidly from sea level near the Hudson River to about 1,400 feet above sea level. The moderately rugged terrain is mostly composed of gneiss and granular-type crystalline bedrock.

The Valley and Ridge Province, located in the middle of Orange County, exhibits generally low-rolling hills. The majority of this province was and is presently utilized for agriculture. The Valley and Ridge Province is underlain by layered sedimentary bedrock units.

The Appalachian Plateau Province lies in the northwestern portion of Orange County and is a very rugged, heavily-forested area with minimal population and development. This province consists of elevated flat land underlain by layered sedimentary bedrock units. Portions of the plateau have experienced significant erosion over time where streams have incised steep-walled valleys. The picturesque rugged hills and mountains in this province are the foothills to the Catskill Mountains (Frimpter, 1972).

## GROUND-WATER UTILIZATION

Ground water is widely used and is available throughout Orange County. It is estimated that there are about 35,000 wells currently withdrawing ground water throughout Orange County (United States Bureau of Census, 1990). Water for domestic use, farms and small commercial development in rural areas is commonly derived from individual wells. Typically, such small water demands range from 300 to 2,500 gpd. Residential, commercial and industrial developments in the cities/ villages and urbanized areas of the towns in Orange County generally obtain water from public and private water-supply systems. Public water-supply systems use ground-water and surface-water supplies, or both.

### Private Supplies

The "Environmental Health Water Program, Single Line Inventory Report, for all Community Water Supplies", dated December 1994, was prepared by the OCDOH. That report indicates 239,849 people (78 percent) of the total population of about 307,647 people for the County (United States Bureau of the Census, 1990) are estimated to be supplied water from public water supplies (surface-water and ground-water supplies). Therefore, 22 percent of the population or 68,000 people utilize ground water from individual well supplies. Studies conducted by the United States Environmental Protection Agency (USEPA) estimate average daily domestic water consumption to be about 55 gpd per person. Average daily water consumption throughout the County is generally estimated to be 75 gpd per person (NYSDOH guidelines) for metered public water supplies. That is considered to be a generous estimate for people on individual domestic supplies in the County. Utilizing the estimate of 75 gpd per person for the 68,000 people, the present demand for individual well supplies in rural areas not supplied by public water systems is estimated to be about 5 mgd. It is likely about 95 percent of the 5 mgd, or about 4.7 mgd, is developed from ground-water supplies and mostly from wells completed in the bedrock aquifers in the County.

### Public Supplies

There are 168 public water-supply systems in Orange County; 137 utilize ground water; 17 use surface water; four use both ground water and surface water; and 10 purchase water (from both surface- and ground-water sources). A total of 412 wells were inventoried on table 1 in the Existing Conditions Report for existing and proposed public ground-water supply systems in Orange County. The total estimated yield capacity (table 1) is about 31.8 mgd from 108 sand and gravel wells, 23.6 mgd from

280 bedrock wells, and less than 2.9 mgd from the 27 wells where data do not indicate the aquifer material the well is completed in. Table 1 indicates the total yield capacity of public water systems in Orange County is about 58.3 mgd.

Table 2 indicates that the present yield withdrawn from the public ground-water systems in the County is much less than the total yield capacity. About 17.1 mgd of ground water is presently withdrawn from the sand and gravel aquifers, 53 percent to the total estimated yield capacity (31.8 mgd) of wells completed in the sand and gravel aquifers. About 9 mgd is presently withdrawn from the bedrock aquifer, about 38 percent of the total estimated yield capacity (23.6 mgd) of wells completed in the bedrock aquifers. Finally, about 0.3 mgd is withdrawn from wells completed in unknown aquifer types, about 10 percent of the total estimated yield capacity from wells completed in the unknown aquifer types. Table 2 indicates the present ground-water withdrawal from public water systems in the County is about 26.4 mgd, only 45 percent of the total estimated yield (58.3 mgd) of wells developed. This excess yield capacity provides the ability to meet peak water demands.

Table 2 indicates the estimated total present withdrawal of ground water in Orange County from both individual well supplies in rural areas and public water supplies in the County totals about 31.1 mgd.

## GEOLOGIC HISTORY

The science of geochronology measures geologic time and the dating of past geological events and is often difficult to understand. To assist in the understanding of the geologic time scale, figure 4 shows major events in the geological history of New York State, including Orange County. In addition, the following definitions are provided (AGI, 1972):

- **Age** - Formal geologic time unit corresponding to a period (i.e., Silurian Age).
- **Epoch** - A division of geologic time corresponding to a series of rock units and a subdivision of a period (i.e., Pleistocene Epoch).
- **Era** - A large division of geologic time (i.e., Paleozoic Era).
- **Orogeny** - Rock deformation episode (i.e., Taconic Orogeny).
- **Period** - Standard geologic time unit corresponding to an interval of time (i.e., Silurian Period).
- **Revolution** - Time of profound orogeny and other crustal movements (i.e., Appalachian Revolution).
- **Time (geologic)** - Any division of geologic chronology (i.e., Precambrian Time).

The oldest bedrock units in Orange County originated as sediments deposited in a vast ocean which covered the region in Precambrian time, more than 500 million years ago. Following deposition of these ocean sediments, the strata were subjected to great heat and pressure and were metamorphosed to gneiss. The formation of gneiss was accompanied by intrusions of granite. The gneiss and granite are generally similar in appearance and are referred to as undifferentiated granite and gneiss in the respective geologic maps (Broughton et al., 1976).

During Cambrian time, the first period of the Paleozoic Era, and continuing into the Ordovician Age, the oceans advanced over the area and deposited thick layers of sediments consisting of sand and limey mud. The sediments eventually consolidated into bedrock units of shale, limestone and sandstone. Throughout the remainder of the Ordovician Age, the dominant influence on the geology was the mountain-building episode known as the Taconic Orogeny. The bedrock units were folded, metamorphosed and raised above the ocean sea level during this period. During the Taconic Orogeny, the shale, sandstone and limestone were converted to quartzites, marbles, slates and phyllites. Some deposition may have occurred during this period but subsequently eroded away, considering that no bedrock younger than Ordovician Age is reported.

During the Silurian Period, the oceans receded and Orange County was dry land, again covered by mud flats. Sediment composed of a mixture of windblown and waterlaid quartz sand was deposited over parts of the exposed land surfaces. In Orange County, the continuing erosion during this period piled up 1,000 feet of white sand and quartz pebbles. This resulted in the highly-resistant Shawangunk Formation in the County along the Shawangunk Mountains.

At the beginning of the Devonian Period, shallow oceans covered the County and deposited limey sediments which consolidated in Helderberg limestone and Onondaga limestone and other undifferentiated Devonian bedrock units in the County. Movement of the earth's crust during the end of the Devonian Age, known as the Acadian Orogeny, affected the bedrock units in Orange County. During this orogenic episode, the rocks were folded, faulted and metamorphosed.

At the close of the Paleozoic Era, the bedrock units were again folded and displaced along thrust faults during significant movement of the earth's crust called the Appalachian Revolution. Many of the significant region faults, fractures and joint systems in Orange County probably resulted from these crustal movements.

The ensuing Mesozoic Era and subsequent Cenozoic Era resulted in vertical uplift and erosion of the landscape to lowlands. During the Cenozoic Era, the most recent era in earth's history, the land surface was again uplifted as a repeated cycle of erosion began. The physical provinces of the County, shown on figure 3, were shaped during this era. During the Pleistocene Epoch, continental glaciers advanced repeatedly over most of New York. The scarred landscape indicates a southward or southeastward ice movement. During this period, mixed unconsolidated material consisting chiefly of clay and boulders called till, was deposited over much of Orange County. Gravel, sand and silt were deposited in the stream valleys during and after the glacial ice melt. At places where the glacial meltwater streams were blocked, large glacial lakes formed and deposited thick deposits of silt, clay, some peat and other fine-grained materials. Following complete meltback of the glaciers, the land was again significantly uplifted.

The present-day streams are eroding both glacial deposits and exposed bedrock. Although erosion is dominant at present, some deposition of sediments is occurring in lakes, wetlands and flood plains. Sediments deposited during the last few thousand years are referred to as recent alluvium. These deposits consist mostly of thin layers of material consisting of sand, gravel, silt and clay.

## OCCURRENCE AND MOVEMENT OF GROUND WATER

An aquifer is a saturated bed, formation or a group of formations which yields water in sufficient quantities to be economically useful. An aquifer may be capable of yielding enough water to serve a city or may be limited to yields sufficient for a household. Ground water in Orange County is developed from both unconsolidated sand and gravel aquifers and consolidated bedrock aquifers (figure 5). The shape of the openings in rocks or sediments, their size, volume and interconnection are the significant factors which determine their potential to yield water. Water is introduced into the underground system by infiltration of precipitation.

An aquifer performs two important functions, the storage and movement of ground water. The interstices (openings) in a water-bearing formation allow storage and act as part of a network of openings for ground-water movement. Ground water is constantly moving through these openings driven by the local hydraulic gradient, which is the elevation difference or water head between two points. Natural ground-water movement occurs at rates of a few feet per year to several feet per day. Water in an aquifer is being held in moving storage, and if not used, will be discharged to lakes, streams or oceans (Driscoll, 1986).

Ground-water environments generally comprise three general classes:

1. porous media interstices between individual particles in sand and gravel and sandstone formations;
2. fractures, crevices, joints, faults and bedding planes in bedrock formations; and
3. solution channels (generally fractures enlarged by dissolution of soluble rock).

Ground water occurs underground in two states, unconfined or water-table aquifers and confined or artesian/semi-artesian aquifers. The physical state of the water in the aquifer determines what forms of energy or hydrostatic pressure the water possesses (Driscoll, 1986). The sand and gravel aquifers in Orange County exist in both unconfined and confined environments. The bedrock aquifers in the County are usually considered confined or semi-confined aquifers. A majority of the bedrock aquifers are overlain by confining layers of till or low-permeability materials. Bedrock aquifers can, but rarely do, exist in unconfined environments. In addition, some sand and gravel and bedrock aquifers in the County are partially overlain by a confining layer and exhibit both confined and unconfined characteristics.

### Unconfined Aquifers

Ground water in some aquifers occurs under water-table conditions. The upper limit of the aquifer is defined by the water table itself. At the top of the aquifer, the water table (top of the saturated aquifer unit) is at atmospheric pressure. Under this condition, the aquifer is commonly referred to as an unconfined or water-table aquifer (figure 5).

The hydraulic pressure at any level within an unconfined aquifer is equal to the depth from the water table. Consequently, when a well is drilled in an unconfined aquifer, the static water level in the well equals the same elevation as the water table (Driscoll, 1986). The water table is not stationary but seasonally moves up and down. It rises during periods of recharge, mainly in winter and spring, and drops during non-recharge periods and natural aquifer discharge periods during the summer and fall.

### Confined Aquifers

Ground water in some aquifers occurs under artesian conditions. Under this condition, water in the aquifer is under pressure greater than atmospheric pressure.

When a well is drilled through the upper confining layer (i.e., clay or silty clay) into a confined aquifer, water rises in the well to some level above the top of the aquifer (figure 5). The water level in the well represents the artesian pressure in the aquifer (Driscoll, 1986). Just as in the unconfined aquifer, the static water level in a confined aquifer is free to rise and fall in response to the volume of water in the aquifer. The hydrostatic pressure within a confined aquifer is sometimes enough to cause the water to rise and flow above land surface. The water level in the well represents the confining pressure at the top of the aquifer. Confined pressure is defined as the vertical distance between the water level in the well and the top of the aquifer.

## WATERSHED AREA DELINEATION

Watershed areas (also called recharge areas) are the areas directly contributing ground water and surface water to all supply sources (figure 6). The watershed boundaries in the County have been delineated so that ground-water divides will be coincidental with surface-water drainage divides. Watershed boundaries have been delineated to include all land areas that contribute surface water and ground-water flow to the aquifer or surface-water body, up to a distance determined by basin drainage divides. Drainage divides forming the boundaries of the watershed areas were outlined using topographic mapping with a contour interval of 20 feet.

Major watershed areas and boundaries are delineated by the USGS and OCWA. In addition, the smaller watershed areas for the villages in Orange County which rely on ground water from bedrock aquifers were delineated by LBG to conduct water-budget analyses comparing the recharge to the watershed for the respective villages to their projected water demands. Figure 7 presents the watersheds mapped in Orange County and table 3 indicates the areas of the watersheds in square miles.

## GROUND-WATER AVAILABILITY

### Hydrologic Cycle

The earth's water cycle, or hydrologic cycle, is the continuous circulation of moisture and water on the planet. The continuous cycle commonly begins with waters of the ocean and cycles the water back to the oceans.

The following hydrologic cycle (figure 8) summarizes the source and movement of ground water. Orange County is a small segment of the world's hydrologic cycle which consists of constant evaporation, predominantly from global oceans, precipitation, runoff and infiltration. Eventually, on a larger scale, all ground water not utilized by plants (transpiration), evaporated or consumed by humans or animals finds its way back to the oceans. The time frame of the cycle locally in Orange County can take anywhere from several hours to as long as tens of millions of years to complete its course.

The available ground water in both sand and gravel and bedrock aquifers is a renewable resource that is continuously replenished by precipitation on the local watersheds in Orange County. The sand and gravel aquifers in the County are recharged from precipitation which falls directly on the surface of the aquifer, from ground-water flow from surrounding hills, mountains and, most importantly, some aquifers are recharged from overlying surface-water bodies (rivers, lakes, ponds) (figure 6). Bedrock aquifers are recharged from precipitation which falls directly on bedrock outcrops exposed at land surface and some portion of the precipitation that infiltrates the soil and overburden materials eventually recharges the bedrock fracture systems and is available for capture by bedrock water wells (figures 6 and 8).

The hydrologic cycle continually replenishes ground water in Orange County by precipitation. There are precipitation data available from three rain gage stations in Orange County located in Gardnerville, Middletown and Port Jervis. These data were utilized to prepare probability distributions of annual precipitation at the three stations. The probability distributions were used to estimate average annual precipitation and precipitation during a one-year-in-thirty drought (3.3-percent probability) to the study watersheds in the County. For Orange County, the Gardnersville, Middletown and Port Jervis gaging stations indicate average annual precipitation of 41.5 inches, 44 inches and 43 inches per year, respectively (figures 9, 10 and 11). The average rainfall report from the three stations is about 43 inches per year. The difference in rainfall at the respective localities is likely related to topography of the region and location with respect to the Hudson River Valley.

Outflow from the hydrologic cycle is runoff and evaporation of precipitation. Runoff occurs if precipitation occurs in sufficient quantities to result in overland flow to streams and other surface-water bodies. Many sediment materials adjacent to or underlying streams and lakes are relatively permeable, and water can flow easily into the ground-water system once the streams or lakes have temporarily risen above the water table. Inflow to a stream during a storm may consist not only of overland flow but also direct channel precipitation and interflow (Driscoll, 1986). Interflow is the water that moves toward a stream above the ground-water table, but underneath the soil-water zone (ibid). The soil-water zone is just below the surface and provides water for plant growth (ibid). Water is lost from this zone by transpiration, evaporation and percolation when oversaturation occurs. Streams recharge the ground water during and some time after storms. Evaporation results when water molecules on the earth's surface acquire sufficient energy from solar radiation to vaporize. Transpiration results from moisture given off by plants and returned to the atmosphere.

Baseflow is the amount of ground water recharging a stream, not including direct precipitation and runoff. The hydrologic cycle ends and begins again with rivers and ground water flowing into the oceans (figure 8).

### Water-Budget Analysis

Ground water in both sand and gravel and bedrock aquifers is a renewable resource that is continuously replenished by precipitation, but the volume of ground water in storage and available recharge varies greatly between aquifer types in the County. The use of ground water has significantly increased in Orange County since the 1960's and early 1970's. A water-budget analysis compares long-term withdrawals of ground water to recharge estimates.

Recharge is generally related to precipitation, but the amount of rainfall which becomes ground-water recharge is difficult to measure directly. In Orange County, the average precipitation is about 43 inches per year. About half of this amount is lost to evaporation and transpiration processes, the remainder is available to become surface- and ground-water runoff. Ground-water recharge results from a portion of the total rainfall and snowmelt that infiltrates the soil and overburden materials. The sand and gravel aquifers in Orange County are recharged from precipitation which falls directly on the surface of the aquifer, from ground-water flow from surrounding hills and mountains and, most importantly, from significant streams or overlying surface-water bodies. A portion of the total runoff that infiltrates into the soil and overburden materials (including sand and gravel aquifers) eventually recharges the bedrock fracture system and is available for capture by bedrock wells.

When wells completed in the sand and gravel and bedrock aquifers are pumped, the hydraulic head is lowered in the aquifer unit, the downward flow gradient is increased and the rate of recharge may be increased. For this reason, a stream which bisects a thick deposit of saturated permeable sand and gravel or a water body on top of a sand and gravel deposit may function as a reservoir which will increase the potential to recharge to the sand and gravel aquifer. Similarly, a thick section of saturated, permeable material overlying a bedrock formation acts as a reservoir which increases the potential to recharge the bedrock aquifer. Because of the relatively high recharge rates to both aquifers, wells completed within the sand and gravel or in bedrock aquifers overlain by saturated overburden material can be expected to have relatively high yields.

Figures 9, 10 and 11 show that precipitation for Gardnersville, Middletown and Port Jervis during a one-year-in-thirty drought (3.3-percent probability of recurrence) decreases to about 27.7 inches, 30.5 inches and 29.7 inches, respectively. The average drought precipitation is about 29.3 inches or 68 percent of the average annual precipitation in Orange County. During extreme drought conditions, the USGS has estimated recharge to decrease to as little as 40 percent of the average rate (Cervione et al., 1972).

The following studies have developed estimates of ground-water recharge considered in evaluating recharge rates to the aquifers in Orange County.

- An estimate was developed by the USGS for recharge to sand and gravel and bedrock aquifers in the Fishkill-Beacon Area (Snavely, 1980). The estimates for this study for recharge to the till-covered sedimentary bedrock in Dutchess County indicate that the average recharge rate there is about 400,000 gpd (gallons per day) per square mile or about eight inches annually. Recharge to the sand and gravel deposits in the Fishkill-Beacon area is an recharge rate of 1,000,000 gpd per square mile, or about 21 inches annually. These volumes of recharge to the bedrock and sand and gravel aquifers are about 20 percent and 49 percent, respectively, of the average annual local precipitation of 43 inches. These recharge estimates may be applicable to the aquifers in Orange County.

- R.E. Wright (1982), in his report on the Upper Delaware River Basin, estimated that recharge to local multi-textured sand and gravel deposits during a year of normal precipitation is about 790,000 gpd to 985,000 gpd per square mile, or about 16.5 inches to 20.5 inches. Estimated recharge to the local sedimentary bedrock units during a year of normal precipitation is 815,000 gpd per square mile or about 17 inches. These volumes of recharge to the bedrock and sand and gravel aquifers constitute about 43 percent and 40 percent, respectively, of the average annual local precipitation (43 inches) in the County. Considering the local geology and topography, it is LBG's opinion that the Wright recharge estimate for the bedrock units is excessive and not appropriate for the bedrock units in Orange County. The recharge estimates for the sand and gravel aquifers are considered in the appropriate range for the sand and gravel aquifer units in the County.

- In northwestern Connecticut, Cervione et al., (1972) of the USGS, estimated that recharge to the till-covered metamorphic rocks is about seven inches annually or about 350,000 gpd per square mile. Such recharge to the bedrock aquifer constitutes about 16 percent of the average annual local precipitation in the County. This recharge estimate for the metamorphic bedrock units is considered applicable to undifferentiated granite and gneiss units in Orange County.

- Frimpter (1972), in his report "Ground-Water Resources of Orange and Ulster Counties", estimated that recharge to certain sand and gravel aquifers during a year of normal precipitation is about 500,000 gpd per square mile or about 10 inches annually. This volume of recharge to the sand and gravel aquifers is about 23 percent of the average annual local precipitation. This recharge estimate for the sand and gravel aquifers is considered very conservative, but may be applicable to sand and gravel aquifers where little to no data are available.

Table 4 summarizes the above-mentioned recharge estimates for the respective aquifer types in Orange County under normal and drought conditions.

The above studies estimate recharge to sand and gravel aquifers in regions similar to Orange County to be from 500,000 gpd to as high as 1,000,000 gpd per square mile. The recharge estimate of 500,000 gpd may be applicable to sand and gravel aquifers where little to no data are available related to the aquifer thickness, well yields, areal extent, aquifer parameters and induced recharge. Where data are available, increased estimates of recharge as high as 1,000,000 gpd may be appropriate. The estimated safe yield from recharge for the significant sand and gravel aquifers is discussed in the Yield Potential of Sand and Gravel Aquifer section (pages 30 through 55). The total estimated safe yield of the significant aquifers listed on table 5 in Orange County is estimated to be about 92 mgd. It should be noted the safe yield of the sand and gravel aquifers may be less during proloned drought conditions.

A water-budget analysis has been conducted to determine if there is sufficient ground-water recharge to the bedrock aquifer units in the County. The analysis reviewed recharge directly to the bedrock aquifer within the Town boundaries (figure 12) and to the respective watersheds (figure 7). The watersheds are also delineated on the respective map sets. The appropriate recharge to the sedimentary bedrock units is estimated to be 400,000 gpd per square mile (Snavely, 1980). In addition, the appropriate recharge to the undifferentiated granite and gneiss bedrock unit is estimated to be 350,000 gpd (Cervione et al., 1972).

The recharge to the bedrock aquifers actually available for ground-water supply may be greater than the amount contributed from precipitation in the watershed area where permeable saturated sand and gravel deposits overlie bedrock and are presumed to induce some recharge from the saturated sand and gravel material. The volume of the indirect recharge is not measurable without extensive studies, but it would increase non-linearly as withdrawals increase. For the GWRS, the bedrock aquifer units overlain by saturated sand and gravel deposits have conservatively not been given higher recharge rates.

Estimated recharge (direct recharge) to the bedrock aquifers within the respective Town boundaries was compared to present water demands and presented on table 6A. The water-budget analysis conducted for the respective towns conservatively compares the present and future water demands only to available recharge to bedrock wells within the respective town boundaries. The areal extent and percentage of sedimentary and undifferentiated granite and gneiss within the respective town boundaries were determined and appropriate recharge rate for the bedrock aquifers applied under normal and drought conditions (tables 6A and 6B).

The areal extent and percentage of sedimentary and undifferentiated granite and gneiss within the respective watersheds were determined and appropriate recharge rates to bedrock aquifers applied (tables 3 and 7). In addition, estimated recharge to bedrock aquifers within the respective watersheds, irrespective of political boundaries, was compared to the maximum yield potential of existing and proposed public supply wells completed in the bedrock aquifer units under normal and drought conditions and presented on table 7.

In overall perspective, the estimated recharge to the bedrock aquifers within the respective town boundaries under normal and drought conditions is significantly higher than present and future water demands estimated to the year 2020 for the respective towns (table 6). The estimated recharge to the bedrock aquifers within the respective watersheds under normal and drought conditions is significantly higher than maximum yield potential of existing and proposed public supply wells (bedrock wells) with the exception of Watersheds 1, 35, 138, 169, 172, 173, 174 and 176 (table 7).

Table 7 indicates the estimated recharge to the bedrock aquifers in Watersheds 1 and 169 (figure 7) is more than adequate under normal precipitation (1.75 mgd and 1.01 mgd, respectively) and 30-year drought conditions (1.19 mgd and 0.69 mgd, respectively) compared to the maximum yield potential of existing and proposed bedrock supply wells (1.11 mgd and 0.44 mgd, respectively). However, recharge to Watersheds 1 and 169 during extreme drought conditions (0.70 mgd and 0.40 mgd, respectively) is less than the maximum yield potential of the existing and proposed bedrock supply wells in these two watersheds.

The watershed areas delineated for Watersheds 35, 138 and 176 are small, 0.10, 0.31 and 0.12 square mile, respectively (table 3) (figure 12). Consequently, estimated recharge under normal precipitation available to the bedrock aquifers in Watersheds 35, 138 and 176 is proportionally low (0.04 mgd, 0.12 mgd and 0.04 mgd, respectively). The available recharge under normal precipitation conditions to Watersheds 35, 138 and 176 is considerably less than the maximum yield potential of existing and proposed bedrock supply wells (0.16 mgd, 0.24 mgd and 0.41 mgd, respectively). However, it is likely the smaller watersheds delineated are recharged from the larger adjacent watersheds (figure 12).

The maximum yield potential of existing and proposed public supply wells completed in the bedrock aquifer units in Watersheds 172, 173 and 174 (1.07 mgd, 2.09 mgd and 2.25 mgd, respectively) exceed estimated recharge to the respective watersheds under normal precipitation conditions (0.86 mgd, 1.03 mgd and 2.01 mgd, respectively) to the bedrock aquifer units. The estimated maximum yield potential of existing and proposed public supply wells on table 7 conservatively assumes all existing and proposed public supply wells will be pumped continuously (24-hour duration) and simultaneously. However, under normal pumping conditions of multiple well systems, wells are usually pumped at maximum duration periods of 18 hours, allowing wells to recover. In addition, wells are alternated between pumping and non-pumping cycles. Consequently, the wells inventoried would not likely withdraw the estimated maximum yield potential presented on table 7. Watersheds 172 (Village of Goshen), 173 (Village of Kiryas Joel) and 174 (Village of Harriman) include the villages which utilize public supply wells completed in the bedrock aquifer units with high present and future water demands. A detailed water-budget analyses of these watersheds comparing present and future water demands for these villages to the available recharge to the respective watersheds is discussed below.

Water-budget analyses were conducted for the villages in Orange County presently utilizing public supply wells completed in bedrock aquifer units. Estimated recharge to the bedrock aquifers within the respective watersheds to the villages was compared to the present and future water demands under normal and drought conditions and presented on table 8. Some of the villages have developed their public water supplies from a combination of surface water and bedrock wells; combined with both sand and gravel and bedrock wells and solely with bedrock wells. The water-budget analyses conducted for the respective villages conservatively compares the present and future water demands of the villages to available recharge to bedrock wells within the respective watersheds.

Table 8 indicates the Village of Goshen has an estimated recharge of about 1.81 mgd under normal precipitation to the bedrock aquifers from the respective watersheds (Watershed 53, 114, 171, 172 and 176). The recharge under drought conditions decreases to as low as 0.72 mgd. The present water demand is estimated to be about 1.20 mgd and is estimated to increase to about 1.64 mgd by the year 2020. The water-budget analysis for the Village of Goshen indicates under normal precipitation the recharge to the bedrock aquifer is greater than present and future estimated water demand. However, under a one-year-in-thirty drought condition, the recharge to the bedrock aquifer is marginal to meet present water demand and significantly less than the projected water demands by the year 2020. Recharge during extreme drought conditions is significantly less than both present and future estimated water demands for the Village of Goshen (table 8).

The Village of Harriman has adequate recharge to the bedrock aquifer from its watershed (Watershed 17) under normal precipitation (1.73 mgd) and extreme drought conditions (0.69 mgd) to meet present water demands of about 0.40 mgd. However, the estimated recharge to the bedrock aquifer from the watershed during extreme drought conditions (0.69 mgd) is marginal to meet project demands of the Village by the year 2020, estimated to be about 0.70 mgd (table 8).

The water-budget analysis for the Village of Kiryas Joel indicates recharge to the bedrock aquifer from the respective watershed (Watershed 17) is only adequate during normal precipitation conditions (1.03 mgd) to meet present water demands of about 0.85 mgd. Recharge estimates during drought conditions (0.41 to 0.70 mgd) are substantially less than present (0.85 mgd) and future water demands (1.80 mgd) (table 8).

The Village of Goshen marginally meets present water demands from existing surface water and bedrock wells. The Village of Kiryas Joel marginally meets present water demands from existing bedrock wells. However, additional wells to be placed in service by the Village of Kiryas Joel by the end of 1995 would likely provide surplus water. The ground-water recharge to the bedrock aquifer for the Village of Kiryas Joel is sufficient to meet present water demands. However, future water needs for the Villages of Goshen and Kiryas Joel should be developed from widely-spaced well fields. The development of significantly larger future water supplies will likely require both villages to develop ground-water supplies outside the village boundaries and the immediate watershed areas.

The water-budget analysis for both the Village of Maybrook and Village of Montgomery indicate recharge available to the bedrock aquifer from the respective watershed is substantially greater than the present and future water demand during both normal and extreme drought conditions (table 8).

In overall perspective, estimated recharge to bedrock aquifers in Orange County under normal and drought conditions is significantly higher than present and future water demands. The total estimated recharge to the bedrock aquifers is about 325 mgd under normal precipitation conditions and about 130 mgd under extreme drought conditions (table 6A). The available recharge is substantially greater than present estimated withdrawal of 9 mgd (table 2) and the total yield capacity of about 23.6 mgd (table 7) from existing bedrock supply wells.

It should be noted that not all ground-water withdrawal from public and private water systems is consumptive. Certainly a percentage of water withdrawn from the aquifer would be returned to the ground-water system via septic-system leachfields and effluent discharge from sewage treatment plants. The consumptive water use for homes or commercial-type developments utilizing onsite wells and underground septic systems is low and not typically considered in water-budget analysis. Approximately 85 percent of water withdrawn from the aquifer from an onsite well would be returned to the ground-water system via onsite septic-system leachfields. The remaining consumptive water is primarily associated with watering lawns and gardens, washing cars and outdoor recreation.

The recharge actually available for ground-water supply within the respective towns and villages is not limited to political boundaries and may also be much greater than the amount contributed from precipitation in the watersheds. Direct recharge estimates to a study property, town or village is the most conservative approach to estimate available recharge to aquifers. Recharge to watershed areas to a study property, well or well field, town and village is likely more representative of available recharge.

It should be noted that water-budget analyses are useful in estimating available ground-water resources. However, the drilling and testing of the proposed supply wells would ultimately indicate the availability of bedrock and without significant impact to neighboring water supplies.

## SURFICIAL SOILS

The Soils Survey of Orange County, New York (Olsson, 1981) was reviewed to delineate surficial soils which could possibly indicate underlying sand and gravel aquifers and/or permeable sand and gravel deposits which would readily recharge underlying or adjacent sand and gravel or bedrock aquifer units. The summary of the surficial sand and gravel deposits from the Soil Survey of Orange County is listed on table 9.

The digital soils maps for Orange County available from OCWA were queried for the selected soils on table 9 using a geographic information system. The result of that query was a map showing only the selected soils. The map of the selected soils was electronically overlaid on the sand and gravel aquifer maps (Map Set 1). The selected soils on table 9 are represented on the map legend and respective map sets as "sand and gravel deposits at land surface, vertical thickness unknown" and labelled with black cross-hatch pattern and unnumbered.

## AQUIFER TYPES

Ground water in Orange County is developed from two aquifer types, sand and gravel and bedrock aquifers. Tables 1 and 5 indicate that the sand and gravel aquifers in Orange County supply a majority of the ground water presently used in Orange County. The sand and gravel aquifers are the most prolific in the County. Although not as prolific as sand and gravel aquifer units, the bedrock aquifers in Orange County are utilized for development of domestic water to larger municipal public water supplies, which yield in excess of 1 mgd (i.e., Town of Woodbury and Village of Kiryas Joel). The bedrock aquifers in Orange County are a dependable and suitable ground-water supply source for developing high-yielding wells.

**Sand and Gravel Aquifers**

In Orange County, sand and gravel aquifers, also called unconsolidated deposits, are the best source for development of large quantities of ground water. However, the sand and gravel aquifers which are capable of developing high-yielding wells are of limited areal extent within the County. Sand and gravel aquifers available for development in the respective Towns of Orange County are presented on table 10.

The unconsolidated deposits must contain pores or open spaces which can fill with water, and these openings must be large enough to permit water to move through them toward wells at an adequate rate. Individual pores in a fine-grained material like clay or silt are extremely small and, consequently, water cannot move readily through the tiny pore spaces. This means clay and silt formations will not yield adequate water for development of high-yielding wells.

Coarser sand and gravel material contains larger open spaces through which water can move readily. Therefore, saturated coarse sand and gravel formations are more suitable for development of high-yielding wells. The legend and Map Set 1 for this Study delineates the sand and gravel aquifer material and saturation conditions likely to be encountered during drilling of the aquifer materials. It should be understood that not all of the mapped sand and gravel deposits would be suitable for ground-water supply development.

The unconsolidated sand and gravel deposits have been mapped as follows:

- Stratified Sand and Gravel at Land Surface and Below the Water Table - These sand and gravel aquifer units are labelled by a red cross-hatch pattern and the numeral one on the respective map sets. These aquifer units consist of unconfined sand and gravel aquifer units exposed at land surface and likely extend below the water table. These aquifer units have excellent potential to develop high-yielding wells if the sand and gravel aquifer material consists of coarse sand and gravel material, has adequate horizontal and vertical extent for recharge and storage capacities, and are adjacent to surface-water bodies to receive induced filtration. The potential of this aquifer unit varies throughout the County and has good potential for development of high-yielding wells.

- Stratified Sand and Gravel Below Clay or Silt and the Water Table - These confined sand and gravel aquifer units are labelled by a blue cross-hatch pattern and the numeral two on the respective map sets. These aquifer units have good potential for development of high-yielding wells if aquifer material consists of coarse sand and gravel materials, has adequate horizontal and vertical extent for recharge and storage capacities, and the confining clay or silt layers allow adequate recharge and are not continuous throughout the aquifer. The potential of this aquifer varies greatly throughout the County and has fair to good potential for development of high-yielding wells.

- Stratified Clay and Silt With Thin to No Layers of Sand and Gravel at Land Surface and Below the Water Table - The confined or semi-confined aquifer units are labelled by a yellow cross-hatch pattern and the numeral three on the respective map sets. The clay and silty sand and gravel units will not typically yield adequate water for development of high-yielding wells. However, small, isolated coarser sand and gravel materials of good areal extent and thickness are occasionally encountered during drilling of these units. However, due to limited storage and recharge of these small, isolated sand and gravel aquifer units, the yield potential is low to moderate and likely to yield less than 100 gpm (gallons per minute). The aquifer unit generally has poor potential for developing high-yielding wells.

- Stratified Sand and Gravel at Land Surface and Above the Water Table - The unconsolidated sand and gravel deposits are labelled by a green cross-hatch pattern and the numeral four on the respective map sets. These sand and gravel deposits are likely unsaturated and, as a result, have poor potential for development. However, these sand and gravel deposits usually exhibit good permeability and absorb any direct precipitation and runoff from surrounding till-covered uplands. Consequently, these deposits recharge adjacent sand and gravel aquifers and/or underlying bedrock aquifers.

- Stratified Sand and Gravel at Land Surface, Vertical Thickness Unknown - These sand and gravel deposits are labelled by a brown reverse-hatch pattern and are unnumbered. These aquifer units have good potential for development of high-yielding wells if aquifer material consists of coarse sand and gravel material with adequate horizontal and vertical extent for recharge and storage capacities. Consequently, sand and gravel deposits from this unit have greater potential for development of high-yielding wells when located adjacent to a significant sand and gravel unit or adjacent to surface-water bodies to receive induced infiltration. These aquifer units exhibit good permeability and absorb any direct precipitation and runoff from surrounding till-covered uplands. Consequently, these units recharge underlying and adjacent sand and gravel and bedrock aquifers. Small, isolated sand and gravel deposits of the unit would likely be of limited horizontal and vertical extent and, as a result, have poor potential for developing high-yielding wells.

**Bedrock Aquifers**

Ground water also occurs in the bedrock units underlying Orange County. The bedrock units may be a high-yield aquifer if there is sufficient porosity and permeability. The bedrock aquifers occur throughout the County and some possess excellent water-bearing properties. Bedrock aquifers available for development in the respective Towns of Orange County are presented on table 11.

Ground water occurs in bedrock units in pores, joints, fractures, solution cavities and fault zones and other secondary openings. The yield of bedrock aquifers varies greatly, depending on the porosity and permeability of the bedrock units. The permeability of a bedrock unit depends on the degree of interconnection of fractures, joints and other secondary openings. Bedrock aquifers in Orange County are developed from sedimentary, igneous and metamorphic rocks. The legend and Map Sets 2 and 3 delineate bedrock aquifers likely to be encountered during drilling in Orange County.

## SAND AND GRAVEL AQUIFERS

A majority of the sand and gravel aquifers in Orange County are of glacial origin. During the Pleistocene Epoch, about 18,000 to 20,000 years ago, movement of glaciers (large ice sheets) covering the County moved in a southerly direction across the region (Frimpter, 1972). Significant erosion by the glaciers removed the mantle of weathered rock which had formed during previous ages. The rock material moved by the glaciers was redeposited by glacial lakes and streams as till or stratified deposits. The significant unconsolidated stratified-drift glacial deposits are shown on figure 13.

**Glacial Till**

The soils map for the County, taken from the Soils Survey of Orange County, New York (Olsson, 1981), indicate that a majority of upland areas in the County are overlain by a mantle of till. The till can extend from the upland area underlying unconsolidated deposits in low valley plain areas (figure 5). Till is an unstratified, heterogenous, relatively impermeable mixture of clay, unsorted sand, gravel and stones to boulder-size material. Till varies in thickness, however, averages about 20 feet in thickness (Frimpter, 1985). Till has low permeability and is considered a poor aquifer due to low yields.

**Aquifers of Glacial Origin**

Glacial deposits vary in shape and size in Orange County (figure 13). Outwash deposits formed from glacial meltback, as meltwater flowed from the glaciers, carried the gravel, sand, silt and clay held in the ice and deposited the material downstream. The aquifer material is not continuous vertically, but occurs in layers interbedded with silty and clayey lenses. The fine-grained materials were deposited by sluggish streams capable of transporting only silt and clay-size particles or during temporary glacial-lake environments resulting from ice damming. However, at times, the streams were regenerated and during these periods of high flow, coarse-grained materials were deposited. The best aquifers are glacial outwash materials deposited by swifter meltwater streams. Such outwash deposits are the best sand and gravel aquifers in Orange County. The outwash deposits apparently are highly permeable and readily recharged. Examples of sand and gravel aquifers in Orange County developed from glacial outwash deposits are the Neversink-Basherkill River Valley (L) and Wallkill River Valley (U) aquifers located on figure 13.

Ice-contact deposits were deposited at the margins of the melting ice. These deposits typically overlie till deposits in valleys and along hillsides. These deposits can exceed 200 feet in thickness, however, are generally thinner. Ice-contact deposits are usually less permeable than outwash deposits and of small areal extent.

Glacial lake deposits caused by ice and moraine damming are extensive in Orange County. The still water of the lake environment allowed silt and clay to settle out in thick deposits up to 150 feet. Glacial lake deposits occur near Pine Island in the Wallkill River Valley and in the Black Meadow Valley in Chester. Other wide valley plains are underlain by silt and clay deposited by the previous glacial lakes.

The glacial lake deposits vary widely in thickness, areal extent and shape. Due to the fine textured clay and silt deposited by the glacial lakes, glacial lake deposits are not considered good aquifers. However, sand and gravel deltas deposited along with the lake deposits may exist and if readily recharged by streams, these sand and gravel deposits can yield moderate ground-water supplies (Frimpter, 1972).

**Alluvial Deposits**

Recent alluvial deposits from rivers and streams exist in the County, however, these deposits are relatively thin, usually less than 10 feet. Consequently, no significant alluvial aquifers exist in the County. However, recent alluvial deposits overlie glacial stratified-drift deposits or bedrock aquifers. If the alluvial deposits consist of coarse sand and gravel or sand, these deposits can transmit recharge to the underlying aquifers.

## YIELD POTENTIAL OF SAND AND GRAVEL AQUIFERS

An evaluation of the yield potential of the significantly developed and undeveloped sand and gravel aquifers located within Orange County is provided below. This evaluation was conducted to designate areas with good potential for development of high-yielding sand and gravel production wells in the County. During this investigation, a safe-yield value and the aquifer parameters (transmissivity and the storage coefficient) were estimated for each of the sand and gravel aquifers. The safe-yield value is the rate at which ground water can be withdrawn from the aquifer over a period of time without significant changes in ground-water storage. As a conservative estimate, safe yield typically is equal to annual aquifer recharge. In this report, the safe yield or average annual recharge was assumed to have two components, direct infiltration from precipitation on the aquifer and infiltration from surface-water bodies, if present. Other forms of recharge, such as artificial recharge from irrigation, septic systems, sewage disposal facilities and ground water from adjoining aquifers, were not considered. Consequently, the estimated safe yield of the aquifers may be greater. Once an estimation of safe yield and aquifer parameters was completed, an assessment was made as to whether or not the aquifer could support additional high-yielding production wells. Table 5 summarizes the safe-yield capacity and reported yield of wells completed in the respective aquifers. A detailed discussion of safe yield and aquifer parameters for each aquifer is followed by the letter symbol keyed to the legend on the aquifer map (figure 13).

**Beaverdam Brook Valley (O)**

The Beaverdam Brook Valley aquifer is located southwest of the Village of Maybrook (Maps 1-17 and 1-25). The aquifer is composed of unconsolidated deposits which consist primarily of well-sorted gravel, sand, silt and clay. An outline of the aquifer is shown on figure 13 and designated by the Symbol O.

In general, the Beaverdam Brook Valley is an unconfined aquifer. There are two areas, however, in which the coarser-grained deposits are overlain by clay and silt deposits in the area just north of Route 207 in Campbell Hall and the area at the confluence of Beaverdam Brook and an unnamed stream (Maps 1-17 and 1-25).

Because there are limited data on Beaverdam Brook's hydraulic connection to the aquifer, and a portion of the brook flows on a confining unit, it was assumed that recharge from the river and other surface-water bodies in the area was limited. Therefore, the estimate of recharge to the aquifer is limited to direct infiltration from precipitation in the areas where the aquifer is not confined. The amount of water contributed to the aquifer from direct precipitation is estimated to be 0.4 mgd. This value is consistent with the value presented in Frimpter (1972) of 0.3 mgd or more.

Data were not available to calculate aquifer parameters such as transmissivity and storage coefficient. Therefore, no direct assessment can be made as to whether the aquifer is hydraulically capable of supporting high-yield production wells.

At present, there are no high-yield production wells operating in the Beaverdam Brook Valley aquifer. In 1992, an infiltration gallery operated by the Maybrook Water District that yielded 200 gpm or 0.28 mgd was taken offline for repairs. The yield of the infiltration gallery will be less than that of the estimated safe yield of the aquifer (0.4 mgd) when it is back in service. This indicates that the aquifer could potentially be further developed in locations adjacent to Beaverdam Brook or Otter Kill (Maps 1-17 and 1-25). Further study is required of river bottom permeability, aquifer parameters and aquifer thickness and composition before an evaluation can be made as to whether or not the aquifer is capable of supporting additional high-yield production wells.

**Black Meadow Creek Valley (AA)**

The Black Meadow Creek Valley aquifer is located near Chester in the central portion of Orange County (Maps 1-40 and 1-41). The aquifer is composed of stratified gravel and sand deposits which are overlain by low-permeability silt and clay lake deposits. The lake deposits act as a confining unit and cover the majority of the sand and gravel delta deposits. The areal extent of the aquifer is shown on figure 13 and designated by the Symbol AA.

The Black Meadow Creek generally flows on lake deposits that limit the amount of recharge from the creek to the aquifer. The lake deposits also limit the area in which recharge by direct infiltration from precipitation is possible. Recharge by direct infiltration is limited to the delta deposits along the edges of the valley where the sand and gravel deposits outcrop. The aquifer yield was estimated by multiplying the recharge area by an average annual recharge rate. The estimated safe yield of the aquifer is 0.42 mgd. The short-term yield of a well placed in the aquifer may be significantly larger, however, the small storage capacity of the aquifer may limit the long-term safe yield.

An estimation of aquifer transmissivity was obtained from a short-term pumping test performed on a test well (Well CT-18) located within the south-central portion of the aquifer (Map 1-41). The time-drawdown relationship was used to calculate the transmissivity value. No value was calculated for the storage coefficient because of limited data. Aquifer transmissivity is 80,000 gpd/ft (gallons per day per foot), indicating that wells in this portion of the formation would be highly productive.

The only high-yield production wells located within the aquifer are wells CT-18, CT-26 and CT-27 (Map 1-41). Wells CT-26 and CT-27 are maintained and operated by the Village of Chester and are used to supplement the Village's surface-water supply. The yield capacity of these wells is about 1 mgd. A test well, CT-18, developed for Chester Properties on Cold Spring Farm has a reported yield of 300 gpm. The combined yield of the three wells presently developed is about 1.3 mgd. The pumping test data on CT-18 and well monitoring program conducted on CT-26 and CT-27 during the test on CT-18 indicate the aquifer can sustain yields up to 1.3 mgd. This value is significantly larger than that of the long-term safe yield of the aquifer (0.4 mgd). Therefore, further development of the aquifer is not recommended. Any decision to produce more than 1.3 mgd should be based on additional testing and review of pertinent well-field data collected.

Wells CT-19 and CT-29 (Map 1-32), developed for the Greens of Chester, have yield capacities of 50 gpm and 18.5 gpm, respectively. The wells are developed in isolated sand and gravel aquifers in the northwestern portion of Black Creek Valley. Exploration drilling south and east, offsite of the Greens of Chester property, indicates the sand and gravel aquifer tapped by CT-19 and CT-29 is small and isolated. The data indicate the aquifer does not extend offsite in a southerly or easterly direction and is not directly hydraulically connected to the sand and gravel aquifer tapped by CT-18, CT-26 and CT-27.

Present data indicate the best sand and gravel aquifer material for development in the Black Meadow Creek Valley aquifer is in the south-central portion where CT-18, CT-26 and CT-27 are located (Map 1-41). However, present data indicate the aquifer has likely been developed to its maximum potential in this area. Additional exploration drilling has only located small, isolated sand and gravel aquifer deposits with low to moderate yield potential (5 to 50 gpm). If further exploration drilling of this aquifer is considered, locations south of Route 17 along Black Meadow Road and northeast of Durland Hill would likely be favorable, in addition to the southwestern portion of the aquifer northeast of Sugar Loaf-Florida Road. It is likely additional drilling of this aquifer would only locate small, isolated sand and gravel aquifer deposits with low to moderate yield potential.

**Greenwood Lake (Z)**

The Greenwood Lake aquifer is located north of Greenwood Lake in the southern portion of the Town of Warwick (Maps 1-52 and 1-53). The aquifer consists of interbeds of well-sorted gravel, sand, silt and clay deposits. It is believed that this unconsolidated material is the result of post-glacial alluvial deposits that developed as tributaries discharged into the lake. The coarser beds (sand and gravel) were deposited by rapidly-moving streams of variable sizes. The finer beds were deposited by slow-moving streams and impoundments. The areal extent of the aquifer is shown on figure 13 and designated by the Symbol Z.

Data presented in Frimpter (1972) indicate that the aquifer is unconfined and that the water level in the aquifer is directly controlled by the stage of the lake. Therefore, the aquifer has two primary sources of recharge, direct infiltration from precipitation and recharge from Greenwood Lake. The amount of water contributed to the aquifer from direct precipitation is estimated to be approximately 0.6 mgd. This value was derived by multiplying the estimated recharge area by an estimated average recharge of 500,000 gpd/mi$^2$ (gallons per day per square mile). The amount of water that could potentially be induced from the lake is estimated to be approximately 3.2 mgd. This value is based on average daily overflow for the lake at Awosting, New Jersey (Frimpter, 1970). The total recharge to the aquifer is estimated to be about 3.8 mgd. A study of lakebed permeability would be necessary to predict the exact amount of water which could be induced from the lake. Furthermore, because the water levels in the aquifer are directly related to the water level in the lake, a natural decline in lake water level could directly affect the yield of existing and proposed wells.

Estimates of aquifer transmissivity (T) and storage coefficient (S) values were obtained from an analysis of a pumping test performed on Well 7. The drawdown-distance relationship was used to calculate aquifer parameters. Aquifer transmissivity and storage coefficient values for Well 7 are 47,000 gpd/ft and 0.007, respectively. The transmissivity value indicates that the aquifer is hydraulically capable of supporting high-yield production wells. The storage coefficient is representative of a semi-confined aquifer. Some of the geologic logs indicate a low-permeability layer exists in the upper portion of the aquifer. The low-permeability areas appear be located in the western portion of the aquifer. However, the low-permeability layer does not impact the recharge potential of the lake.

There are presently two active ground-water production wells located within the aquifer with one additional well proposed. A review of the data indicates that the aquifer could support additional wells. Further study is required of lakebed permeability, aquifer thickness and composition to evaluate locations that would be suitable.

Additional development of high-yielding wells from this sand and gravel aquifer is favorable. The most suitable area for development of high-yielding wells from this sand and gravel aquifer extends over a large area west of Route 210 to the base of Bellvale Mountain, bounded by Random Road to the north and Waterstone Road to the south, just north of Greenwood Lake (Maps 1-52 and 1-53). In the LBG report entitled, "Ground-Water Supply Assessment, Village of Greenwood Lake, New York", dated 1989, several proposed well locations were discussed. The most favorable location for drilling an additional sand and gravel well is on the Sorrentino property. In 1964, a test hole was drilled approximately 120 feet southeast of the intersection of Burr Avenue and Village Drive. LBG believes that an 8-inch diameter production well completed in the sand and gravel aquifer at this location could produce 500,000 to 575,000 gpd (350 to 400 gpm).

Another favorable location for drilling a production well is on Village property south of Walnut Street. This location is probably located on the main part of the sand and gravel aquifer and a production well would likely produce an estimated 350 to 400 gpm.

The yield of Well WT-5 (Map 1-53) is presently reduced from full potential from turbidity at higher pumping rates. A replacement well for WT-5 at the Cane Road property is another alternative for development of additional water supply and is expected to yield between 350 to 400 gpm.

Vacant property in the area of Walnut Street and Elm Street located near WT-6 (Map 1-53) is also favorable. In addition, vacant property east of Village Drive was previously explored during the 1964 study by Caisson Wells, Inc. Wells at these locations would be expected to yield up to 350 gpm.

**Manhagen Brook Valley (T)**

The Manhagen Brook Valley aquifer is located south of Middletown (Maps 1-23 and 1-31). The aquifer is composed of interbeds of well-sorted gravel, sand, silt and clay deposits. An outline of the aquifer is presented on figure 13 and designated by the Symbol T.

Boring data and geologic maps presented in Frimpter (1972) indicate that portions of the highly-permeable sand and gravel deposits are overlain by clay and silt deposits which act as confining units. Areas in which the aquifer is confined are generally located near the Manhagen Brook and its tributaries. Because most of the brook and its tributaries is underlain by a confining unit, the amount of recharge from the brook is limited. Therefore, direct infiltration from precipitation is the only major source of recharge for the aquifer. The yield of this aquifer was estimated by multiplying the mapped recharge area by an estimated recharge rate of 800,000 gpd/mi$^2$ (Frimpter, 1972). The safe yield of the aquifer is estimated to be about 0.4 mgd.

Aquifer transmissivity (T) was estimated using boring data from Well 124-426-3 installed in 1965 (Frimpter, 1970) using a method developed by the United States Geological Survey (USGS). The procedure involves multiplying an estimated permeability coefficient of the type of material by the individual thickness to calculate a transmissivity value for the specific interval of the aquifer. Once each individual unit has a calculated transmissivity, the transmissivities are then totalled. Aquifer transmissivity at Well 124-426-3 is estimated to be 32,000 gpd/ft. The value indicates that the aquifer is hydraulically capable of supporting moderately high-yield production wells. Because of limited data, the storage coefficient for the aquifer cannot be calculated. However, published storage coefficient values for unconfined aquifers range from 0.1 to 0.01.

The sand and gravel aquifer has not been developed at present. Two areas in which the aquifer might be most productive are between Dolsontown Road and Interstate 84 and a smaller, isolated area south of Interstate 84 where the river is not underlain by a confining unit and water may be induced from the river (Maps 1-23 and 1-31). However, further study is required of riverbed conductivity, aquifer thickness and composition to evaluate if this location is suitable.

**<u>Moodna Creek Valley (Q)</u>**

The Moodna Creek aquifer is located northwest of Skunnemuck Mountain and southeast of Beaverdam Lake (Maps 1-26 and 1-27). The aquifer comprises unconsolidated sediments consisting of stratified layers of gravel, sand, silt and clay deposits. It is presumed that these sediments were deposited by glacial and post-glacial streams of variable sizes. These deposits have been mapped and are presented on figure 13 and designated by the Symbol Q.

Boring data and the surficial geologic map presented in Frimpter (1972) indicate that the portions of the highly-permeable sand and gravel north of Orrs Mill Road and near Taylor Road (Map 1-27) are overlain by low-permeability silt and clay deposits. These deposits act as a confining unit that somewhat limit the amount of direct infiltration from precipitation that recharges the aquifer. The amount of recharge that might be induced from the creek is unknown. Additional information is needed to evaluate the hydraulic connection between the creek and the aquifer before an assessment can be made as to whether the creek is a significant recharge source. A safe yield value was calculated for the aquifer assuming no recharge is available from the river. Based on this assumption, the safe yield of the aquifer was calculated to be 0.3 mgd or larger, a value consistent with the data presented in Frimpter (1972) indicating a potential yield up to 1 mgd.

An estimate of aquifer transmissivity was calculated using specific-capacity data from four production wells operated in the Star Expansion Water District. The four wells, CW-1, CW-2, CW-3 and CW-4, are located just south of the Otterkill Road and Taylor Road intersection (Map 1-27) along Moodna Creek. A review of the boring logs and surficial geology mapping in the area indicates that this portion of the aquifer is confined. Therefore, the transmissivity in the area was calculated by multiplying the specific capacity of each well by 2,000 (Driscoll, 1986). The estimated transmissivity in the area ranged from a low of 27,500 gpd/ft at Well CW-2 to a high of 300,000 gpd/ft at Well CW-3. These values illustrate that the aquifer is hydraulically capable of supporting high-yield production wells. The storage coefficient of the aquifer could not be calculated using this method.

At present, the southwestern portion of the aquifer has been tapped by six production wells, two operated by the Village of Cornwall-on-Hudson's main system and four operated by the Star Expansion System. The two wells operated by the Village of Cornwall-on-Hudson's main system are permitted to withdraw 1.0 mgd. The reported maximum yield of the four Star Expansion wells is 0.74 mgd. The total maximum yield of the aquifer is 1.74 mgd, a value significantly larger than the estimated safe yield of the aquifer of 0.3 to 1 mgd. However, as stated above, the amount of recharge this aquifer derives from the creek is unknown. Therefore, the safe yield of the aquifer may, in fact, be larger. Further development of this aquifer at this location should be based on additional testing and review of pertinent well-field data.

An additional area favorable for the possible development of high-yielding wells is between Otterkill Road and Orrs Mills Road along the Moodna Creek where the river is not underlain by a confining unit and water may be induced from the river (Map 1-26).

**<u>Moodna Creek Valley (P)</u>**

The Moodna Creek Valley aquifer is near the Village of Washingtonville along Route 94 (Map 1-26). The aquifer is composed of stratified gravel and sand deposits that range from 10 to 40 feet in thickness. An outline of the aquifer is presented on figure 13 and designated by the Symbol P.

The surficial geologic mapping presented in Frimpter (1972) and Cadwell et al. (1988), indicates that the aquifer is unconfined and suggests that the Moodna Creek is in good hydraulic connection with the aquifer. Therefore, the aquifer has two primary sources of recharge, direct infiltration from precipitation and water induced from Moodna Creek. The amount of water contributed to the aquifer from direct precipitation is estimated to be 0.3 mgd. This value was derived by multiplying the estimated recharge area by an estimated average recharge rate of 800,000 gpd/mi$^2$. The amount of water that could potentially be induced from Moodna Creek is unknown because of limited data on streambed permeability. However, data in Frimpter (1972) suggest that at least 0.7 mgd could be induced from the creek, making the total yield of the aquifer 1 mgd or greater. Further study is required to make a more exact calculation of aquifer yield potential.

Because of limited data, no transmissivity and storage coefficient estimates were calculated.

At present, there are two inactive (BG-30 and BG-31) and one active (BG-32) ground-water production wells located in the southwestern portion of the aquifer (Map 1-26). A review of the data indicate, as stated earlier, that further study is required prior to making an assessment as to whether the aquifer can support additional high-yield production wells.

Additional areas favorable for the possible development of high-yielding wells are close to Moodna Creek where the river is not underlain by a confining unit and water may be induced from the river (Map 26) and at the confluence of the Otter Kill, Moodna Creek and Cromline Creek east of Washingtonville (Maps 1-25 and 1-26).

**Neversink-Basher Kill River Valleys (L)**

The Neversink-Basher Kill Valley aquifer is a 28-mile long unconsolidated aquifer consisting of kame sand and gravel deposits. The aquifer extends from Summerville, New York to Milford, Pennsylvania (Maps 1-13, 1-14, 1-21, 1-22, 1-28, 1-29 and 1-37). The aquifer averages about one mile in width over its entire length. The portion of the aquifer which is located in New York is approximately 21 miles long. This portion of the aquifer averages 0.5 mile in width and ranges in thickness from less than 10 feet to more than 150 feet. The variability in aquifer thickness is due primarily to the irregular surface of the underlying bedrock. An outline of the aquifer is presented on figure 13 and is designated by the Symbol L.

The Neversink-Basher Kill Valley aquifer is the largest and most prolific sand and gravel aquifer in Orange County. The portion of the aquifer located within Orange County ranges from the Sullivan County line along the valley of the Neversink River to the New Jersey State line near Port Jervis. Most of the Neversink-Basher Kill Valley aquifer is unconfined, however, there is a layer of fine sand and silty material which overlies a portion of the aquifer near Martin Lake and the area east of Port Jervis. This layer of low permeability is as thick as 50 feet at Port Jervis near the confluence of the Neversink and Delaware Rivers (Maps 21, 29 and 37).

The largest source of recharge to the sand and gravel aquifer is the Neversink River. Data presented in Frimpter (1972) indicate that an estimated 6 mgd per mile or a total of 48 mgd could be induced from the river between Godeffroy and Port Jervis (Maps 21 and 29), provided that the flow in the river is sufficient. Other sources of recharge include direct infiltration from precipitation and recharge from the Basher Kill and its tributaries. The estimated recharge that occurs between Godeffroy and Port Jervis is 22 mgd. Therefore, the potential yield of the aquifer between Godeffroy and Port Jervis is approximately 70 mgd. The potential yield of the aquifer between Godeffroy and Summitville is 39 mgd, making the potential yield of the aquifer in New York 109 mgd. It should be noted that the development of the above-estimated yield figures may be feasible, however, additional detailed field investigation and pumping tests are required.

An estimate of aquifer transmissivity was calculated using specific-capacity data from test Well 123-440-4 (Frimpter, 1970). A review of the boring log and the aquifer mapping in the area indicates that this portion of the aquifer is semi-confined. Therefore, transmissivity was estimated by multiplying the specific capacity of the well by 1,500 (Driscoll, 1986). The aquifer transmissivity at the well is estimated to be 50,500 gpd/ft which is consistent with the value of 50,000 gpd/ft presented in Frimpter (1972) and indicates that the aquifer can hydraulically support high-yield production wells. According to Frimpter (1972), the storage coefficient for the aquifer is approximately 0.2, a typical value for an unconfined aquifer in the region.

The United States Federal Correctional facility located in the northwest portion of the Town of Mount Hope has developed a water-supply system from two active and one emergency sand and gravel wells (Wells MH-9, MH-10 and MH-11). Each sand and gravel well has a yield in excess of 350 gpm or about 0.5 mgd. These wells are completed in the Neversink-Basher Kill aquifer. According to the OCDOH, the sand and gravel wells (Wells MH-9, MH-10 and MH-11) are located approximately 75 feet from the Basher Kill, with no confining layer between the surface water and the water-bearing aquifer material. The OCDOH has requested a determination if the wells are under direct influence of surface water, as required by the Surface Water Treatment Rule (USEPA).

The Neversink-Basher Kill aquifer at Westbrookville developed for the Federal Correctional facility has great potential for development of large ground-water supply of good water quality. The potential yield of this aquifer in this vicinity was estimated to be in excess of 3,000 gpm or about 4.3 mgd (Virogroup, 1994).

The total yield of production wells located within the aquifer is approximately 1.7 mgd. This value is substantially less than the estimated safe yield of the aquifer in Orange County of about 70 mgd. Therefore, the aquifer is able to support additional high-yield production wells. The areas most likely to produce high-yield wells are the areas adjacent to the Neversink River where the aquifer is in good hydraulic connection to the aquifer. It should be noted that developing up to 48 mgd from the six-mile sand and gravel aquifer underlying the river between Godeffroy and Port Jervis may be feasible. However, further investigation will be required to substantiate the above-estimated yield potential by detailed field investigation and pumping tests. It should be noted that the aquifer is located within the geographic boundary of the Delaware River

Basin. All ground-water withdrawals in the area are subject to regulations and controls of the Delaware River Basin Commission (DRBC). The DRBC is an agency responsible for planning and regulating use of the resources of the Delaware River Basin (Virogroup, 1993).

LBG estimates wells completed along the Basher Kill between Godeffroy and Port Jervis would likely yield between 400 and 750 gpm with depths expected to be about 100 feet. Conceptual well spacing as close to 1,000 to 1,500 feet between wells along the Basher Kill would likely be feasible if multiple well development is required.

A large-scale conceptual aquifer development plan of the Neversink-Basher Kill River Valley sand and gravel aquifer is outlined in the report entitled, "Orange County, New York, Water Supply Development and Management Plan, Volume I, Engineering Report", dated December 1982, and prepared by Camp, Dresser and McKee. The study reviews the aquifer as a regional source of water supply for Orange County.

**Pine Bush Valley (BB)**

The Pine Bush Valley aquifer is located in the hamlet of Pine Bush and the Town of Crawford, east of the Shawangunk Kill (Maps 1-2 and 1-3). The aquifer consists of sediments composed of isolated stratified sand and gravel deposits which are overlain by low-permeability silt and clay glacial lake deposits. The areal extent of the aquifer is shown on figure 13 and is designated by the Symbol BB.

Only small unnamed streams flow on the lake deposits. The silt and clayey lake deposits limit the amount of recharge from the streams. In addition, the extensive lake deposits covering most of this aquifer also reduce the recharge from precipitation. The aquifer is not considered to induce recharge from the Shawangunk Kill to the northwest of the aquifer (Map 1-2). Considering that most of the aquifer is overlain by a confining unit, the amount of recharge to this aquifer is limited. The yield of this aquifer was estimated by multiplying the mapped recharge area (aquifer boundary) by a conservative estimated recharge rate of 500,000 gpd (Frimpter, 1972). The safe yield of the aquifer is estimated to be about 1.2 mgd by LBG. In the analysis presented in Frimpter (1972), the safe yield of the aquifer was determined to be 1 mgd or less.

At present, the western portion of this aquifer has been tapped by two production wells (CF-4 and CF-5) (Map 1-2) for the Pine Bush Water District. The two wells originally had a combined yield capacity of about 0.9 mgd, however, over time the wells have experienced a loss in yield capacity and presently have a combined yield of about 0.2 mgd. The present combined yield is substantially lower than the estimated safe yield of the aquifer. Considering the loss in yield capacity from both wells and the limited recharge, further development of this aquifer should be based on additional testing and review of pertinent well-field data. Therefore, additional exploration of this aquifer should be away from the existing wells.

The aquifer appears to be comprised of small, isolated pockets of sand and gravel aquifer material interbedded with the clay, silt and fine sand lake deposits. This aquifer material would most likely yield less than 200 gpm if favorable aquifer material could be located. Additional locations to consider would be along the unnamed creek south of Ulsterville Road and west of Route 302 where the aquifer material is unconfined and would likely induce recharge from the creek. An additional location is along the creek which bisects Dubois Street and Drexel Drive east of Pine Bush.

**Ramapo River Valley (Y)**

The Ramapo River Valley aquifer is located in southeastern Orange County (Maps 1-42, 1-49, 1-53 and 1-54). The aquifer consists of unconsolidated deposits which run from mountain lakes in the north to We-wah Lake in the south. The aquifer ranges in width from 0.6 mile to 0.19 mile. The unconsolidated deposits consist of stratified sand and gravel deposits. In some locations, these deposits are overlain by silt that was deposited during flooding of the river. An outline of the aquifer is shown on figure 13 and designated by the Symbol Y.

Despite the fact that the Ramapo River flows on a silty confining layer, the river appears to be hydraulically connected to the aquifer (LBG, 1988). Therefore, the aquifer has two primary sources of recharge, water induced from the river and direct infiltration from precipitation along the edges of the aquifer where the sand and gravel deposits outcrop. The amount of water contributed to the aquifer during dry conditions is estimated to be 1 mgd. The amount of water which could be induced from the Ramapo River and its tributaries is unknown. Therefore, the safe yield of the aquifer is 1 mgd or greater.

The Ramapo River Valley sand and gravel aquifer is mapped in the far eastern edge of the Town of Monroe in the Village of Harriman. Reported yields from wells drilled in the aquifer range from 70 gpm (Well MT-50) to 75 gpm (Well MT-39). The reported yield for the original Mary Harriman Well 1 (Well MT-47) was 350 gpm. These three wells are located on Map 1-42.

In the Town of Tuxedo, two wells are reported to be completed in the sand and gravel aquifer along the Indian Kill, near the confluence of the Indian Kill and Ramapo Rivers and are reported to have yield capacities of about 100 gpm (0.14 mgd) each. Presently, there is available information on only one of these two wells (Well TX-2) (Map 1-54). In Tuxedo, an additional well drilled along the Ramapo River, Well TX-5 (Map 1-54), is reported to have a yield capacity of about 100 gpm. No wells completed in the Ramapo River Valley aquifer in Tuxedo are presently in service, however, this aquifer has good potential for development of high-yielding public supply wells in the Town. High-yielding wells are completed in the same aquifer south of the Town of Tuxedo in Rockland County for the Spring Valley Water Company.

An estimation of aquifer transmissivity was calculated using specific-capacity data from Production Well 3 located on Baily Farm. Aquifer transmissivity at the well is estimated to be 33,000 gpd/ft. The value was calculated by multiplying specific capacity by 2,000 (Driscoll, 1986). Because of limited data, the storage coefficient for the aquifer could not be calculated.

Presently, there are one active and six inactive wells located in Harriman and Tuxedo within the aquifer. These wells would yield 0.85 mgd if they were all active. This value is less than the estimated safe yield of the aquifer (1 mgd or greater), indicating that the aquifer could support additional production wells. Additional data on river bottom permeability is required before an assessment can be made as to where additional wells can be located.

Extensive drilling of the sand and gravel aquifer by the Village of Harriman and the developer of Harriman Business Park indicates that most of the aquifer is not suitable for production well development. Minimal exploration drilling has been conducted in the southern portion of the aquifer along the Ramapo River in the Town of Tuxedo south of Harriman. Additional areas favorable for the possible development of high-yielding wells are close to the Ramapo River where the river is not underlain by a confining unit and water may be induced from the River. Good examples are the area south of Arden along the Ramapo River between the New York State Thruway and Route 17 (Maps 1-49 and 1-54) and the area along the Ramapo River near the confluence of the Indian Kill and Warwick Brook (Maps 1-53 and 1-54).

**Rutgers Creek Valley (S)**

The Rutgers Creek Valley aquifer is located between Unionville, New York and Johnson, New York in Orange County (Maps 1-45 and 1-58). The interbedded unconsolidated material consists of beds of well-sorted gravel, sand, silt and clay. The best water-yielding material in the aquifer is the coarse sand and gravel delta deposits. Some of these deposits are overlain by silt and clay lake deposits which act as a confining unit. The delta deposits outcrop in the area of Pine Hill Road and the area near Westtown. The aquifer is shown on figure 13 and is designated by the Symbol S.

Data presented in Frimpter (1972) indicate that the aquifer does not receive substantial amounts of recharge from stream infiltration. Therefore, recharge to the sand and gravel aquifer occurs mainly as direct infiltration from precipitation. The amount of water contributed to the aquifer (safe yield) is estimated to be 1.6 mgd (Frimpter, 1972). This value is based on the value of 0.58 mgd per square mile calculated from stream-gage data multiplied by 2.8 square miles of aquifer recharge area in the basin.

Aquifer transmissivity was calculated using boring data from Wells 120-433-a and 120-433-b (Frimpter, 1970). Transmissivity was estimated using a method developed by the USGS. The procedure involves multiplying an estimated permeability coefficient for the type of material by the individual thickness to calculate a transmissivity value for the specific interval of the aquifer. Once each individual unit has a calculated transmissivity, the transmissivities are totalled. The aquifer transmissivity at Wells 120-433-a and 120-433-b are estimated to be 23,000 and 25,500 gpd/ft, respectively. These values suggest that the aquifer is hydraulically capable of supporting moderate-yielding production wells. Because of limited data, the storage coefficient for the aquifer could not be calculated.

The Village of Unionville and the Minisink Rubber Mill are the only major withdrawers from the aquifer. The reported total yield for these wells is less than 0.25 mgd, a value which is less than the safe yield of the aquifer (1.6 mgd). Therefore, the aquifer is capable of supporting more production wells. Further study of aquifer thickness and composition is required to evaluate potential locations for additional ground-water wells.

Consideration should be given to drilling larger diameter production wells to replace MS-1, MS-2 and MS-3 (Map 1-45) in the Village of Unionville along Rutgers Creek. If favorable aquifer material is located, larger diameter and high-yielding wells would be more practical than the existing well supply. Additional areas favorable for the possible development of high-yielding wells are northwest of the Village where the Creek is not underlain by a confining unit and water may be inducted from the Creek (Maps 1-38 and 1-45) and the area south of Westtown near the confluence of Rutgers Creek and the tributary from Lockenhurst Pond.

**Seeley Brook Valley (W)**

The Seeley Brook Valley aquifer is located between Chester and Monroe in Orange County (Maps 1-41 and 1-48). The aquifer consists of interbeds of well-sorted sand, gravel, silt and clay. The best water-yielding and water-bearing material in the aquifer is the coarse sand and gravel material. The aquifer is shown on figure 13 and is designated by the Symbol W.

Data presented in Frimpter (1972) indicate that the aquifer is unconfined and is in excellent hydraulic contact with Seeley Brook. Therefore, the aquifer has two major sources of recharge, direct infiltration from precipitation and recharge infiltrating from Seeley Brook. The amount of water contributed to the aquifer (safe yield) is estimated to be approximately 1.3 mgd (Frimpter, 1972). This value is based on a stream-flow reduction calculations at a gaging station on Seeley Brook.

An estimation of aquifer transmissivity was calculated using specific-capacity data from Well 119-415-3 installed in 1964 (Frimpter, 1970). Aquifer transmissivity at the well is estimated to be 13,000 gpd/ft. This value was calculated by multiplying specific capacity by 1,500 (Driscoll, 1986). The magnitude of the aquifer transmissivity near Well 119-415-3 limits the potential yield withdrawals in the area. The storage coefficient for the aquifer cannot be calculated because of limited data. Published values of storage coefficient in unconfined aquifers range from 0.1 to 0.01.

Currently, Well CT-15 (Map 1-41) is the only active production well located in the aquifer. The reported yield of this well is 0.15 mgd which is significantly less than the safe yield of the aquifer (1.3 mgd). Therefore, the aquifer is capable of supporting more production wells. Data suggest that the yield of wells in the aquifer will be low to moderate. Further study is required of aquifer thickness, aquifer parameters and composition to evaluate potential locations and yields of any additional ground-water withdrawals in the aquifer.

Additional areas favorable for possible

development of high-yielding wells are close to the Seeley Brook where the river is not underlain by a confining unit and water may be induced from the brook (Maps 1-41 and 1-48). Areas favorable for exploration of productive sand and gravel aquifer material are north and south of Lazy Hill Road along Seeley Brook and east of Laroe Road at the confluence of Seeley Brook and unnamed tributaries.

**Shawangunk Kill Valley (M)**

The Shawangunk Kill Valley aquifer underlies the Village of Otisville and extends north along the Shawangunk Kill (Maps 1-14, 1-15 and 1-22). The aquifer is situated in a narrow Vee-shaped bedrock valley cut by the pre-glacial Shawangunk Kill and is filled with unconsolidated deposits of well-sorted gravel, sand, silt and clay (Frimpter, 1972). The coarser sand and gravel beds were deposited by rapidly-moving glacial meltwater streams. The finer beds were deposited by slow-moving glacial streams and impoundments. The water-bearing and water-yielding properties of stratified-drift aquifers vary from excellent to poor. These characteristics depend largely upon the relative amounts of fine-grained versus coarse-grained interbeds the stratified drift contains. The aquifer is located on figure 13 and is designated by the Symbol M.

Boring data and data presented in Frimpter (1972) indicate that portions of the highly- permeable sand and gravel deposits in the center of the valley are overlain by clay and silt deposits that act as a hydraulic confining unit. Areas in which the aquifer is confined are generally located near the Shawangunk Kill and its tributaries. The amount of recharge from the Shawangunk Kill is limited because the majority of the river and its tributaries are underlain by silt and clay. Therefore, direct infiltration from precipitation is the only major source of recharge for the aquifer. The yield of this aquifer was estimated by multiplying the recharge area by an estimated recharge rate. Using this method, the safe yield of the aquifer is estimated to be 1.5 mgd, a value consistent with the value (between 1 and 2 mgd) presented in Frimpter (1972).

An estimate of aquifer transmissivity was calculated using specific-capacity data from Test Well 128-432-1 installed in 1966 (Frimpter, 1970). A review of the boring log for Test Well 128-432-1 indicates that the aquifer is confined in the area. Therefore, a transmissivity value was estimated by multiplying the specific capacity of the well by 2,000 (Driscoll, 1986). Aquifer transmissivity at Well 128-432-1 is estimated to be 33,000 gpd/ft. The magnitude of the transmissivity suggests that the aquifer is hydraulically capable of supporting moderately high-yield production wells. The storage coefficient for the aquifer was not calculated because of limited data. Published storage coefficient values for confined aquifers generally range from 0.001 to 0.0001.

The aquifer in this area has not been extensively explored and has good potential for development of additional water supplies in the Village of Otisville and the Town of Mount Hope along the Shawangunk Kill. The Village of Otisville recently developed a well (MH-20) (Map 1-14) in this aquifer with a reported yield greater than 200 gpm or about 0.3 mgd.

The Village of Otisville has not placed Well MH-20 in service and, at present, there is no significant ground-water withdrawal from the aquifer in this vicinity. The aquifer tapped by Well MH-20 has good potential for development of additional wells. Additional exploration should be conducted in the area bounded by Main Street to the north, Seybolt Cove to the south, and Field Road and Orchard Street to the west and east, respectively, along the unnamed tributary where the aquifer is unconfined and will likely induce recharge from the stream (Map 1-14).

An unnamed tributary located east of Sanitarium Road and south of Robbins Road eventually intersects Shoddy Hollow Road to the south (Map 1-14). Further south of Shoddy Hollow Road, the tributary is underlain by unconfined sand and gravel aquifer material and has good potential for developing high-yielding wells. Considering the stream is not underlain by a confining unit, water may be induced from the stream. The Whitlock Farm Water Company located off Whitlock Road in the Town of Mount Hope has developed a well (Well MH-8) completed in the Shawangunk Kill valley aquifer (Map 1-14). The well is reported to have a yield capacity of 330 gpm or about 0.5 mgd. The well is utilized as a back-up well due to high iron and manganese concentrations in the water.

Two additional locations in which aquifers might be productive are near Shoddy Hollow Road (Maps 1-14 and 1-15) and Grange Road (Map 1-14), where the river is not underlain by a confining unit and water may be induced from the river.

The Shawangunk Kill to the north of Otisville is the boundary between Sullivan and Orange Counties (Maps 1-1, 1-7 and 1-15). Little data are available on the aquifer in this area. Additional exploration should be conducted where the river is not underlain by a confining unit and water may be induced from the river (Map 1-7). However, further study is required of riverbed conductivity and aquifer thickness and composition to evaluate if these locations are suitable.

**Wallkill River Valley (U)**

The Wallkill River Valley aquifer system is located along the western side of the Wallkill River Valley. The aquifer system extends from Stoney Ford in the north to the New Jersey State line in the south (Maps 1-16, 1-17, 1-24, 1-31, 1-32, 1-38, 1-39 and 1-45). The aquifer is composed of sand and gravel outwash deposits that are interbedded with lenses of silt and clay deposits. The majority of high permeability sand and gravel deposits located south of Denton (Maps 1-31, 1-38, 1-39 and 1-45) are overlain by organic silt and clay lake deposits. North of Denton, the aquifer is comprised of several separated sand and gravel deposits of limited extent (Maps 1-24 and 1-32). These deposits are generally hydraulically connected to the Wallkill River and, thus, receive recharge from the river. The areal extent of the Wallkill River Valley aquifer system is shown on figure 13 and is designated by the Symbol U.

According to Frimpter (1972), the rate of recharge to the aquifer between Denton and the New Jersey State line is limited to direct infiltration from precipitation. Recharge from the river is limited because the Wallkill River flows primarily on the silt and clay lake deposits which cover the sand and gravel in this portion of the valley. Based on direct infiltration from precipitation, the safe yield of the aquifer from the New Jersey State line to Denton, New York is 1.0 mgd.

A review of the available data indicates that the majority of the northern portion of the aquifer (between Denton and Stony Ford) (Maps 1-16, 1-17, 1-24, 1-31 and 1-32) is unconfined and in good hydraulic connection with the Wallkill River. Therefore, the aquifer system in the area has two major sources for recharge, direct infiltration for precipitation and recharge induced from the Wallkill River. The amount of water contributed to the aquifer system by direct precipitation is estimated to be 2.3 mgd. This value was derived by multiplying the exposed sand and gravel deposits between Denton and Stoney Ford by an average recharge rate of 1 mgd per square mile (Snavely, 1980). This rate was used because of the aquifer's general high permeability and limited depth and extent. Further study is needed of the Wallkill River's streambed permeability to calculate the amount of water that could be induced from the river.

A conservative estimate of the safe yield of the Wallkill River Valley aquifer system is 3.3 mgd or greater. Because the aquifer is connected to the river in the north, it is expected that the safe yield may be significantly larger.

An estimation of aquifer transmissivity and storage coefficient values was obtained from an analysis of a pumping test performed at Well 126-422-4 near Phillipsburg (Map 1-24) (Frimpter, 1972). The drawdown-distance relationship was used to analyze and calculate aquifer parameters. Aquifer transmissivity and storage coefficient values are 50,000 gpd/ft and 0.008, respectively. These values illustrate that the aquifer is hydraulically capable of supporting high-yield wells. The storage coefficient indicates that the aquifer is confined in this region. Data were not available to calculate aquifer parameters in the unconfined portions of the aquifer.

Several high-yield production wells are located within the Wallkill Valley aquifer system. These production wells have a total combined capacity of 3.9 mgd, a value which is greater than the estimated safe yield (3.3 mgd) of the aquifer. The well fields are discussed in detail in the Town of Wallkill Section of the Existing Conditions Report. However, because the safe yield does not include recharge from the river or recharge from the organic soil which covers most of the sand and gravel in the aquifer, the actual safe yield is probably larger than 3.3 mgd. Therefore, the aquifer system probably could support additional production wells. The Town of Wallkill Section in the Existing Conditions Report, prepared by EA Engineering, Science and Technology (EA) (June 1994) discusses six locations (Sites A to F) favorable for the development of high-yielding wells (Maps 1-17 and 1-24). The sites are detailed in the Town Study and are summarized as follows:

- **Site A** - Includes three separate areas located adjacent to and along the Wallkill River in the southern portion of the Town (Map 1-24). Initial data indicate at least 35 feet of saturated sand and silty sand adjacent to the Wallkill River. Additional drilling is required at this site to further evaluate the potential to develop the aquifer at this location.

- **Site B** - Area B (Crystal Run well field) is located adjacent and north of the Wallkill River approximately 1,800 feet west of the Goshen Turnpike (Map 1-24). Wells have been developed at this site, however, have not been placed in service to date.

- **Site C** - Area C is located north and adjacent to the Wallkill River (Map 1-24). Additional field investigation and drilling are required at this site to further evaluate the potential to develop the aquifer at this location.

- **Site D** - Area D is located northwest and adjacent to the Wallkill River both southwest and northeast of Stoney Ford Road (Map 1-24). An initial investigation of only a small portion of this site indicates fine-grained unconsolidated material not suitable for development of high-yielding wells. However, an additional investigation of other portions of this site is suggested by EA (1994) to further define the potential to develop high-yielding wells at this location.

- **Site E** - Area E is located in the northern portion of the Town and adjacent to the Wallkill River (Map 1-17). Additional field investigations and drilling are required at this site to further evaluate the potential to develop the aquifer at this location.

- **Site F** - Area F is referred to as the Bart Bull Road aquifer and is located west of and adjacent to the Wallkill River in the eastern portion of the Town (Map 1-17). Data collected to date indicate the aquifer at this location has an estimated potential yield of about 350 gpm (EA, 1994). The Bart Bull Road site is underlain by glacial and alluvial deposits including silty sand and gravel occasionally interbedded with silt and clay and dense clayey/silty till deposits. Additional studies are recommended to further evaluate the potential of the aquifer at this location.

Additional field investigations and exploration methods should be conducted at additional locations where the river is not underlain by a confining unit and water may be induced from the river. Two examples are as follows:

- east side of the Wallkill River just north of the intersection of Route 84 and the river

(Map 1-17); and

- east side of the Wallkill River between Route 467 and the river, north of Grover Street (Map 1-17).

**Tin Brook (I)**

The Tin Brook Valley aquifer is located northeast and east of the Village of Walden (Maps 1-4 and 1-10). The aquifer consists of unconsolidated sediments and is situated in a pitted outwash plain. The unconsolidated sediments consist of sorted gravel, sand, silt and clay deposits. The deposits are presumed to have been laid down over and around remnant blocks of ice and depressions were formed when the ice melted. The areal extent of the aquifer is shown on figure 13 and is designated by the Symbol I.

Portions of the sand and gravel deposits with the greatest water-bearing potential in the valley are overlain by clay and silt deposits. These low-permeability silt and clay deposits act as a confining layer in the aquifer, limiting the amount of direct precipitation recharge to the aquifer. Regardless, direct infiltration from precipitation is an important recharge source for the aquifer. Although the majority of Tin Brook, Lake Osiris and other streams in the valley are located on confining units and have limited induced infiltration potential, some of the upper reaches of Tin Brook and the smaller tributaries are in hydraulic contact with the aquifer. Therefore, induced infiltration from surface-water bodies is an important source of recharge for the aquifer. In an analysis presented in Frimpter (1972), two methods were utilized to estimate average annual recharge of the aquifer, a baseflow analysis of Tin Brook which drains the aquifer and multiplying the recharge area by an estimated annual recharge rate. The safe yield of the aquifer was determined to be 1 mgd using both methods.

An estimate of aquifer transmissivity (T) was calculated using specific-capacity data from Well MG-25 (Map 4) and Test Well 133-409-1 (Frimpter, 1970). A review of the boring logs for the two wells indicate that the aquifer is confined in both areas. Therefore, transmissivity was estimated by multiplying the specific capacity for Well MG-25 and Test Well 133-409-1 by 2,000 (Driscoll, 1986). Aquifer transmissivity at Well MG-25 and Test Well 133-409-1 is estimated to be 37,000 and 66,000 gpd/ft, respectively. Both values indicate that the aquifer can support high-yield wells. The storage coefficient for the aquifer cannot be calculated because of limited data.

The Village of Walden currently has five wells developed in the sand and gravel aquifer (Maps 1-4 and 1-10). The current total combined capacity of these wells is 1,320 gpm or 1.9 mgd. Review of the data indicates that the aquifer could not safely support any additional high-yield production wells. The safe-yield value calculated for the aquifer is 1.0 mgd, significantly less than the current capacity of the production wells (1.9 mgd). Any decision to produce more than the current capacity of the production well over 1.9 mgd should be based on additional testing and review of pertinent well-field data collected.

If additional development of this aquifer is considered, the exploration should be conducted in areas away from the existing well fields. Favorable areas to be considered for possible development of high-yielding wells are south of Route 52 and in the north portion of the aquifer in the vicinity of Lake Osiris and adjacent to the Tin Brook (Maps 1-4 and 1-10).

**Wawayanda Creek Valley (V)**

The Wawayanda Creek Valley aquifer is located near the Village of Warwick (Maps 1-47, 1-48 and 1-52). The aquifer system bisects the town in a northeast to southwest direction. The unconsolidated material consists of interbeds of gravel, sand, silt and clay deposits. These deposits are associated with outwash and ice-contact deposits in the region. The areal extent of the aquifer is shown on figure 13 and is designated by the Symbol V.

The majority of the aquifer's highly-permeable sand and gravel deposits are overlain by silt and clay deposits which act as a confining unit. Therefore, direct infiltration from precipitation is limited to the outcrops of coarse-grained delta deposits located at the edges of the main valley. In addition, the aquifer also receives significant recharge from tributary streams which cross the exposed delta deposits. Much of this recharge occurs during the spring when stream flow is at high levels. The yield of the aquifer is estimated to be 1.35 mgd. The value was calculated by multiplying the estimated area of direct recharge by an annual average recharge rate of 500,000 gpd/ft per square mile (Frimpter, 1972). The estimated yield value calculated for the aquifer is consistent with the value presented in Frimpter (1972), less than 1.5 mgd.

An estimate of aquifer transmissivity was calculated using specific-capacity data from a test well located within the well field operated by the Warwick Water Company. A review of boring logs and aquifer mapping in the area indicate that this portion of the aquifer is confined. Therefore, transmissivity was estimated by multiplying the specific capacity of the well by 2,000 (Driscoll, 1986). The aquifer transmissivity at the Warwick well field is estimated to be 37,000 gpd/ft and, therefore, can support high-yield wells. The storage coefficient of the aquifer was not calculated due to limited data. However, because the aquifer is confined, it is expected that the storage coefficient will range between 0.001 and 0.0001 (Driscoll, 1986).

At present, the northern portion of the Wawayanda aquifer has been tapped by a number of production wells around Wickham Lake near the headwaters of the Wawayanda Creek. The reported yield of these wells is 0.16 mgd. The aquifer has also been tapped near the central portion of the Town of Wawayanda, east of the Village of Warwick. The yield of these production wells is 1.15 mgd. The total yield of the production wells located within the aquifer is 1.31 mgd. This value is very close to the estimated safe yield of the well field of 1.35 mgd. Any decision to produce more than the current estimated yield capacity of 1.35 mgd should be based on additional testing and review of pertinent well data collected. However, if it is possible the aquifer can be developed southwest of the Village, the yield capacity of the aquifer could be substantially greater than 1.35 mgd.

If additional development of this aquifer is considered, the exploration should be conducted in areas away from existing well fields until additional testing and review of pertinent well-field data. The recent development along State Highway 94 south of the Village of Warwick has revealed additional sand and gravel deposits along the creek in the vicinity of the Warwick Drive-In Theater (Map 1-52). Favorable areas to be considered for possible development of high-yielding wells are southwest of the Village of Warwick and north of Route 94 along the creek and unnamed tributaries where the aquifer is unconfined and wells will likely induce recharge from the creek (Map 1-52). Further study is required before an assessment can be made as to how the additional development of the southwestern portion of this aquifer will impact present aquifer yield.

**Woodbury Creek Valley (X)**

The Woodbury Creek Valley aquifer is located near Highland Mills in eastern Orange County (Maps 1-34, 1-35 and 1-42). The aquifer consists of interbeds of well-sorted sand, gravel, silt and clay. The best water-yielding and water-bearing material in the aquifer is the coarse sand and gravel delta deposits. These deposits are overlain by silt and clay lake deposits of low permeability that act as a confining unit and covers the majority of the aquifer. The aquifer is located on figure 13 and is designated by the Symbol X.

Because Woodbury Creek flows on bedrock or lake sediments, the amount of water which can be infiltrated from the creek is limited. Therefore, recharge is limited to direct infiltration of precipitation along the western side of the valley where the sand and gravel deposits outcrop. In addition, water is induced from tributaries of Woodbury Creek which flow on the sand and gravel along the western portion of the valley. The amount of water contributed to the aquifer from direct precipitation is estimated to be 0.5 mgd (Frimpter, 1972). The amount of water that could be induced for the tributaries of Woodbury Creek is estimated to be 0.5 mgd (Frimpter, 1972). Therefore, the safe yield of the aquifer is about 1.0 mgd.

An estimation of aquifer transmissivity and storage coefficient values were obtained from an analysis of aquifer tests made at the Woodbury well field. The Theis nonequilibrium method was used to analyze and calculate aquifer parameters. Aquifer transmissivity and storage coefficient values are 60,000 gpd/ft and 0.0005, respectively. The storage coefficient is representative of a confined aquifer near the well field (Frimpter, 1972).

The only successfully developed high-yield production wells in the aquifer are at the Town of Woodbury's Hunter Road well field. The current capacity of this well field is 1.4 mgd. Extensive drilling of the sand and gravel aquifer by the Town of Woodbury indicates that most of the aquifer is not suitable for production well development. Furthermore, a review of the data indicates that the sand and gravel aquifer probably could not safely support any more high-yield production wells. The safe-yield value calculated for the aquifer is approximately 1.0 mgd, a value less than the current capacity of the Hunter Road well field (1.4 mgd). Therefore, further development of the sand and gravel aquifer in this area is not recommended.

**Additional Small Sand and Gravel Deposits**

Figure 13 and Map Set 1 indicate small areas of unconsolidated sand and gravel deposits. These deposits are of limited areal extent and isolated from the large regional sand and gravel aquifers. A majority of small sand and gravel deposits have yet to be explored, therefore, limited data are available.

Some of the smaller sand and gravel deposits developed include the sand and gravel aquifer along Trout Brook in the Town of Chester (Map 1-23), south of Pine Island Turnpike in Pine Island (Map 1-46) and north of Route 17 in the Village of Goshen (Map 1-32).

Most of these deposits are overlain or partially overlain by a confining unit limiting recharge from overlying streams and from precipitation directly recharging the aquifer. Considering the limited recharge potential and areal extent of these areas, the yield capacities of wells developed in these areas are generally low to moderate (5 to 50 gpm). If the small sand and gravel deposits consist of suitable sand and gravel aquifer material for development, the total safe yield of these aquifers is estimated to be less than 0.25 mgd.

Exploration of the small sand and gravel aquifers should be conducted in areas where surface-water bodies are not underlain by a confining unit and water may be induced from the overlying water body.

## YIELD POTENTIAL OF BEDROCK AQUIFERS

Ground water occurs in the bedrock units underlying Orange County. The bedrock aquifers underlie the entire County and are the principal source of ground water in areas where sand and gravel aquifers are not available for development of water supply. The bedrock aquifers in the County are developed from sedimentary, igneous and metamorphic rock types. The occurrence of bedrock in Orange County is shown on figure 14.

The younger sedimentary bedrock units in the County consist of a variety of rock types including shale, limestone, siltstone, sandstone, conglomerate dolomite, marble and schist of Paleozoic Age. The older igneous and metamorphic bedrock units of Precambrian Age consist mainly of granite and gneiss. Differences in age, degree of metamorphism and lithology influence the water-bearing properties of the bedrock units. The following discusses the various bedrock types to aid in the understanding of occurrence of ground water in bedrock units in the County. The principal bedrock types are differentiated on table 12.

**Sedimentary Bedrock Aquifers**

Most of Orange County, with the exception of the southeastern portion of the County, is underlain by sedimentary bedrock units. Sedimentary bedrock units are widely distributed and possess excellent water-bearing properties. The highest-yielding bedrock wells in Orange County are completed in the sedimentary bedrock units, which are the largest ground-water reservoirs in the County.

Sedimentary bedrock units were formed from materials deposited as sediments and derived from both weathering and erosion of pre-existing bedrock. Deposition of sediments occurred in past oceans and on dry land. The transported sediments accumulated layer on top of layer and became compacted and cemented.

Many factors influence the water-bearing properties of sedimentary bedrock aquifers. Although the primary permeability available from the porosity of bedrock is generally low, secondary permeability caused by the presence of many interconnected fractures can be low to high. Water is contained in fractures, joints, faults and other secondary openings in the bedrock (figure 15). The yield of a well depends upon the number of fractures intersected by the borehole and their degree of connection with other fracture systems (figure 14). The denser the fractures and joint systems and the greater degree of interconnection, the stronger the likelihood of developing high-yielding wells.

**Lower Walton Formation (Dsw)**

**Dsw** consists of gray and green sandstone, red and green shale and quartz conglomerate. The unit occurs in a small area in the northeast section of Orange County. There are no data presently inventoried to indicate the yield of wells completed in this unit in Orange County for this study. The area in Orange County where this unit occurs is of small areal extent, rugged, and very rural with little to no development with high water demand needs.

The multi-textured bedrock units likely exhibit low to moderate primary permeability from the porosity of the bedrock units. Secondary permeability caused by the presence of many intermittent fractures can be low to high. Water is contained in fractures, joints, bedding planes and other secondary openings in the bedrock.

No wells are inventoried in this bedrock to estimate average and median yield from wells developed. The yield potential was estimated comparing this multi-textural unit to other similar multi-textural units with reported yield capacities in the County. The yield potential of the **Dsw** is conservatively projected to range from 50 to 150 gpm at favorable well sites (table 12). Moderate to high yields from wells completed in this unit would most likely be developed from the coarser-textured sand, stone and conglomerate units which exhibit extensive fracture and joint systems with a relatively high degree of interconnection.

**Oneonta Formation (Dgo)**

**Dgo** consists of gray and green sandstone, with red and gray shale. The unit occurs in a small area in the northeast section of the County. There are little data presently inventoried to indicate the yield of wells completed in the unit in Orange County.

This unit is similar to other fine-grained bedrock units in the County likely exhibiting low to moderate primary permeability from the porosity of the bedrock units, however, secondary permeability cased by the presence of many interconnected fractures can be low to high. Water is contained in fractures, joints, bedding planes and other secondary openings in the bedrock.

The yield potential of the **Dgo** is projected to range from 50 to 100 gpm at favorable well sites. Wells would be likely to have a lower yield if wells are completed in the shale unit. The yield potential was estimated comparing this fine-grained unit to other similar fine-grained bedrock units with reported yield capacities in the County. Table 12 indicates one well (DP-15) (Map 2-20) completed in the **Dgo** which is reported to yield 200 gpm at a relatively shallow depth of 200 feet.

**Undifferentiated Hamilton Group (Dh)**

**Western Orange County**

In western Orange County, west of the Basherkill River, the **Dh** consists of gray to black shale, siltstone and sandstone. There are minimal data presently inventoried to indicate the yield of wells completed in this unit in Orange County. The area is rural with little large-scale development with high water demands. Two wells completed in this bedrock unit for the Village of Wurtsboro, immediately northwest of Orange County in Sullivan County, yield 75 and 160 gpm at completed depths of 550 and 500 feet, respectively. The wells are to be utilized for public water supply. The **Dh** bedrock units west of the Basherkill River are fine-grained units, consisting mostly of shale and siltstone and some sandstone units. The fractures exhibited are few and mostly closed fractures. These units are resistant to weathering. The fine-grained bedrock units likely exhibit low permeability based on the low porosity of the bedrock units. Secondary permeability resulting from interconnected fractures can be low to moderate in these units. Water is contained in fractures, joints, bedding planes, contacts and other secondary openings in the bedrock units. Wells drilled in favorable well sites would likely yield between 50 and 100 gpm. Table 12 indicates average and median yields of 17 gpm and 15 gpm, respectively, at a relatively shallow average depth of 221 feet from four wells inventoried. Wells drilled deeper may have yielded higher yield capacities. The yield ranges reported are from 4 to 35 gpm. The yield potential was estimated comparing this fine-grained textural unit to other similar fine-grained textural units with reported yield capacities in the County. Moderate to high yield from wells completed in this unit would most likely be developed from coarse sandstone units exhibiting extensive fractures and joint systems with a relatively high degree of interconnection.

**Eastern Orange County**

In eastern Orange County, the mountain ridge west of Greenwood Lake and extending north to Skunnemunk Mountain includes the Skunnemunk Formation consisting of sandstone and conglomerate; Bellvale Formation consisting of shale, sandstone, conglomerate and graywacke; and the Cornwall shale.

There is a significant amount of data on wells completed in these **Dh** units in eastern Orange County. Two high-yielding bedrock wells presently in service in Orange County were completed for the Village of Kiryas Joel (Wells MT-37 and Well 18) (Map 2-42) and each has a reported yield capacity of about 200 gpm. The **Dh** units in eastern Orange County underlie a region of dense urban development. The unit is a very prolific bedrock aquifer in eastern Orange County and has greater potential for development of future water-supply needs in the region.

The coarse-grained bedrock units likely exhibit low to moderate primary permeability from the porosity of the bedrock units; secondary permeability caused by the presence of many interconnected fractures can be low to high. These rock units are brittle, forming numerous open fractures. The units are highly resistant to weathering. Water is found in fractures, joints, bedding planes, contacts and other secondary openings in bedrock units.

The yield potential in the **Dh** bedrock unit in eastern Orange County is projected to range from 75 to 250 gpm, with yields between 75 and 100 gpm common at favorable well sites. Table 12 indicates average and median yield of 77 gpm and 60 gpm, respectively, and yield ranges from 9 to 200 gpm. The higher yields are commonly obtained from wells completed in the coarser textured units (sandstone, conglomerate) which are highly fractured and jointed with a relatively high degree of interconnection.

### Onondaga Limestone (Dou)

**Dou** consists of gray, shaley limestone and limey mudstone and siltstone, with gray blocky shale and siltstone. This unit occurs in the Basherkill River Valley in the western portion of Orange County. There are little to no data presently inventoried to indicate the yield of wells completed in the unit in Orange County. The area in Orange County where the unit occurs is of small areal extent and very rural with little to no development.

The **Dou** bedrock unit consists of limestone and is relatively brittle and under deformational stress from numerous open fractures. Limestone is relatively soluble, consequently, the fractures are frequently widened by dissolution. Limestone units likely exhibit low to moderate permeability from the porosity of the bedrock unit. Secondary permeability caused by the pressure of many interconnected fractures and dissolution cavities can be low to high. Water is contained in fractures, joints, bedding planes, solution cavities and other secondary openings in the bedrock units.

Although only one well (Well DP-1, Map 2-29) is inventoried (table 12) to be completed in the **Dou** unit in Orange County, the well is reported to yield only 22 gpm at 286 feet. Wells completed in this carbonate bedrock aquifer at favorable well sites may be expected to yield from 50 to 300 gpm. Wells would likely yield in the higher range when completed in limestone units of this formation.

### Helderberg Group (Dhg)

**Dhg** consists of gray shaley limestone. Similar to the younger **Dou** unit, the **Dhg** unit occurs in the Basherkill River Valley in the western portion of Orange County. There are no data presently inventoried to indicate the yield of wells completed in this unit in Orange County. The area in Orange County where the unit occurs is of limited areal extent and very rural, with little to no development with high-yield wells. This unit would likely exhibit similar characteristics to other carbonate bedrock units (**Dou**, **Dew**, **Dhg**) discussed in this section. The unit has good potential for developing high-yielding bedrock wells ranging from 50 to 300 gpm at favorable well sites.

### Undifferentiated Lower Devonian and Silurian Rocks (Ds)

The **Ds** unit in Orange County consists of undifferentiated bedrock units of sandstone, conglomerate, shale, siltstone and graywacke (Jaffe, 1973). The unit occurs on the eastern and western valley floor adjacent to Skunnemunk Mountain. There are significant data presently inventoried on this unit in Orange County. The unit is a very prolific aquifer in an area of high-density urban development in eastern Orange County. Two wells recently drilled in this unit for the Town of Woodbury (Well WB-10) (Map 2-42) and Village of Kiryas Joel (Well MT-26) (Map 2-42) both have reported yields of 300 gpm, respectively. Several additional wells drilled in this unit yield between 100 and 175 gpm. This bedrock aquifer has substantial potential for development of future water-supply needs in the region where it occurs.

These multi-textured bedrock units likely exhibit low to moderate primary permeability from the porosity of the bedrock units; secondary permeability caused by the presence of many interconnected fractures can be low to high. Water is found in fractures, joints, bedding planes, contacts and other secondary openings in bedrock units.

The yield potential in the **Ds** bedrock unit in eastern Orange County is projected to range from 50 to 300 gpm with yields between 75 and 150 gpm, common at favorable well sites. Higher yields would likely be obtained from coarser sandstone and conglomerate units exhibiting extensive fracturing and joint systems with a relatively high degree of interconnection. Table 12 indicates an average and median yield of 174 gpm and 154 gpm, respectively, and a reported range from 55 to 300 gpm for this unit.

### Undifferentiated Silurian Rocks I (Srp)

The **Srp** unit in Orange County consists of undifferentiated bedrock units of dark gray to gray limey sandstone, shale and siltstone and shaley limestone and dolomite. The unit occurs on the western flank of the Shawangunk Mountain in western Orange County. There are no data presently inventoried to indicate the yield potential of this unit in Orange County. The area in Orange County where the unit occurs is of limited areal extent; rugged terrain and very rural with little to no development with large water-supply demands.

This unit is reported to be characteristic of fine-grained units and consists mostly of shale and siltstone and shaley limestone and dolomite in Orange County. The fractures exhibited are few and mostly closed fractures. These units are resistant to weathering. The units likely exhibit low permeability based on the porosity of the bedrock units, and secondary permeability caused by the presence of interconnected fractures can be low to moderate in these units. Water is contained in fractures, joints, bedding planes, contacts and other secondary openings in the bedrock units. Wells drilled in favorable well sites would likely yield between 50 and 100 gpm, similar to other fine-grained textural bedrock units with reported yield capacities in the County. No wells are inventoried in this bedrock unit (table 12). Higher yields would likely be obtained from sandstone and dolomite bedrock units exhibiting extensive fracturing and joint systems with a relatively high degree of interconnection.

**Undifferentiated Silurian Rocks II (Sbs)**

The **Sbs** units include the Bloomsburg Formation, consisting of predominantly red with some green and gray sandstone, siltstone and minor conglomeratic sandstone; Gymard Quartzite; Otisville Shale; and Shawangunk Formation consisting of light-gray to dark-gray, medium to coarse grained sandstone and conglomerate with some siltstone and shale. The unit occurs on the western flank of the Shawangunk Mountain in western Orange County. There are minimal data presently inventoried to indicate the yield potential of the bedrock unit. The area where the unit occurs is of small areal extent; rugged topography and very rural with minimal development. The coarse-grained units consist mostly of sandstone and conglomerate and exhibit low to moderate primary permeability based on the porosity of the bedrock units, and secondary permeability caused by the presence of interconnected fractures can be low to high. The rock units are brittle, forming numerous open fractures. The unit is highly resistant to weathering. Water is contained in fractures, joints, bedding planes, contacts and other secondary openings in bedrock units.

The yield potential in the **Sbs** unit is projected to range from 25 to 150 gpm at favorable well sites. Table 12 indicates an average and median yield of 28 gpm and 30 gpm, respectively, and yields ranging from 12 to 35 gpm for this unit. The higher yield would likely be obtained from the sandstone and conglomerate units exhibiting extensive fracturing and joint system with a relatively high degree of interconnection.

**Martinsburg Formation (On)**

The name of the dark-gray shale unit underlying the central region of Orange County was reported to be the Normanskill Formation by Offield (1967). Re-evaluation of the characteristics of the unit by Jaffe (1973) identified the prevalent shale unit in Orange County as the Martinsburg Formation (Landing, 1994). According to the later interpretation, the Martinsburg Formation consists of the following (Jaffe, 1973):

- Penn Argyl Member - shale (Offield's Snake Hill Member)
- Ramseyburg Member - graywacke and sandstone (Offield's Austin Glen Member)
- Bushkill Member - shale and siltstone - (Offield's Mt. Merino Member)

The Penn Argyl Member, consists of dark gray to grayish-black calcareous shale. The Ramseyburg Member comprises graywacke and sandstone. The Bushkill Member consists of dark gray calcareous shale and siltstone. These bedrock units occur in the central region of Orange County. There is a significant amount of data presently inventoried on the yield potential of the bedrock aquifer.

The fractures exhibited in the fine-grained bedrock units are few and mostly closed fractures. These units are resistant to weathering. The unit likely exhibits low permeability based on the porosity of the bedrock unit, and secondary permeability caused by the presence of interconnected fractures can be low to moderate. Water is contained in fractures, joints, bedding planes, contacts and other secondary openings in the bedrock units. Well MG-14 (Map 2-17) drilled for the Village of Maybrook is reported to yield as high as 225 gpm. Several additional wells completed in this unit yield between 100 and 200 gpm.

Wells drilled at favorable well sites would likely yield between 25 and 100 gpm. Table 12 indicates average and median yields of 56 gpm and 30 gpm, respectively, with yields ranging from 3 to 225 gpm for this unit. Higher yields would likely result from moderately to highly fractured units with a relatively high degree of interconnection.

**Wappinger Group (OEw)**

**OEw** consists of dark gray to gray-black limestone dolomite units. In Orange County, the Wappinger Group consists of the following formations:

- Balmville Limestone - limestone
- Rockdale Formation - limestone, dolomite
- Halcyon Lake Dolostone - calcareous, dolomite, cherty
- Briarcliff Dolostone - dolomite
- Pine Plains Formation - dolomite, shale
- Stissing Formation - dolomite, shale

The unit occurs in southern and eastern portions of Orange County. There is a significant amount of data on wells completed in this unit. Well GT-43 (Map 2-32) is reported to yield as high as 285 gpm. Several additional wells yield between 100 and 200 gpm.

Similar to other carbonate units, the unit is relatively brittle and, under deformation stress, forms numerous open fractures. The limestone and dolomite units are relatively soluble. Consequently, the fractures are frequently widened by dissolution. The carbonate units likely exhibit low to moderate permeability based on the porosity of the bedrock unit and secondary permeability caused by the presence of many interconnected fractures and dissolution cavities can be low to high. Water is contained in fractures, joints, bedding planes, solution cavities and other secondary openings in the bedrock units.

Table 12 indicates the wells inventoried have average and median yields of 100 gpm and 80 gpm, respectively, and yields range from 20 to 285 gpm. Wells drilled at favorable well sites would likely yield between 50 and 300 gpm. Wells completed in the limestone units in this bedrock unit would likely yield in the higher range estimate due to enlargement of fractures, joints and bedding planes in the formation by solution activity.

**Igneous and Metamorphic Bedrock**

Igneous and metamorphic bedrock units exist in the southeastern portions of Orange County (figure 13). Igneous rocks are formed from molten material deep within the earth's crust. As the molten material approached the earth's surface, it became cool and solidified. In Orange County, the coarse texture granite-type igneous bedrock units are not porous and have little primary permeability.

Metamorphic bedrock includes igneous and sedimentary rocks that have been altered by heat and pressure within the earth's crust. In Orange County, a majority of the metamorphic bedrock consists of gneiss bedrock units, which also have little primary permeability. Both igneous and metamorphic bedrock units exhibit low to moderate secondary permeability caused by crevices, fractures and faults and weathering (figure 15). In general, igneous and metamorphic bedrock units are not considered prolific aquifers, exhibiting low to moderate water-bearing properties.

**Undifferentiated Gneiss and Granite, Granitic Gneiss (Mu and Mgu)**

The undifferentiated gneiss, **Mu**, and undifferentiated granite, granitic gneiss, **Mgu**, are metamorphic rocks of Precambrian Age. These rock types include gneiss, granite, amphibolite and calcsiliate rocks. The bedrock units are undifferentiated for the mapping conducted by LBG, however, subdivided on the basis of mineral composition by Fisher et al., 1970.

The undifferentiated granite and gneiss occur in southwestern and southeastern extremes of Orange County (figure 13). There are significant data presently inventoried to indicate the yield potential of these units in Orange County.

The general appearance of most of these units shows light and dark minerals, a randomly speckled appearance exhibited by granite-type rocks and layered in gneiss. The granite has a coarser-grained appearance and the gneiss a fine to medium-grained appearance. These granite and gneiss units are highly resistant to weathering and to erosion from previous glaciation. The erosion resistance is reflected by the more rugged topography and higher altitudes in the areas underlain by these rock types.

The original solid structure of granite and gneiss bedrock units are generally unfavorable for storage or transmission of ground water. However, previous tectonic displacement and metamorphic changes to the granite and gneiss bedrock units have enhanced the potential usefulness of these bedrock units in Orange County for water supply. These resultant changes include jointing, fracturing and weathering of the bedrock units. Over long intervals of geologic time, the hydraulic capability of the granite and gneiss bedrock units improves so it can store and transmit ground water in fractures, joint systems and weathered zones. The porosity of weathered zones can be significant and increase the porosity by as much as 35 percent (Driscoll, 1986) in the upper portion of the bedrock unit.

In general, granite and gneiss exhibit very low primary permeability, and secondary permeability caused by the presence of interconnected fractures can be low to moderate in these units. Water is contained in fractures, joints, faults and weathered zones. Well WT-15 (Map 2-52) is reported to have an original yield of 100 gpm. Table 12 indicates average and median yields of 46 gpm and 38 gpm, respectively, and yields range from 10 gpm to 100 gpm. Wells drilled at favorable well sites would likely yield between 25 gpm and 75 gpm. High yields are obtained from highly fractured and jointed units with a relatively good degree of interconnection.

**Calcite and Dolomite Marble (Mb)**

**Mb** consists of white-whitish gray calcite and dolomite marble. The unit occurs in small areas in southern Orange County. There are no data presently inventoried to indicate the yield of wells completed in this unit in Orange County. The area in Orange County where this unit occurs is of small areal extent and very rural with little to no development.

The metamorphism of limestone and dolomite forms marble. The marble units exhibit similar characteristics to carbonate units, however, no solution cavities are reported. The marble bedrock units likely exhibit low primary permeability based on the porosity of the bedrock units; and secondary permeability caused by the presence of many interconnected fractures can be low to high. The bedrock unit is less resistant to erosion than adjacent bedrock rock units and, as a result, occurs in the valley areas in southern Orange County (Maps 2-46 and 2-47). The unit is brittle and under deformational stress forms numerous open fractures. Water is contained in many interconnected fractures, joints and other secondary openings in the bedrock units. Wells completed in this bedrock aquifer at favorable well sites may be expected to yield from 50 to 150 gpm. Table 12 indicates no wells are inventoried in this bedrock unit, however, wells completed in the Stockbridge Formation consisting of marble in Putnam and Westchester Counties, similar to the marble in Orange County, yield 50 to 150 gpm at favorable well site locations.

## EXPLORATION METHODS FOR DEVELOPING HIGH-YIELDING BEDROCK WELLS

The demand for ground water in Orange County has increased dramatically from the 1970's to the 1990's and will likely continue to increase. The demand for ground water developed from the bedrock aquifers in the County has also increased dramatically. High-yielding wells completed in the bedrock aquifer can be located utilizing available geologic maps, combined with additional mapping interpretation techniques. The yield potential of wells completed in the bedrock aquifer depends on several factors. Most important among these are the following (Grossman, 1957):

- occurrence, spacing, width and interconnection of joints, fractures, faults and other secondary openings;
- characteristics of overlying unconsolidated deposits;
- topographic position; and
- type of rock.

Maps prepared for the GWRS to designate favorable locations for development of high-yielding bedrock wells utilized base maps prepared by the NYSDOT for the respective USGS quadrangle maps covering Orange County. The GWRS maps include the following layers and are the third set of maps presented at the end of this report:

- topography;
- bedrock geology, including faults and geologic contacts;
- bedrock wells inventoried;
- sand and gravel deposits;
- State and Federal wetlands;
- fracture-traces and lineaments; and
- target locations favorable for development of high-yielding bedrock wells.

All of the above layers combine to provide a useful tool for targeting locations for development of high-yielding bedrock wells. The major techniques for ground-water exploration of high-yielding bedrock wells are discussed from the viewpoint of the professional hydrogeologist.

Map Set 3 includes the mapping layer of the sand and gravel deposits with the exception of the sand and gravel deposits at land surface, vertical thickness unknown. The large digital file size of this mapping layer, when combined with the other mapping layers, exceeded the memory capacity of the computer utilized by OCWA. However, Map Set 1 can be reviewed to determine which of the fracture traces and faults on Map Set 3 are overlain by the sand and gravel deposits at land surface, vertical thickness unknown (Map Set 1).

**Topography**

The topography of Orange County is influenced by the geologic material in the study regions. The region's topography and geologic material influence the location of ground water. Consequently, topography affects the yield of bedrock wells. Well yields are generally highest from bedrock wells situated in valleys, and the yields decrease as elevation increases in hilly and mountain regions (Simmons et al., 1961) (Grossman, 1957) (Driscoll, 1986) (Maslansky and Rich, 1984). Studies conducted in the adjacent Dutchess and Putnam Counties indicate yields greater than 1.3 to 3 times for wells completed in valleys compared to hilltop wells (Grossman, 1957) (Simmons et al., 1961). A dramatic increase in yield was noted in wells completed in valleys in undifferentiated granite and gneiss as compared to wells completed in the same unit in hilltops (Simmons et al., 1961).

The water table is generally closer to the land surface in valleys than on adjacent hills. Therefore, wells in valleys likely penetrate a greater saturated geologic unit than on hills and would likely yield more water. On hills, the expansion of the cone of depression from a pumping well is restricted to the topography. However, in valleys, the cone of depression may extend to the larger area of the valley floor and possibly the adjacent hills.

**Sand and Gravel Deposits**

Bedrock wells drilled in valleys are reported to have higher yields, not only because of favorable topography location, but also because the bedrock unit is more permeable and more likely to be overlain by permeable overburden material (Simmons et al., 1961). Mapping of sand and gravel aquifers and permeable overburden material to target locations for developing high-yielding bedrock wells is a useful tool (Map Sets 1 and 3). Permeable sand and gravel material and saturated sand and gravel aquifer material readily recharge the underlying bedrock aquifer units. Bedrock wells drilled in areas underlain by permeable and saturated sand and gravel aquifer material typically have a higher than average yield capacity. Wells drilled in areas underlain by saturated sand and gravel aquifers in Orange County are reportedly the highest-yielding bedrock wells in the County. Examples of high-yielding bedrock wells completed in areas underlain by permeable sand and gravel material and saturated sand and gravel aquifers are as follows:

| Well identification | Map location | Reported yield |
|---|---|---|
| MT-20 | 1-42 | 250 |
| MW-26 | 1-42 | 300 |
| MW-38 | 1-49 | 171 |
| MT-51 | 1-42 | 185 |
| WB-9 | 1-42 | 200 |
| WB-10 | 1-42 | 300 |
| CT-2 | 1-41 | 100 |
| CT-16 | 1-41 | 100 |
| CT-23 | 1-40 | 100 |
| MS-5 | 1-45 | 100 |
| BG-3 | 1-34 | 200 |
| MG-1 | 1-10 | 100 |
| MG-12 | 1-17 | 190 |

| Well identification | Map location | Reported yield |
|---|---|---|
| MG-18 | 1-9 | 125 |
| MG-5 | 1-17 | 100 |
| CF-6 | 1-2 | 135 |
| GT-59 | 1-32 | 100 |
| GT-30 | 1-32 | 102 |
| DP-11 | 1-9 | 120 |
| DP-10 | 1-14 | 100 |

The average yield of the 20 wells inventoried above is 154 gpm, and the above list includes several of the highest-yielding bedrock wells in the County.

**Geologic Maps**

Geologic maps (Map Sets 2 and 3) include geologic bedrock units, faults, geologic contacts, unconformities and wells completed in bedrock units. These data indicate the bedrock rock types, distribution of the geologic units and structures. Fault lines, geologic contacts and unconformities between the bedrock units are mapped from available data.

Faults are fractures or a zone of fractures along which there has been a significant displacement of a bedrock unit. The majority of faults exhibited in the bedrock units in Orange County trend northeast. Many exist in whole or part in valley plain areas. Significant faulting has taken place in the southeastern portion of the County, particularly in the metamorphic rock units. The location of the faults are shown on figure 16. The majority of faults and significant regional fault zones in Orange County are steep vertical faults. Large vertical displacements can take place along faults that may produce significant widening of cracks and rubble zones. The highly-fractured fault zones are highly permeable and are optimal for targeting high-yield bedrock well locations (Driscoll, 1986) (Freeze and Cherry, 1979). However, depending on the nature of the bedrock, some fault zones are filled with clayey, crushed material known as gouge, resulting in relatively low permeability. The following are two examples of wells targeted on fault zones in Orange County.

Well MT-45 (75 gpm) for the Village of Harriman and Wells MT-48 (160 gpm) and MT-51 (185 gpm) for Harriman Business Park, located on Map 2-42, were drilled by LBG to target high-yielding wells on or adjacent to the fault where the wells are located or adjacent to. The yield of the three wells indicate this fault zone is highly fractured and permeable.

Wells WB-21 (9 gpm), WB-22 (60 gpm) and WB-20 (120 gpm) (Map 2-42) drilled for Highland Lakes Estate under the supervision of LBG were located to target high-yielding wells on the fault. Although WB-22 (60 gpm) and WB-20 (120 gpm) were successful well sites, the yield of WB-21 (9 gpm) is considerably lower than the yield of the other two wells drilled. It is likely that during the drilling of WB-21, the fault zone was not encountered.

Unconformities are stratigraphic features in bedrock units. An unconformity is a surface that represents an interval of time during which deposition was negligible or nonexistent, and during which the surface of the existing rocks was weathered, eroded and/or fractured (Freeze and Cherry, 1979). Often the underlying rocks were warped or tilted prior to the deposition of new sediments over that unconformity (ibid). Similar to faults, unconformities commonly exhibit highly-weathered and fractured zones and are optimal for targeting high-yielding bedrock wells. The location of the unconformities are shown on Map Sets 2 and 3. The majority of the unconformities shown on the respective maps are steep vertical unconformities and coincide with geologic contacts. An example is the unconformity between the Martinsburg Formation (On) and the Wappinger Group (OEw) shown on Map 2-38 which coincides with geologic contact between these two bedrock units.

The following are two examples of wells targeted on unconformities in Orange County.

Due to the limited area/extent of the unconformities in the County, only few wells are completed on or adjacent to the unconformities. During the drilling of test wells on Houston Farm, the unconformity shown on Map 2-32 was targeted by LBG to develop high-yielding wells. Well GT-38 and GT-39 yielded 60 gpm and 87 gpm, respectively, during pumping tests. The unconformity at this location is moderately to highly weathered and fractured. Additional wells were drilled for Kings Estates on the unconformity shown on Map 2-48. The Wells WT-24, WT-25, WT-26 and WT-27 (Map 2-48) yield 20 gpm, 50 gpm, 40 gpm and 65 gpm, respectively. Prior to drilling, these four wells on the Kings Estates site, three wells were drilled at locations farther away from the unconformity and these three wells yielded less than 5 gpm. Wells drilled on or adjacent to the unconformity have significantly greater well yields in this locality.

**Fracture-Trace Analysis**

One of the techniques employed in evaluating the potential for developing high-yield water wells from the bedrock aquifers in Orange County is fracture-trace analysis. The fracture-trace maps include the delineation of faults, fracture-trace joint systems, old river and stream courses and major unconformities. These features frequently are indications of fractured or weathered zones within the bedrock and their identification is a useful tool in selecting favorable well sites (figure 15).

Fracture zones can sometimes be located by inspecting geologic and topographic maps and by studying stereographic aerial photographs of the study area. The surface expressions of bedrock fractures often appear on aerial photographs as a linear feature (less than one-mile long) and lineaments which are significant linear traces longer than one mile (Driscoll, 1986). Many streams, valleys and topographic depressions tend to follow the fault, fracture zones and similar geologic features (figure 15). In addition, changes in vegetative densities and configurations of natural ponds and lakes serve to aid in fracture mapping.

Higher-yielding bedrock wells would likely be developed on more significant lineaments in the region and most likely represent possible fractures or fault zones in bedrock units. However, linear traces less than one mile are also useful to target locations for high-yielding bedrock locations. Higher yields are generally found at the intersection of two or more fracture-trace patterns. Bedrock test well locations utilizing the fracture-trace analysis method should be checked in the field to confirm that the perceived fracture traces are natural and not the result of manmade artifacts.

Fracture-trace analysis included the review of published information referenced on the respective map, as well as analysis of aerial photographs and topographic maps. LBG compiled the data from the Preliminary Brittle Structure Map of New York, Lower Hudson Sheet (Isachsen and McKendree, 1977) to the NYSDOT base maps for the fracture-trace analysis of the County. The Preliminary Brittle Structure Map (Brittle Structure Map) includes detailed mapping of faults, shear zones, and fracture traces (lineaments) and major unconformities of the Lower Hudson region, including Orange County. The Brittle Structure Map includes compilation of faults and significant structural features identified from published geologic maps, including an evaluation utilizing Landsat 1 multi-spectral scanner imagery, Skylab color-infrared transparencies and stereoscopic analysis high-altitude (U2) and color infrared transparencies.

LBG also conducted a fracture-trace analysis using low altitude stereo-pair aerial photographs with a scale of 1 inch = 1,400 feet and topographic maps with a scale of 1 inch = 2,000 feet (USGS Quadrangle Maps). LBG obtained a complete file of aerial photographs for Orange County (1970's) with a 1 inch = 1,000-foot scale, and these photographs were utilized to provide more detail in required areas.

LBG compiled fracture-trace analysis previously conducted from regional studies for the Town of Woodbury, Village of Harriman/Village of Kiryas Joel (Town of Monroe) and additional studies for community water-supply development in Orange County. These data were compiled onto the fracture-trace base maps. The location of the fracture traces are shown on figure 16. Similar to the faults, the majority of the fracture traces are steep, vertical fractures trending northeast.

Fracture-trace analysis is a method which has proven to be highly effective in the location of high-yielding bedrock wells. Fracture-trace analysis has resulted in greatly improving the development of high-yielding bedrock wells. The following is an abstract from a technical paper prepared by LBG, written by Robert C. Luhrs, entitled, "A Comparison of Well Yields Based on Fracture-Trace Analysis To Regional Norms".

*Well yields for randomly located wells in crystalline bedrock are a function of the ability to intersect water-bearing fractures. Yields for more than 500 wells located in Philipstown, New York were plotted on probability paper. Results show that well yields in the town range from 0 to 60 gallons per minute (gpm) for the rocks of the Hudson Highlands, a region of Precambrian high-grade metamorphic gneiss and amphibolites. The average well yield for the region, located at the 50th percentile on the probability plot, is about 9 gpm.*

*These yields were compared to eight wells drilled in the same rock unit for use in a community water supply for a 2,500-acre development. The wells completed as part of this ground-water exploration program were located based primarily on fracture-trace analysis, resulting in sustainable well yields ranging from 26 to 230 gpm. The lowest-yielding well in this program had a sustainable yield which was greater than 90 percent of the wells previously completed in the town. These data indicate a significant difference in well yields between randomly located wells and those located by fracture-trace analysis.*

*This study quantifies historical yields of wells located in the town and shows the potential for targeting well sites to achieve higher yields by applying sound hydrogeologic techniques.*

**Federal and State Wetland Delineation**

Federal and State wetland delineations are mapped to indicate wetland areas which would likely recharge underlying bedrock units and possibly indicate fracture zones in the underlying bedrock. Although the majority of the unconsolidated material underlying a wetland consists of low-permeable silt or clayey material, the unit is usually saturated and readily recharges underlying permeable bedrock units. Therefore, wetlands of large areal extent may afford excellent recharge to the underlying permeable bedrock aquifers. Fracture traces and faults likely follow large, elongated wetland patterns (Map 3-15). The fracture zones in bedrock underlying wetlands are expected to be more deeply weathered and decomposed.

The following are examples of wells targeted in wetland areas by LBG. Wells CT-2 and CT-3 (Map 3-41) each have reported yields of 100 gpm, respectively. Wells MT-48 and WB-10 (Map 3-42) have reported yields of 160 gpm and 300 gpm, respectively.

Drilling in a buffer zone (100 feet from wetland) to a wetland may require applicable permits. Federal, State and Town (if applicable) wetland regulations should be reviewed prior to drilling in a buffer zone to a wetland in

Orange County.

**Designation of High-Yielding Bedrock Well Locations**

LBG has utilized the fracture-trace analysis and pertinent hydrogeologic data to locate possible locations for development of high-yielding bedrock wells. Fractures are the main water-bearing zones in bedrock aquifers, and higher yields can be expected from wells drilled in densely fractured and faulted areas.

Fracture-trace maps were interpreted with additional layers of topography; bedrock geology, including faults, geologic contacts and wells inventoried; sand and gravel deposits; and State and Federal wetlands to locate favorable locations to target high-yielding bedrock wells. The favorable locations were identified in areas with one or more of the following features:

- fault zones;
- intersection of fault zones and lineations, or intersection of two or more lineations;
- unconformities;
- bedrock overlain by permeable sand and gravel and/or saturated sand and gravel aquifer material;
- bedrock overlain by large wetland areas;
- locations in valley plains; and
- in proximity to streams, ponds, lakes and/or drainage systems.

Locations which exhibit more than one of the above features are considered to be the most promising locations for drilling high-yielding bedrock wells. These features frequently are indications of fractured or weathered zones within the bedrock, are a useful tool in identifying major fracture conduits for ground-water recharge and aid in selecting favorable well sites to develop high-yielding bedrock wells.

On the maps prepared for the GWRS, no significant faults or fracture lineations may be indicated in some areas, or no faults or lineations intersected, or both. However, further evaluation of aerial photographs may indicate smaller linear features not mapped in these areas which would be favorable for targeting a possible high-yielding bedrock well location.

Proposed areas for further exploration should consider favorable geologic data, locations near existing well fields and the municipal distribution system, regulatory requirements, existing and potential ground-water contamination areas and waste-water discharge locations. The above data were completed on the respective fracture-trace maps of the County and favorable target locations for development of high-yielding bedrock wells designated. Exploration for water from bedrock sources is an inexact science in which not all test wells can be expected to produce enough water for public use.

## WATER QUALITY

Water quality is an important consideration in the development of ground water because ground water is a major drinking water source in Orange County. Almost all of the public ground-water supplies currently meet water-quality standards promulgated by the NYSDOH, Title 10 NYCRR Chapter 1 State Sanitary Code, Subpart 5-1.50 (table 13). The ground water beneath more than 90 percent of the land in Orange County is considered to be suitable for drinking without significant treatment. The quality of the ground water in each major aquifer in Orange County is generally good to excellent and suitable for most uses. The mineral contents of ground water is influenced by the rock through which it flows, and the mineral concentrations in water from some aquifers has been elevated by the contact of the ground water with the aquifer unit. Water-quality analyses were evaluated for the aquifer units in Orange County and the median concentration of certain parameters were used to calculate statistically the variations in chemical quality for the respective aquifer units (table 14).

**Dissolved Solids**

The total concentration of dissolved minerals in a water sample is a general indication of the suitability for any particular use. Water high in mineral matter is generally not suitable for drinking water or industrial use. Water that contains less than 500 mg/l (milligrams per liter) of total dissolved solids is generally satisfactory for drinking water and industrial use.

Frimpter (1972) indicated the concentration of dissolved solids ranged from 42 to 1,470 mg/l, however, only two samples exceeded the 500 mg/l limit. Table 14 indicates the dissolved solids concentration in all three aquifer types range from 44 mg/l to 610 mg/l, and only five wells exceed the 500 mg/l limit. Water samples from the sand and gravel aquifer indicate the highest median dissolved solids concentration of 293 mg/l, with a range from 130 mg/l to 590 mg/l. Only one sample well inventoried in the sand and gravel aquifer produced more than 500 mg/l dissolved solids. The water-quality data for the sedimentary bedrock aquifer indicate a median dissolved solid concentration of 180 mg/l, with a range from 44 mg/l to 610 mg/l. Only three wells inventoried in the sedimentary aquifer unit produced more than 500 mg/l dissolved solids. Similarly, the data for the undifferentiated granite and gneiss bedrock aquifer indicate a median dissolved solid concentration of 180 mg/l, with a range of 80 mg/l to 560 mg/l, with only one well producing more than 500 mg/l dissolved solids.

**Iron and Manganese**

Iron and manganese are considered the most troublesome constituents in ground water in Orange County. Concentrations of iron and manganese greater than 0.3 mg/l and 0.05 mg/l, respectively, may produce distasteful water and stain plumbing fixtures, glassware and laundry. Maximum concentration levels (MCL) required by the NYSDOH and shown on table 12 for iron and manganese are 0.3 mg/l and 0.3 mg/l, respectively, and the combined concentration of iron and manganese may not exceed 0.50 mg/l. Manganese presents much less of a problem than iron; manganese concentrations in Orange County are commonly below 0.30 mg/l. Median concentrations of iron and manganese (table 13) are significantly lower than the MCL required by the NYSDOH (table 12). For the sand and gravel aquifers in Orange County, about 37 percent of the wells inventoried exceeded the recommended standard for one or both constituents. Manganese presented more of a problem than iron in the sand and gravel aquifer wells inventoried. The median concentrations and ranges of iron and manganese in the sand and aquifer units reported on table 13 are 0.05 mg/l ( < 0.01 to 18.0 mg/l) and 0.20 mg/l ( < 0.01 to 1.3 mg/l), respectively.

The median concentrations and ranges of iron and manganese in the undifferentiated granite and gneiss aquifer units reported are < 0.05 mg/l ( < 0.01 to 0.91 mg/l) and 0.01 mg/l ( < 0.01 to 0.10 mg/l), respectively (table 13). About 30 percent of undifferentiated granite and gneiss bedrock wells inventoried exceeded the recommended standards for iron only.

The median concentration and ranges of iron and manganese in the sedimentary bedrock aquifer reported are 0.12 mg/l ( < 0.03 to 19.0 mg/l) and 0.05 mg/l (0.01 to 1.75 mg/l), respectively (table 13). About 22 percent of the sedimentary bedrock wells inventoried exceed the recommended standard for one or both constituents.

Elevated concentrations of iron most commonly occur in the wells completed in undifferentiated granite and gneiss bedrock units, whereas elevated concentrations of manganese are more common in wells completed in sand and gravel aquifers in Orange County. Iron presents less of a problem in the shale unit (Martinsburg Formation) in Orange County. However, the carbonate aquifers, consisting of limestone and red conglomerate bedrock units, commonly yield elevated iron concentrations. Wells completed in Undifferentiated Lower Devonian and Silurian Rocks (Ds) and Undifferentiated Hamilton Group (Dh) in southeastern Orange County commonly contain iron-bearing water. A majority of the wells developed for the Village of Kiryas Joel completed in the Ds and Dh bedrock units produce elevated levels of iron and manganese, however, iron presents more of a problem. Wells developed for the Village of Kiryas Joel have reported concentrations of iron ranging from 0.15 mg/l to 13 mg/l.

Certain bacteria in ground water exhibit large growth plumes in water rich in iron. These iron bacteria can become a serious nuisance and clog well screens and pipes in the distribution system. This is a particular problem for wells completed in the Wallkill River sand and gravel aquifer for the Town of Wallkill.

When the iron and manganese content of water is naturally high, treatment for removal is the ultimate solution. Practices common in Orange County are use of sequestering agents for low to moderate concentrations of iron and flocculation-filtration treatment for high concentrations of iron.

**Hardness**

The term "hardness" is applied to the soap-neutralizing power of water. Hardness is commonly related to the water source and the different amounts of soap needed to make suds and the formation of insoluble scum or scaling on water fixtures and pipes. Hardness in water is caused primarily by dissolved calcium and magnesium. Generally, soft water requires smaller amounts of soap to produce suds and little to no scum or scaling results. However, moderate to very hard water requires larger amounts of soap to produce suds and insoluble scum or scaling buildup is common. Hard water presents more of a nuisance than a health risk.

Hardness is reported on table 13 as total hardness and calcium hardness. Total hardness is usually 2.5 times greater than calcium hardness of most ground-water samples.

Calcium and magnesium, which contribute to the hardness of water, are two principal elements that comprise the majority of the sedimentary bedrock units which exist in Orange County. Broken-up sedimentary bedrock is also the major constituent of the unconsolidated material which forms the sand and gravel aquifers in Orange County. Consequently, water produced from the sand and gravel aquifers and sedimentary bedrock units (table 13) are considered hard to very hard. The water from the undifferentiated granite and gneiss is also considered hard. Frimpter (1972) reported the hardness of 50 samples in Orange and Ulster Counties ranged from 23 mg/l to 1,470 mg/l and averaged at 142 mg/l. Hardness of water is commonly described as: (Frimpter, 1972)

| **Degree of Hardness** | **Total Hardness** |
|---|---|
| Soft | 0 to 60 mg/l |
| Moderately Hard | 61 to 120 mg/l |
| Hard | 121 to 180 mg/l |
| Very Hard | over 180 mg/l |

Table 13 indicates the total hardness, calcium hardness and ranges are highest for sand and gravel aquifer units. Although the median concentration of calcium hardness for undifferentiated granite and gneiss (100 mg/l) is slightly higher than the sedimentary bedrock units (87 mg/l), the sedimentary bedrock unit commonly produces harder water than the undifferentiated granite and gneiss.

Treatment for hard water is easy and inexpensive. Water softeners are commonly installed in homes to soften water for domestic use. Hardness of water is dramatically reduced by water softeners which replace the calcium and magnesium ions with sodium ions. This process, however, increases sodium concentrations in the effluent water 13 mg/l to 17 mg/l (Frimpter, 1972). In addition, waste brine from the water softeners is commonly disposed of in underground septic systems, discharging high concentrations of sodium chloride into the ground water. Consequently, elevated concentrations of sodium and chloride in water supplies from wells in areas where brine from water softeners is disposed of in underground septic systems is a common problem.

Consideration should be given by town and County regulatory agencies to prohibit the disposal of waste brine from water softeners on the land surface or into underground septic systems, particularly in high-density suburban areas and areas overlain by sensitive aquifers.

Requirement of replaceable exchange water softener cartridges would eliminate the disposal of waste brine into ground-water resources. Replaceable exchange water-softener cartridges are regenerated offsite by water softening and conditioning service contractors. The waste brine is properly disposed of by the contractor.

**Sodium and Chloride**

Sodium and chloride, the constituents of common salt, occur naturally in all ground water at relatively low concentrations. Sodium and chloride are present in ground water in aquifers in Orange County from previous salt water oceanic episodes millions of years ago, which covered most of the earth's crust. Sodium and chloride leach from rocks and sediments and remain in solution. A majority of sedimentary bedrock units were deposits in past oceans, therefore, they exhibit higher concentrations of sodium and chloride than granite and gneiss bedrock units.

The MCL required by the NYSDOH on table 12 for chloride is 250 mg/l. Table 12 indicates the maximum recommended concentration for sodium is 270 mg/l. The NYSDOH must be notified if sodium levels in public water supplies exceed 20 mg/l, and consumers must be notified if the sodium levels exceed 270 mg/l.

Elevated concentrations of chloride cause distasteful water and result in increased corrosivity. Elevated concentrations of sodium can cause water to be very soft causing excessive foaming, affects plant growth during irrigation and may affect persons on low sodium diets with some circulatory diseases.

Table 13 indicates the median concentrations of sodium and chloride are significantly lower than the recommended maximum concentrations for sodium and chloride required by the NYSDOH (table 12) for the granite and gneiss aquifer and the sedimentary bedrock aquifer. The median concentrations and ranges reported for sodium and chloride in the sand and gravel aquifer unit on table 13 are 23 mg/l (5.4 mg/l to 70.6 mg/l) and 25 mg/l (<2.0 mg/l to 512 mg/l), respectively. The median sodium concentration reported at 23 mg/l marginally exceeds the recommended MCL of 20 mg/l. About 55 percent of the wells completed in the sand and gravel aquifer units exceed the 20 mg/l notification guideline, and no wells inventoried exceeded the 270 mg/l recommended MCL required by the NYSDOH for sodium. Only one well inventoried for the sand and gravel aquifers reported an extremely high chloride concentration of 512 mg/l, which exceeds the MCL for chloride (250 mg/l) required by the NYSDOH.

The median concentrations and ranges of sodium and chloride (table 13) in the undifferentiated granite and gneiss aquifer wells reported are 15 mg/l (7.9 mg/l to 53 mg/l) and 19 mg/l (<2.0 mg/l to 160 mg/l), respectively. About 25 percent of the wells completed in the undifferentiated granite and gneiss unit exceed the 20 mg/l notification guidelines and no wells inventoried exceed the 270 mg/l recommended MCL required by the NYSDOH for sodium. No wells inventoried exceeded the MCL for chloride.

The median concentration and ranges of sodium and chloride (table 13) in the sedimentary bedrock aquifer wells reported are 10.8 mg/l (2.4 mg/l to 128 mg/l) and 5.8 mg/l (<2.0 mg/l to 160 mg/l), respectively. About 31 percent of the wells completed in the sedimentary bedrock aquifer exceed the 20 mg/l notification guideline and no wells inventoried exceed the 270 mg/l recommended MCL required by the NYSDOH for sodium. No wells inventoried exceeded the MCL for chloride.

The usual concentration of sodium and chloride is about 10 mg/l ($\pm$4 mg/l) and 12 mg/l ($\pm$4 mg/l), respectively, in all aquifers. However, elevated concentrations of sodium and chloride in Orange County are most commonly from deicing road salt and disposal of brine in underground septic systems from water softeners. Sand and gravel aquifers are most susceptible to salt contamination and are likely to be further affected in the future. The sand and gravel aquifers indicate a significantly higher concentration of sodium and chloride levels as compared to the two bedrock aquifer types.

Treatment of well-water supplies for high sodium and chloride concentrations is usually cost prohibitive. Most are abandoned and alternate sources developed away from the contaminated areas. In multiple well water-supply systems, water from wells with higher sodium and chloride can be blended with water from wells with lower concentrations to reduce the levels of sodium and chloride from the well source with the elevated concentrations.

**Sulfate**

The source of sulfate is the solution of gypsum, and other sulfate minerals, which occur more commonly in sedimentary bedrock units in Orange County. The median and range of sulfate concentrations as reported on table 13 for sand and gravel aquifers, differentiated granite and gneiss aquifers and sedimentary aquifers are 30 mg/l (13 mg/l to 155 mg/l), 13 mg/l (<10.0 mg/l to 30 mg/l) and 22 mg/l (<5.0 mg/l to 48 mg/l), respectively. The reported median and ranges of sulfate concentrations for all three aquifers are significantly below the MCL (250 mg/l) required by the NYSDOH. Concentrations of sulfate close to or greater than 250 mg/l makes water taste bitter and may act as a laxative.

**Nitrate**

Nitrogen in ground water, unlike other elements, is not derived from mineral matter but rather results from organic material. Nitrogen enters the ground-water sources from nitrogen fixed to soils by certain plants, from decomposing plant debris, animal wastes and nitrate fertilizers. Additional nitrogen may enter the ground from sewage discharge (surface and underground). Some industrial waste chemicals also contain high nitrogen concentrations. Natural nitrate concentrations in ground water range from 0.1 mg/l to 10 mg/l (Driscoll, 1986), as nitrate ion.

High nitrate concentrations, or nitrate concentrations showing increasingly elevated levels over time, present a major concern. High concentrations originate from either direct discharge of contaminated surface water into a surface-water supply or well, or recharge by contaminated surface water. Elevated nitrogen in a ground-water source may indicate direct recharge from underground septic systems, livestock waste, sewage lagoons and from overuse of fertilizers high in nitrogen in highly-permeable soils. In addition, high nitrate concentrations are used as warning indicators that the water supply should be tested for harmful pathogenic bacteria which may accompany contamination from these nitrate sources (Driscoll, 1986).

Nitrate in concentrations greater than 45 mg/l is undesirable in domestic water supplies because of the potential toxic effects in infants, whereas young children and adults are not affected. The MCL for nitrate is 10 mg/l as required by the NYSDOH (table 12).

The median nitrate concentration in ground water is $<1.0$ mg/l in all three aquifers (table 14). No wells inventoried were reported to produce water with more than 10 mg/l of nitrate. Frimpter (1972) reported nitrate concentrations in 17 wells in Orange and Ulster Counties ranging from 0.0 mg/l to 5.6 mg/l. Table 14 indicates the analysis of 80 wells in Orange County have nitrate concentrations ranging from $<0.1$ mg/l to 3.3 mg/l.

**Turbidity**

Turbidity refers to solids and organic matter that do not settle out of water. Ground water is rarely turbid, usually less than 1 NTU (nephelometric turbidity unit). Eliminating turbidity not only improves the aesthetic quality of the water, it also helps remove contaminants that cling to suspended solids and inhibits the formation of trihalomethane after chlorination treatment by removing organic precursor substances. An MCL has been established for turbidity because solids in water can interfere with disinfection processes and microbiological determinations (Driscoll, 1986). Table 13 indicates the MCL for turbidity is 1 NTU as required by the NYSDOH. However, the NYSDOH may establish a monthly average entry point turbidity MCL of 5 NTU based on justification submitted by the supplier of water as outlined in State Sanitary Code Subpart 5-1.

Table 14 indicates the median concentrations of turbidity are significantly lower than the MCL of 1 NTU for the sand and gravel aquifers and undifferentiated granite and gneiss bedrock units. However, the median concentration of turbidity for the sedimentary bedrock units (1.4 NTU) slightly exceeds the NYSDOH MCL of 1 NTU. The median concentration and range for turbidity in the sedimentary bedrock units on table 13 are reported at 1.4 NTU (0.07 NTU to 82 NTU). Almost 58 percent of the wells completed in the sedimentary bedrock units exceed the MCL of 1 NTU required by the NYSDOH and about 35 percent exceeded the 5 NTU level.

The median concentration and range for turbidity in the sand and gravel aquifer reported on table 13 are 0.26 NTU (0.1 NTU to 7.4 NTU). About 7 percent (only one well) of the wells inventoried exceeded the MCL of 1 NTU, and this well also exceeded the 5 NTU level.

The median concentration and range for turbidity in the undifferentiated granite and gneiss bedrock units reported on table 14 are 0.23 NTU (0.1 NTU to 1.5 NTU). About 11 percent (only one well) of the wells inventoried exceeded the MCL of 1 NTU required by the NYSDOH and no wells exceeded the 5 NTU level.

Consideration must be given to the fact that some of the turbidity data were collected from newly-drilled test wells. In many cases, following additional pumping and development, the turbidity levels would likely be reduced to acceptable levels. Sedimentary bedrock units are more soluble than the other two aquifer types, consequently, high weathered zones or fracture zones with significant solutioning may produce turbid water continuously or periodically, or may eventually develop to acceptable turbidity levels. Wells completed in the Undifferentiated Lower Devonian and Silurian Rocks (Ds) and Undifferentiated Hamilton Group (Dh) sedimentary units commonly produce turbid water during drilling and initial pumping tests, however, usually develop to acceptable turbidity levels.

Turbidity is reduced or eliminated in problem water supplies by a combination of coagulation, flocculation and filtration.

**Hydrogen Sulfide**

Hydrogen sulfide is one of those chemical parameters not reported on table 14, but can affect the utilization of ground water. Hydrogen sulfide is a dissolved gas present in some ground water developed from the bedrock aquifer units in Orange County. Sulfur water has a "rotten-egg" odor and taste, and is prevalent in wells completed in the Martinsburg Formation. About 24 percent of wells completed in the Martinsburg Formation, consisting mostly of dark shale and sandstone, produce water containing the gas (Frimpter, 1972). The gas is present in extremely small concentrations in the ground water in Orange County and presents no health risks, therefore, it is more of a nuisance constituent. Water with hydrogen sulfide present is generally corrosive.

The exact source of hydrogen sulfide is not presently known. Data indicate the deeper wells in the Martinsburg Formation are more likely to produce water containing hydrogen sulfide.

The most practical and cost-effective treatment method for reducing or removing hydrogen sulfide is mixing water from a source containing hydrogen sulfide with water from other wells in the system where the gas is not present to reduce the concentrations. Considering all public water supplies in New York must be chlorinated, the chlorine used to disinfect the water will oxidize the hydrogen sulfide and will aid in the hydrogen sulfide removal. Additional treatment, if required, can be combined with aeration at the tank or other aeration methods to reduce sulfide gas significantly.

**Radionuclides**

Radioactive decay of certain unstable elements produce radiation called alpha, beta and gamma radiation. The human body is susceptible to damage from alpha and gamma radiation. Long-term radiation exposure can cause leukemia, lung cancer, birth defects, mental retardation and tumors (Driscoll, 1986). No significant radioactive waste discharges from industry are reported in Orange County. Major concerns are naturally-occurring radionuclides.

Concentrations of three naturally-occurring radionuclides, radon, radium and uranium, are a concern in ground water in Orange County. Combined concentrations of radium 226 and radium 228; gamma alpha (gross alpha, including radium 226) and beta alpha (gross beta) are usually significantly below the MCLs required by NYSDOH (table 13). However, there are rare exceptions of elevated concentrations above the MCL for these parameters in all aquifer types in Orange County.

The more recent concerns are the reported high concentrations of naturally-occurring radon in ground water in some parts of Orange County. Radon is a radioactive, odorless, colorless gas. Its solubility in water is inversely proportional to temperature. Radon gas develops from the decay of uranium and occurrence is correlated with uranium content of the bedrock. Radon gas in high concentrations is known to be carcinogenic (Graves, 1987).

The USEPA may be setting a MCL for radon in the near future. It is expected that the MCL for radon will be set between 200 pCi/l (picoCuries per liter) and 1,000 pCi/l. High levels of radon are suspected of causing lung cancer through inhalation of air, especially indoors where radon gas is not dissipated. Indoor air radon levels are contributed to by soil gas, water and building materials. Although the major contribution is soil gas, it has been estimated that radon in domestic water supplies contribute 1 pCi/l of radon for every 10,000 pCi/l of radon in the water supply (Slade, 1990). The highest average levels of radon occurred in wells in Orange County and four additional adjacent counties (ibid), comparing radon levels of other wells throughout New York State.

Radon concentrations from 50 pCi/l to 24,400 pCi/l have been measured during sampling of wells in Orange County (ibid). Table 15 summarizes the radon surveillance survey conducted. The median radon concentrations from table 15 is 460 pCi/l; 65 percent of the samples exceeded 300 pCi/l and 34 percent exceeded 1,000 pCi/l. Consequently, if the USEPA promulgates MCL at levels below 1,000 pCi/l, a substantial number of wells in Orange County will likely require treatment.

The USEPA has designated aeration as the best available technology for radon removal. Aeration is the most effective and economical technology achieving removal rates in excess of 99 percent (Chandler, 1989).

## SURFACE WATER TREATMENT RULE

The USEPA Surface Water Treatment Rule (SWTR) affects the operation of every public water system that uses surface water and some ground-water sources. The purpose of the regulation is to protect the public, as much as possible, from waterborne disease. Waterborne diseases can be transmitted via surface water or ground water that is somewhat "contaminated" by surface water, as in the case of very shallow wells adjacent to surface-water bodies (Von Huben, 1990). The USEPA labels this "groundwater under the direct influence of surface water" (ibid).

The SWTR requires all public water systems using surface water or affected ground- water supplies remove or inactivate disease-causing microorganisms. These microorganisms can be removed by filtration or inactivated by disinfection (ibid).

Ground-water sources most likely to be under the influence of surface water include springs, infiltration galleries, lateral collector wells and shallow wells (figure 17). In addition, wells less than 50 feet deep and less than 200 feet from any surface-water body, including wetland areas are suspect (Von Huben, 1991). The NYSDOH also applies the SWTR to bedrock wells that fall within the 200-foot distance criterion. It should be noted that many wells have been installed to derive water from induced infiltration of a stream or adjacent surface-water body, however, these wells are not automatically considered to be under the direct influence of surface water. Under the SWTR definition, hydraulic connection is not the key, it is whether the water is getting sufficient filtration.

Wells not likely to be under the direct influence of surface water include the following (Von Huben, 1991):

- wells greater than 50 feet deep;
- well construction - well casing penetrates a confining layer when properly installed and sealed;
- location - greater than 200 feet from any surface water;
- water quality - no record of coliform from untreated samples, no excessive turbidity, no disease outbreaks; and
- water-quality analysis - no indication of micro-particulate organisms associated with surface water; correlation between temperature and turbidity of well and adjacent surface-water bodies.

The NYSDOH presently combines several methods to gather information required to determine whether a well is under the direct influence of surface water, as follows:

- Review of Sanitary Survey - Data Review of Existing System - including well construction, geologic logs, previous water-quality analysis review, any record of previous waterborne disease outbreak and consumer complaints regarding water quality and illness.

- Special Water-Quality Analyses - including comparison of water-quality data from both the well and adjacent surface-water bodies and microparticulate analysis of the well.

- Wellhead Protection Programs - include review or development of wellhead protection programs.

- Seasonal Changes - some ground-water supplies are influenced by surface water only at certain times. These sources should be evaluated when most suspect.

The above methods should be reviewed with respective regulations prior to undertaking any specific investigation of a suspect well source. Clearly, when conducting new water-supply exploration, the provisions of the SWTR should be considered to avoid unnecessarily triggering the need for microparticulate analysis and long-term monitoring of the water-quality comparisons between well water and surface water.

## EFFECTS OF LAND USE ON WATER QUALITY

Ground water in parts of Orange County has been contaminated by activities of man, and continuing efforts are being undertaken to improve some areas of contamination. The contamination of ground water is presumably from improper waste disposal, leaks and spills of petroleum hydrocarbons and industrial solvents and the storage of salt. To date, agriculture has had minor impacts on water quality in Orange County. Contaminants are usually introduced into the unsaturated soil zone and migrate to the underlying aquifers. Contaminants also may be carried by surface water as it recharges an aquifer. Generally, contamination is limited in areal extent within a few hundred feet to a few thousand feet from the source at relatively shallow depths, considering the limited extent of most regional ground-water flow. Water quality has improved in problem areas because of improvements in waste disposal and management, agriculture (regulations on herbicides and pesticides), industrial practices, dilution or natural degradation of contaminants, discharge of contaminated ground water, and containment and treatment of contaminated ground water, when feasible.

Existing known ground-water contamination sites, including New York State Department of Environmental Conservation (NYSDEC) inactive hazardous waste sites, remediation projects (NYSDEC Spill Response), solid waste sites, RCRA sites and potential ground-water contamination sites within the County are inventoried in the Existing Conditions Report and shown on the respective map sets. The information was provided by Lawler, Matusky and Skully Engineers (LMS) and gathered from a Freedom of Information Law (FOIL) requested from the NYSDEC (LMS, 1993).

It is estimated that about five percent of the ground water in Orange County is known or suspected of being affected by contamination of pollutant substances based on a review of data inventoried in the Existing Conditions Report. The contamination is largely attributed to waste disposal, including improper storage of hazardous material and urbanization.

### Waste Disposal

There are 29 NYSDEC inactive hazardous waste sites in Orange County. A majority of these sites are still under investigation or subject to post-closure permit requirements. Previous waste disposal sites are continuing to be discovered within the County. In addition, there are numerous private and municipal sewage-disposal systems. The waste disposal sites inventoried to date are discussed in the Inventory of Ground-Water Contamination Problems section in the respective Town studies in the Existing Conditions Report. The inventoried sites are shown on the respective map sets. Certainly the sites located in urbanized and densely populated areas present the greatest potential to affect drinking water supplies.

The total effect of waste disposal on ground-water quality and future effects is unknown and beyond the scope of investigation for this Study. The NYSDEC has detected contamination in the shallow part of the saturated zone at a significant number of NYSDEC inactive hazardous waste sites and mixed waste landfills that are presently monitored. Leachate from unlined landfills is a major concern and presents a potential problem to underlying aquifers.

Improper disposal of industrial solvents is another major cause of contamination. Several public supplies have been contaminated by solvents to date. In addition, domestic and industrial wells have been contaminated.

### Urbanization

Ground-water contamination in urban areas is commonly covered by such sources as leakage of fuels or hazardous waste, or the less identifiable cumulative effects of human activities. Major causes of contamination in urban areas includes leakage from storage tanks containing fuels and other hazardous chemicals, accidental spills of fuels and hazardous chemicals, uncovered storage of road salt or heavy application of road salt for deicing, and disposal of brine from water softeners in underground septic systems.

There are tens of thousands of buried storage tanks mostly for storage of fuel oil or gasoline, which includes numerous underground storage tanks for fuel oil for domestic homes in Orange County. Many have leaked because of deterioration, accidental rupture or improper installation, resulting in petroleum hydrocarbon contamination of ground water. A majority of the ground-water contamination sites inventoried in the County resulted from old underground storage tanks installed prior to the new regulations.

Petroleum and chemical spills are inventoried and investigated by the NYSDEC (NYSDEC Spill Response). A majority of the reported incidents inventoried are small spills on land and the spills are cleaned up. However, it is expected that most spills are not reported and result in slow cleanup or lack of cleanup effort. The lack of quick response and effective clean-up response likely results in the spilled substance contaminating soil and possibly ground water.

## POTENTIAL FOR WATER-QUALITY CHANGES

Future changes in ground-water quality in Orange County are difficult to predict, considering that the magnitude of existing ground-water contamination is not well known. The positive impacts from present and future comprehensive water-quality management plans and the negative impacts resulting from increased development and urbanization of Orange County is uncertain. Sand and gravel aquifers are most susceptible to contamination and are likely to be most affected by the future growth of the County. Land-use decisions and wellhead protection programs and strategies will be an important factor in determining the future ground-water quality in the aquifers.

During the past 10 years, State and Federal legislation, regulations and guidelines have significantly improved management of the major sources of pollution. The regulations cover solid waste disposal, underground storage of fuel and chemicals, industrial use and disposal of toxic and hazardous materials, water-quality standards for effluent discharged from sewage treatment plants and salt storage practices. These are just a few of the examples of how management practices resulting from new regulations have reduced incidents of prevalent sources of ground-water contamination. Some of the best examples are:

- the closure of improperly-constructed landfills and the construction of properly designed landfills, and recycling and resource-recovery methods to solve solid waste disposal problems;
- registration of underground and aboveground storage tanks and replacement of older underground storage tanks with modern corrosion-resistant tanks equipped with leak-detection systems; and
- proper storage of salt in covered structures and restricted application in certain public water-supply watersheds.

Proper management practices for most hazardous material generated, stored, treated or disposed of will decrease the potential for these materials to enter the environment and migrate into the water supplies. These practices can offer economical ways to manage most hazardous materials without placing significant costs on the users. These factors, together with regulations to improve surface-water quality and more stringent regulations in waste disposal, will continue to improve and protect the ground-water quality in Orange County. However, the task to further educate the general public regarding water-quality protection must continue along with promulgation of additional regulations. Wellhead protection programs and strategies must be developed both on the County and local level to regulate land use near public water-supply wells to protect and improve ground-water quality.

Considering all the factors, the potential for incidents of ground-water contamination will likely continue. The population of Orange County increased by 18.5 percent between 1980 and 1990 (United States Bureau of the Census, 1990). Residential, commercial and industrial growth will continue throughout the County. Although farmland is decreasing in the County, the acreage on which commercial fertilizers and pesticides are applied is increasing. Increased residential development using onsite underground septic systems presents concerns of nitrate loading of ground water, discharges of brine into septic system from water softener units and household hazardous chemicals. In addition, salting of high-density road and sidewalk networks may result in a cumulative impact on ground water.

As industrial and commercial development increases and expands, the use and transport of hazardous material and substance increases, and proportionally provides greater opportunities for spills, leaks during transport, storage, handling and disposal. In addition, not all persons will likely comply with proper storage and disposal regulations. Sand and gravel aquifers are most susceptible to contamination from non-point and point sources because the same hydrologic characteristics (highly permeable and transmissivity) that cause these aquifers to be favorable aquifers for development of large-scale regional water supplies also allows easy migration of contaminants into the aquifer. Unconfined aquifers exhibiting one or more of the following characteristics would be highly-susceptible to contamination from highly-urbanized areas:

- high permeability and transmissivity;
- shallow depth to water; and
- induced recharge from surface water.

Bedrock aquifers are less susceptible to contamination, as the units are typically overlain by till in Orange County. However, relatively shallow depth to bedrock or exposed bedrock and highly-fractured weathered bedrock are susceptible to contamination. Contaminants entering along fracture zones can move rapidly with little attenuation to wells completed in the same fracture zones. Consequently, migration of contamination can be difficult to predict or control due to lack of or minimal knowledge of bedrock flow systems through complex subsurface fracture systems.

## GROUND-WATER EXPLORATION

The potential yield of favorable well sites can only be determined by drilling the proposed sites. The review of possible permits (i.e., wetland permit) required to drill a particular location should be considered, in addition to obtaining clearance from underground utilities. The NYSDOH requires a minimum 100-foot radius of ownership and a 200-foot radius of sanitary control from a proposed public supply well. The following summarizes the more common ground-water exploration methods for developing wells in sand and gravel aquifers and bedrock aquifers.

### Sand and Gravel Aquifer

The most common ground-water exploration of a favorable parcel underlain by a sand and gravel aquifer is to drill test borings. The purpose of the test borings is to locate the best sites for test production wells. During the boring program, formation samples are obtained and 2-inch diameter PVC observation wells are commonly installed in selected test borings. The 2-inch diameter observation wells can be utilized to obtain additional data, including aquifer parameters and preliminary water quality of the aquifer.

The samples collected during drilling are utilized to identify the best aquifer material and sieve analyses are run to determine the size of the screen openings. When the best site has been selected, a test production well is drilled. After construction and development of the well is complete, a 24-hour pumping test (minimum) is conducted to determine the sustainable yield and potential for impact to nearby wells, if any. Ground-water samples are obtained near the end of the test. The data collected during the test should be adequate to support an application for a Public Water Supply Permit.

Geophysical exploration methods can be used either before or after test drilling to obtain preliminary data on the depth of the aquifer and the characteristics of the formation. In addition, some methods are also extremely useful in determining the effectiveness of well construction (Driscoll, 1986). Geophysical methods are conducted either at the surface or down a borehole. In sand and gravel aquifer units, enough contrast of material usually exists between deposit layers so the general physical characteristics can be determined. The use of various geophysical methods can minimize the amount of drilling required to explore a large parcel. Geophysical exploration methods are more commonly utilized for sand and gravel aquifer exploration, however, these methods can also be utilized to evaluate bedrock units.

**Bedrock Aquifers**

The yield of a bedrock aquifer can be determined only by drilling a test well and conducting a pumping test. LBG recommends that a 6-inch to 10-inch diameter casing be installed and a 6-inch diameter test hole be drilled into bedrock. The diameter of the well casing installed would typically be larger (8 to 10 inches) in bedrock units expected to yield greater than 75 gpm to accommodate a larger pump. The casing (minimum of 40 feet) should be installed and grouted into competent rock. Test wells should be drilled to a minimum depth of 450 feet, if a suitable yield is not obtained at a shallower depth. A hydrogeologist should analyze the data obtained to 450 feet and decide whether or not to continue drilling beyond that depth.

Test wells should be drilled by the air-rotary method, which is relatively fast and efficient in the type of rock found in the region. Installation of a 6-inch to 10-inch diameter casing and drilling a 6-inch diameter test well to 450 feet can usually be accomplished in two to three days. A hydrogeologist should provide partial supervision to examine the drill cuttings as they are flushed from the borehole and would also determine the depths at which water enters the hole by observing the flow during drilling. Knowledge of the depths of the water-bearing fractures is essential information for interpreting pumping test data and in determining the depth at which to set the permanent pump. If a significant amount of water is developed during drilling, the borehole can be reamed to 8- to 10-inch diameter to accommodate a larger pump, if an 8- to 10-inch diameter casing was installed.

The NYSDOH will require 72-hour pumping tests on successful test wells. If nearby domestic wells are located within the area of the test well, an offsite well monitoring program will likely be required. The offsite well monitoring program should be conducted to determine possible water-level interferences, if any, from the proposed well supply. If two or more wells are to be tested, a simultaneous pumping test may be conducted to save costs and to simulate multiple-well pumping conditions. The pumping test should include water-level recovery measurements periodically on both the pumping and offsite monitoring wells for a minimum of 72 hours following shutdown of the test.

Prior to shutdown, water samples should be collected for analysis of all constituents listed in the New York State Sanitary Code, Part 5, Subpart 5-1, as well as for radon gas, if required. The data collected during the test should support an application for a Public Water Supply Permit.

Some of the limestone-dolostone and conglomerate bedrock units (Ds and Dh bedrock units) in Orange County are so highly fractured and weathered that wells developed in these units produce persistently turbid water or sediment, presenting well-development problems and, particularly, permanent water-quality problems. In addition, highly-fractured and weathered zones encountered during drilling or development may continue to collapse or experience partial collapse of the borehole. In some situations, the borehole may stay open for an extended period of time, but eventually collapse. The collapse of incompetent bedrock units presents a problem during installation, and most collapsed boreholes result in reduced yield and produce turbid or dirty water, partially if the collapse is above the major water-bearing fractures encountered during drilling.

Stabilization of incompetent bedrock units encountered during drilling can sometimes be achieved by three of the following methods:

- casing off incompetent bedrock with the initial well casing installed deeper than usual and/or installation of liner casing through larger-diameter outer casing;
- installation of well screen to stabilize the incompetent bedrock unit encountered during drilling; and
- installing a gravel pack in the well above the incompetent bedrock zone.

It should be noted the above methods to stabilize the incompetent bedrock units encountered during drilling are not always successful and, typically, result in some reduced yield of the well.

## CONCLUSIONS

**Ground-Water Supply**

- The GWRS data indicate that ground water is a feasible and favorable alternative for additional water-supply development for the foreseeable future in Orange County.

- The potential of existing and new ground-water supplies county-wide will be sufficient to meet future water demands of the County for at least the next 25 years.

- The estimated total present withdrawal of ground water in Orange County from both individual well supplies (4.7 mgd) and public water supplies (26.4 mgd) in the County is about 31.1 mgd.

- The total withdrawal of ground water in the County by the year 2020 will likely exceed 50 mgd, about 6.7 mgd for individual well supplies and 44 mgd for public water supplies.

- The consumptive water use for homes or commercial-type developments utilizing onsite wells and underground septic systems is low and not typically considered in water-budget analysis. Approximately 85 percent of water withdrawn from the aquifer from an onsite well is returned to the ground-water system by onsite septic-system leachfields.

**Sand and Gravel Aquifers**

- The total withdrawal from sand and gravel wells for existing and proposed public and private water-supply systems in Orange County is estimated to be about 17.1 mgd and the total yield capacity of these wells is estimated to be about 31.8 mgd. Although the sand and gravel aquifers are the most prolific in the County, and most are capable of producing high-yield wells, they are of limited areal extent within the County.

- Recharge to sand and gravel aquifers in Orange County ranges from 500,000 gpd to as high as 1,000,000 gpd per square mile. The recharge estimate of 500,000 gpd was applied to sand and gravel aquifers where little to no data are available related to the aquifer thickness, well yields, areal extent, aquifer parameters and induced recharge. Where favorable data were available, increased estimates of recharge as high as 1,000,000 gpd were applied.

- The total estimated safe yield of the significant sand and gravel aquifers in Orange County is estimated to be about 92 mgd.

- The Neversink-Basher Kill River Valley (L) sand and gravel aquifer, which extends from Port Jervis to Summitville in Sullivan County, has the largest potential yield (70 mgd) in Orange County and is recharged by the Neversink River. This aquifer has great potential for large-scale development as a regional source of water for Orange County, but its remoteness from any present or future high-density core areas of development has limited its use and make it a high-cost alternative future supply.

- The Greenwood Lake (Z) and Wallkill River Valley (U) sand and gravel aquifers have estimated yield potentials greater than 3.0 mgd. Both these unconfined aquifers are in direct hydrologic connection with overlying water bodies which directly recharge the aquifers. Both these aquifers have good potential for development of additional water supplies, particularly, the Wallkill River Valley, which extends over a large areal extent from the New Jersey State line in the south and extends along the Wallkill River north to the Orange/Ulster County boundary lines.

- A number of smaller sand and gravel aquifers in the County are estimated to have yield potentials of about 1 mgd. Two good examples are the Moodna Creek Valley (P and Q) and Rutgers Creek Valley (S) sand and gravel aquifers. These aquifers typically have some portions of the highly-permeable sand and gravel deposits overlain by clay and silt deposits which act as confining units.

- Small, isolated areas of unconsolidated sand and gravel deposits exist throughout the County, but most have yet to be explored. Most of these deposits are overlain or partially overlain by a confining unit limiting induced recharge from overlying streams and from direct precipitation. The estimated yield capacities of wells developed in these areas are generally low to moderate (5 to 50 gpm) and the safe yields of these aquifers are estimated to be less than 0.25 mgd.

**Bedrock Aquifers**

- The present estimated withdrawal of ground water from bedrock wells in Orange County is about 9 mgd, and the total estimated yield capacity is estimated to be about 23.6 mgd.

- In overall perspective, the estimated recharge to the bedrock aquifers within the respective town boundaries under normal and drought conditions is significantly higher than present and future water demands estimated to the year 2020 for the respective towns.

- The total estimated recharge to the bedrock aquifers within the political boundaries of Orange County is about 325 mgd under normal precipitation conditions and about 130 mgd under extreme drought conditions.

- The recharge to the sedimentary bedrock units is estimated to be 400,000 gpd per square mile.

- The recharge to the undifferentiated granite and gneiss bedrock unit is estimated to be 350,000 gpd.

- The recharge to the bedrock aquifers actually available for ground-water supply may be greater than the amount contributed from precipitation in the watershed areas where permeable saturated sand and gravel deposits overlie bedrock. The volume of the indirect recharge is not measurable without extensive studies, but it would increase non-linearly as withdrawals increase.

- The estimated recharge to the bedrock aquifers within the respective watersheds under normal and drought conditions is significantly higher than maximum yield potential of existing and proposed public supply wells, with the exception of Watersheds 1, 35, 138, 169, 172, 173, 174 and 176 where high-density development has occurred or is planned.

- In overall perspective, estimated recharge to bedrock aquifers in Orange County under normal and drought conditions is significantly higher than present and future water demands. The total estimated recharge to the bedrock aquifers is about 325 mgd under normal precipitation conditions and about 130 mgd under extreme drought conditions (table 6A). The available recharge is substantially greater than present estimated withdrawal of 9 mgd (table 2) and the total yield capacity of about 23.6 mgd (table 7) from existing bedrock supply wells.

- Water-budget analyses are useful in estimating available ground-water resources, however, the drilling and testing of the proposed supply wells ultimately indicates the yield of bedrock wells without significant impact to neighboring water supplies.

- Although not as prolific as sand and gravel aquifer units, the bedrock aquifers in Orange County are locally utilized in excess of 1 mgd (i.e., Town of Woodbury and Village of Kiryas Joel). The bedrock aquifers are a dependable and suitable supply source for developing high-yielding wells in the County.

- The Undifferentiated Lower Devonian (Ds) sandstone and conglomerate rocks are the most prolific bedrock aquifer developed to date in the County. Two wells (Wells MT-10 and MT-26) (Map 2-42) have reported yields of 300 gpm, each and several additional wells drilled in this unit yield between 100 and 175 gpm. The yield potential in the Ds bedrock unit in eastern Orange County is projected to range from 50 to 300 gpm with yields between 75 and 150 gpm, common at favorable well sites.

- The Wappinger Group (OEw) consists of limestone and dolomite units which occur in southern and eastern Orange County. Wells drilled in the OEw at favorable sites would likely yield between 50 and 300 gpm.

- Although little data are available on the Onondaga Limestone (Dou) and Helderberg Group (Dhg) limestone and shale units, the estimated yield potential is between 50 and 300 gpm. The area in the Basher Kill Valley in the western portion of Orange County where the unit occurs is of small areal extent and very rural with little to no development.

- The Undifferentiated Hamilton Group (Dh) in eastern Orange County consists of sandstone, conglomerate and shale units which have yielded 200 gpm at each of two wells drilled for the Village of Kiryas Joel. The yield potential of the Dh rocks is projected to range from 75 to 200 gpm, with yields between 75 and 100 gpm common at favorable well sites.

- The Martinsburg Formation (On) is a shale unit which underlies a large portion of central Orange County, which has yielded 100 to 225 gpm to wells. However, the average yield and median yields reported for this unit are 56 gpm and 30 gpm, respectively, with yields ranging from 3 to 225 gpm for this unit. The Martinsburg Formation (On) has good potential to develop moderate to high-yielding wells at favorable well sites.

- The Undifferentiated Gneiss (Mu) and Undifferentiated Granite, Granitic Gneiss (Mgu) are metamorphic rocks of Precambrian Age, which include gneiss, granite, amphibolite and calcsiliate rocks in southwestern and southeastern Orange County. Wells drilled at favorable well sites would likely yield between 25 gpm and 75 gpm with high yields obtained from highly-fractured and jointed units with a relatively good degree of interconnection.

**Water Quality**

- Almost all of the public ground-water supplies currently meet water-quality standards promulgated by the NYSDOH Sanitary Code. The ground water beneath more than 90 percent of the land in Orange County is considered to be suitable for drinking without significant treatment. The quality of the ground water in each major aquifer in Orange County is generally good to excellent and suitable for most uses.

- Concentrations of naturally-occurring radon are a concern in ground water in Orange County. The USEPA may be setting an MCL for radon in the near future which is expected to be between 200 and 1,000 pCi/l. Radon concentrations from

50 to 24,400 pCi/l have been measured during sampling of wells in Orange County, with the median radon concentration reported as 460 pCi/l; 65 percent of the samples exceeding 300 pCi/l and 34 percent exceeding 1,000 pCi/l. If the USEPA promulgates a radon MCL at 1,000 pCi/l or below, a substantial number of wells in Orange County will likely require treatment. The USEPA has designated aeration as the best available technology for radon removal.

- The SWTR (Surface Water Treatment Rule) requires all public water systems using surface water or ground-water supplies directly affected by surface water to remove or inactivate disease-causing microorganisms by filtration or disinfection. Ground-water sources most likely under the influence of surface water include springs, infiltration galleries, lateral collector wells and shallow wells less than 50 feet deep and less than 200 feet from any surface-water body. The NYSDOH also applies the SWTR to bedrock wells that fall within the 200-foot distance criterion. Although many wells have been installed to derive water from induced filtration of a stream or adjacent surface-water body, these are not automatically considered to be under the direct influence of surface water.

- Ground water in parts of Orange County has been contaminated by the effects of land use related to activities of man including improper waste disposal, leaks and spills of petroleum hydrocarbons and industrial solvents and the storage of salt. To date, agriculture has had only minor impacts on water quality in Orange County.

- Ground-water quality has improved in some problem areas because of improvements in waste disposal and management, agriculture (regulations on herbicides and pesticides), industrial practices, dilution or natural degradation of contaminants, discharge of contaminated ground water, and containment and treatment of contaminated ground water.

- It is estimated that about five percent of the ground water in Orange County has been adversely affected by contamination, largely attributed to waste disposal, improper storage of hazardous material and urbanization.

- There are tens of thousands of buried storage tanks mostly for storage of fuel oil or gasoline in Orange County. Many of those tanks have leaked, resulting in petroleum hydrocarbon contamination of ground water.

- Future changes in ground-water quality in Orange County are difficult to predict, considering that the magnitude of existing ground-water contamination is not well known. The positive impacts from present and future comprehensive water-quality management plans and the negative impacts resulting from increased development and urbanization of Orange County are uncertain.

- Proper management of most hazardous material generated, stored, treated or disposed of will decrease the potential for these materials to enter the environment and migrate into the water supplies. These factors, together with regulations to improve surface-water quality and more stringent regulations in waste disposal, will continue to improve and protect the ground-water quality in Orange County.

- Considering all the factors, the potential for future incidents of ground-water contamination will continue as the population increases. Although farmland is decreasing in the County, the acreage on which commercial fertilizers and pesticides are applied is increasing. Increased residential development using onsite underground septic systems presents concerns of nitrate loading of ground water and discharges of brine into septic system from water softener units and household hazardous chemicals. In addition, salting of high-density road and sidewalk networks may result in a cumulative impact on ground water.

- As industrial and commercial development increases and expands, the use and transport of hazardous materials increases and proportionally provides greater opportunities for spills and leaks during transport, storage, handling and disposal. Sand and gravel aquifers are most susceptible to contamination from non-point and point sources because the same hydrologic characteristics that cause these aquifers to be favorable aquifers for development of large-scale regional water supplies also allows easy migration of contaminants into the aquifer.

- Bedrock aquifers are less susceptible to contamination, as the units are typically overlain by till in Orange County. However, relatively shallow depth to bedrock or exposed bedrock and highly-fractured weathered bedrock are susceptible to contamination. Contaminants entering along fracture zones can move rapidly, with little attenuation, to wells completed on the same fracture zones. Consequently, migration of contamination can be difficult to predict or control due to lack of or minimal knowledge of bedrock flow systems through complex subsurface fracture systems.

**RECOMMENDATIONS**

- Based on quantitative knowledge of the water resources that are available, local and County Planners should utilize the GWRS to develop guidelines to safeguard existing ground-water supplies, and to evaluate and protect favorable undeveloped areas for future development of ground-water supplies.

- Site-specific drilling, testing, water-budget studies and water-quality analyses should be carried out at any of the favorable sand and gravel or bedrock aquifer locations identified in the GWRS to establish their suitability for public drinking water supplies.

- The GWRS information should also be utilized for the 205(J) Water-Quality Management Program and Wellhead Protection Strategies presently being prepared for the OCWA and Hudson Valley Regional Council.

- The provisions of the SWTR should be considered when conducting new water-supply exploration to avoid unnecessarily triggering the need for microparticulate analysis and long-term monitoring of the water-quality comparisons between well water and surface water.

- Wellhead protection programs and strategies should be developed at the County and local levels to regulate land use near existing and proposed public water-supply wells to protect and improve ground-water quality.

- The County should reconsider implementation of well permit programs to inventory data on future private and public ground-water supply development in this County.

- The task of further educating the general public regarding water conservation and water-quality protection should continue, along with promulgation of additional regulations.

- As growth occurs in Orange County, the water demand of some present population centers are likely to exceed the existing supplies. In some cases, the most logical and economic sources of additional water will be located in adjoining towns with low water demands. The OCWA should position itself in leadership and in law to act as the planner and mediator of inter-municipality water allocations, and as an active participant in NYSDEC Water Supply Application proceedings throughout Orange County.

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