1.8 Ground Water Resources

Ground water is the water found below the ground surface in pores or fissures in the bedrock and in the interstices between soil particles. It originates primarily as precipitation that infiltrates through the land surface and moves downward through the unsaturated and saturated soil layers to the water table (See Figures 1.16.1 and 1.16.2). In coarse-grained porous media and in wide fractures, the water table is the top of the saturated zone and rocks and sediments below the water table are saturated. That is, the interstitial spaces between mineral grains or fractures in rocks are full of water. In fine-grained media, such as fine sand, silt, or clay, the saturated zone can extend from several inches to several feet above the water table because of the effects of surface tension. Ground water is stored in and flows through layers of consolidated or unconsolidated rocks or sediments called aquifers.

Aquifers

Aquifers may be defined as geologic units that can store and transmit water at rates sufficient to supply reasonable amounts to wells.

Water generally enters the ground water system where aquifers crop out. That is, where they are present at or near the land surface. The nature and lateral extent of a recharge area vary with the type of aquifer. Aquifer recharge areas are the subject of Section 1.9. Water moves in response to the force of gravity and differences in pressure. After entering the aquifer, water moves toward a discharge point along pathways that are determined by hydraulic head and the path of least resistance. Although ground water typically must travel horizontally from the point of entry to the point of discharge, some vertical movement occurs as well: there is a downward component to flow in recharge areas and an upward component in the immediate vicinity of the discharge. The magnitude of these components also varies with depth. Ground water eventually discharges to surface water bodies such as streams, lakes, the ocean, wetlands, or to a well. The time required for ground water to reach the discharge point depends on its flow path. Water that follows a relatively shallow, or local, flow path moves only short distances and may take only days to reach the discharge point, whereas water that follows a deeper, or regional, flow path moves long distances and may take centuries or millennia to reach the discharge point.

If there is an underlying confined aquifer, separated from the water-table aquifer by a confining layer, some ground water in the upper aquifer may flow vertically through confining layers to recharge the aquifer below. In a discharge area, where the water-table aquifer is discharging water to a surface water body, the pressure in the lower aquifer may be greater than that in the water-table aquifer. In this case, the flow across the confining layer will be upward.

Water from aquifers provides approximately 90% of the drinking water for residents in WMA 6. Approximately 13% of the households in WMA 6 are served by private wells. Many of the municipalities have their own wells. Others have well water provided by purveyors. In addition, many industries make use of ground water for cooling or in production. Surface water is diverted for domestic and industrial purposes from several reservoirs in WMA 6 (Reed *et al*. 2001), particularly for use in population centers in Bergen, Essex, and Hudson Counties, which are outside of WMA 6.

Aquifers in WMA 6

The aquifers in the region were introduced in the Geology section. Bedrock aquifers are shown in Plate 1.8.1, grouped according to typical well yields. Aquifers formed in overburden are presented in Plate 1.8.2, which presents surficial aquifers grouped according to yield and also shows the most current delineation of the Buried Valley Aquifer system in WMA 6. This section will briefly relate the hydrology and water quality of the principal aquifers. They are present in order of decreasing age of the geologic units in which they are formed.

PreCambrian Igneous and Metamorphic Rock Aquifers – These are primarily unconfined aquifers. All the water is borne in fractures because there is no primary porosity between mineral grains. Wells typically yield less than 100 gpm (Gill and Vecchioli 1965). Yield depends upon the number of hydraulically significant fractures that intersect the well bore. Many public supply wells yield less than 25 gpm. Only rarely does one encounter a well that can produce over 300 gpm in this type of aquifer.

Because these aquifers are unconfined, they are more vulnerable to the introduction of contamination than confined aquifers. Fortunately, in many instances the water table is deep and the soils that weathered from the rock are thick and not excessively coarse, allowing oxidation and filtration, which provide protection against pathogens and accelerate the degradation of organic contaminants. The principal pollution concern is nitrate from septic systems, which does not degrade, and pesticides in agricultural areas.

In the natural state, the water in these aquifers is generally acceptable for most uses. The pH tends to be mildly acidic (typically between 4.5 and 6), with low hardness, but with occasionally high iron concentrations, up to 12 ppm (Banino *et al*. 1970; Miller 1974).

Aquifers formed in the Leithsville Dolomite and the Hardyston Quartzite – These are grouped together because of the close association between the two formations, which were deposited without an intervening hiatus. Nevertheless, the hydraulic properties of the quartzite are insignificant in comparison with the dolomite. Where the two co-occur, most of the water is diverted from the adjacent Leithsville aquifer (Banino et al. 1970). Consequently, the chemistry of the quartzite aquifer is dominated by calcium, magnesium, and bicarbonate derived from the dolomite. Where it is alone, the quartzite is only suitable for low-yield domestic wells. There is very little primary porosity in the Leithsville Dolomite and water is transmitted through fractures. However, the dolomite is soluble and the fractures tend to develop into solution channels and caverns, which greatly enhance the rock's ability to transmit and store water. Yields of several hundred gallons per minute can be sustained in some locations.

The Leithsville Dolomite is soft and soluble and consequently erodes more rapidly than the rocks that typically surround it (Banino et al. 1970). Consequently, valleys tend to form in the areas that it underlies. It also contains a significant proportion of insoluble fine sand, silt, and clay, which remain behind when the carbonate is dissolved, forming a low-permeability residue blanketing the rock. Therefore, the aquifers that form in the Leithsville tend to be confined. Because the valleys have a tendency to accumulate alluvial and glacial lacustrine and outwash deposits in WMA 6, it is common for the Leithsville to be buried under a great thickness (up to 100 feet or more) of unconsolidated material, which may contain their own aquifers. In other locations, the unconsolidated cover, may be 10 feet thick or less.

Deep burial affords some protection against pollution, but the low-lying areas where the Leithsville occurs tend to have high water tables and therefore thin unsaturated zones. Consequently, where contamination is introduced, there may be insufficient oxidation to destroy pathogens. Furthermore, if contamination can penetrate to the open conduits provided by caverns and solution channels, it can migrate very quickly.

In contrast to aquifers formed in the crystalline PreCambrian rocks, the ground water in the Leithsville aquifers is very hard and has a somewhat alkaline pH (Gill and Vecchioli 1965). Under natural conditions, this may be the best quality water for drinking in WMA 6, although softeners are usually needed for other domestic uses.

Aquifers formed in the Rocks of the Green Pond Outlier – These rocks consist of shales, siltstones, sandstones, mudstones, conglomerates, limestones, and dolomites. Often a single aquifer is contained in more than one formation. The ground water is primarily transmitted through fractures. The Green Pond Conglomerate, where weathered, can have significant primary porosity and yield moderate quantities of water. The sandstone formations may also exhibit primary porosity. Fractures in the carbonates can develop into solution channels and exhibit moderate yields. Yields from the shales and siltstones tend to be low to moderate, typically less than 50 gpm.

The water from these formations is generally acceptable for most uses, except that it tends to be hard, which requires treatment, especially when derived from the limestone aquifers (Gill and Vecchioli 1965). Specific constituents and physical properties vary with the specific source rock. Contamination can spread quickly through the carbonates and also in the shales, where the latter are intensely fractured.

Aquifers formed in the Rocks of the Brunswick Group – There is practically no primary porosity in these rocks; all the ground water is transported through fractures. The typical Brunswick aquifer is best described as a multi-aquifer system. In any given location, tabular-shaped friable rock units extend hundreds of feet in the direction of dip and thousands of feet perpendicular to the direction of dip (Carswell and Rooney 1976). These units will be stacked vertically with intervening blocky units. As a result of this configuration, wells have a tendency to interfere with one another when aligned along strike. The friable unit closest to the surface may be unconfined and be partly unsaturated. Deeper units are confined, although considerable leakage takes place through the blocky intervals, which serve as confining layers. The average well yields approximately 75 gallons per minute (gpm). Yields of supply wells are known to range from a few gpm to over 500 gpm. The conglomerates formed on the western edge of the Newark Basin along the Ramapo Fault are generally well cemented and poorly fractured, which results in poor yields (Banino et al. 1970). Similarly, the basalt and diabase aquifers have little effective porosity, are normally poorly fractured, and tend to exhibit poor yields.

The ground water in the Newark Basin belongs to the calcium-magnesium-sodium-bicarbonate class (Serfes 1994). It is generally acceptable for most uses, but may need treatment for hardness. Locally, the water can be naturally rich in sulfates and exceed the standard for total dissolved solids, especially in the vicinity of trap rock (Gill and Vecchioli 1965). The pH tends to be neutral to slightly alkaline (Vecchioli and Miller 1973; Gill and Vecchioli 1965). The water from the basalt aquifers may exhibit objectionable concentrations of iron and sulfate in addition to hardness (Gill and Vecchioli 1965).

Because the Newark Basin is ideally suited to industry and residential development, there has been considerable opportunity for contamination to be introduced. The shallower, unconfined strata tend to be the most vulnerable to pollution sources, although they may be protected somewhat by low permeability glacial cover or by favorable upward hydraulic gradients in the valleys. Development of ground water resources has reversed this gradient in most areas and consequently removed the protection an upward gradient confers.

Aquifers formed in Glacial Drift – These include both confined and unconfined aquifers. The unconfined aquifers are typically glaciofluvial and glacial lake deposits which formed from coarse sediments being transported by glacial meltwaters issuing from a retreating glacier. These typically are deposited upon glacial till. However, coarse-sediment laden meltwaters also issues from advancing glaciers. There are areas in northern New Jersey, some of which are within WMA 6, where high velocity meltwaters from an advancing glacier deposited sand and gravel into pre-existing stream valleys, adding to the sand and gravel already deposited by the stream. As the glacier continued to advance the sand and gravel deposits were subsequently buried by glacial till and thereby confined. These buried valley aquifers are prolific aquifers, often in hydraulic connection with the underlying bedrock. Even as the former stream valleys were joined at confluences, the buried valley aquifers are interconnected and thus are referred to as the Buried Valley Aquifer System. The system is extensive in WMA 6, where it is an important source of water.

In addition to the Buried Valley Aquifer System, fine-grained glacial lake or fluvial sediments can confine shallower glacial outwash materials deposited on till by a retreating glacier. Where not covered by glacial till or lakebed deposits, stratified drift aquifers are unconfined. Typically, buried valley aquifers follow the former course of pre-glacial streams. In the case of major buried valleys, these pre-glacial streams followed very nearly the same course as portions of existing streams. Sometimes glacial deposits form a topographic divide that crosses a former stream channel (Canace et al. 1993). In this way, it is possible for deep groundwater to flow under a supposed drainage divide and flow from one drainage basin to another.

Stratified drift sand and gravel aquifers can be very prolific. If properly designed and constructed, individual wells in certain deposits may produce millions of gallons per day. The average well yields approximately 350 gpm (Gill and Vecchioli 1965). The water quality is generally acceptable for most uses.

In WMA 6, ground water in deeply buried stratified drift aquifers discharges to the surface primarily through the bottom sediments of former glacial lakes, supplying the hydraulic base for extensive wetlands. Surficial aquifers formed in outwash sands and gravels, deltas, and ice-contact stratified deposits discharge to local wetlands and streams. Many of these deposits are very localized and can easily be dewatered during drought conditions.

In other areas sheets of glacial till form a poor surficial aquifer, where sufficiently thick in the terminal moraine. These aquifers, which technically are formed in unstratified drift, are called morainic deposits in Plate 1.5.1. Elsewhere the till is not thick enough to provide a sustainable supply of water, but it does transmit some recharge to underlying aquifers, including stratified drift and the Brunswick Group Aquifers.

In many valleys, deeply buried stratified drift aquifers underlie one or more successively shallower stratified drift or alluvial deposits that may be separated by lakebed silts and clays or glacial till (Vecchioli and Miller 1973). These vertically stacked aquifers may drain or transmit water to one another depending on the direction and magnitude of the local hydraulic gradient.

Water obtained from glacial deposits tends to exhibit neutral pH, moderate hardness, and low iron concentration (Gill and Vecchioli 1965). In some locations, low-grade pollution can result in elevated nitrate, sulfate, or chloride levels (Nichols 1968). The concentrations of naturally occurring constituents vary with the source of the glacial drift (Banino et al. 1970). Occasionally, the manganese concentration can be naturally elevated (Nichols 1968).

Because they are so shallow and permeable stratified drift aquifers are especially vulnerable to the introduction and propagation of dissolved contamination. Nitrate contamination is a common problem in unconfined glacial drift aquifers where septic systems are present in the vicinity.

Ground Water Quality

With regard to the water quality at different locations in various aquifers in WMA 6**,** the USGS collects and analyzes surface water and ground water samples across the country and maintains a database on the results. They have a network of monitoring wells in

New Jersey from which they obtain water quality and water level data as well as monitor changes in the extent of salt-water intrusion. Although the USGS publishes an annual ground water report for New Jersey surface water and ground water, entitled "Water Resources Data – New Jersey," the water quality monitoring wells in northern New Jersey are only sampled occasionally. However, the data are accessible through the internet and there are many presentation options. Among these is a column format with physical parameters and chemical analytes for each well as column headings and the results for each of the sampling rounds presented in successive rows under these headings. The website is:

http://waterdata.usgs.gov/nj/nwis

Pollution can be introduced to aquifer in several ways. It can be introduced directly to the ground surface as a liquid chemical spill, which then permeates the unsaturated zone and enters the aquifer. Depending on its density and miscibility, it can float (as usually occurs with petroleum products like gasoline and fuel oil), sink (as occurs with chlorinated solvents like dry cleaning fluid), or simply mix (as is the case with saline solutions and certain organic liquids like alcohol and acetone). If the product does not mix with water, it can be gradually dissolved. Unless the spill is very large or continuous, the liquid product quickly becomes stabilized in a definite location. This location is known as a "source area" because ground water flowing through the area will begin to mobilize (advect) the contamination as it dissolves. The advected dissolved matter is called a "plume" and may be transported tens, hundreds, or thousands of feet from the source area, depending on the physical and chemical nature of the contaminant, its quantities, how quickly it can degrade, and the ability of the aquifer material to adsorb it.

Some contaminants are deposited on the ground surface (or buried) as solids and must be dissolved by percolating water in order to be introduced into the aquifer. Most metal contamination is introduced in this way. The introduction of some contaminants, especially biodegradable materials, can alter the physical chemistry of the ground water by stimulating the growth of microorganism populations. The metabolic activities of the microorganisms deplete the dissolved oxygen and decrease the pH of the ground water. These physical parameter changes can cause naturally occurring metals, originally bound up in the crystal structure of minerals, to dissolve and become concentrated in the ground water at unacceptable levels. This is a common occurrence in aquifers under municipal landfills.

The quality of groundwater has been degraded locally in WMA 6 through the introduction of contamination. However, beyond the NJDEP list of known contaminated sites (see Plate 3.6.1), the monitoring network is too sparse to allow any significant conclusion with respect to the extent and degree of groundwater contamination within WMA 6.

Wellhead Protection Areas

Certain sources or potential sources of contamination are prohibited within wellhead protection areas around public community supply wells. These areas are based upon the estimated velocity of groundwater flow. The distance from a well that it would take ground water two years to traverse is considered an adequate buffer to protect a well from disease-causing pathogens. NJDEP has designated this 2-year travel zone as Tier 1. NJDEP has designated this 2-year travel zone as Tier 1. Major sources of chemical pollution are not allowed within a 5-year time-of-travel distance (Tier 2). When major pollutant sources occur within a 12-year time-of-travel distance (Tier 3), special precautions must be set up to monitor and protect the quality of the water being produced at the well. There are other regulations and restrictions involved in New Jersey's Wellhead Protection Program for different potential sources of contamination. NJDEP has performed an approximate computation of the wellhead protection area delineation, for Tiers 1, 2 and 3, around each of the public community supply wells in New Jersey (see Plate 1.8.3).

Baseflow

In the natural process of the hydrologic cycle, recharged water enters the aquifer system, flows from locations with higher water levels or greater hydraulic potential to areas with lower potential. These areas with lower potential were identified earlier as "discharge areas." Normally, they are associated with streams or wetlands where the ground surface is below the water table and water exposed at the surface is removed. This is usually accomplished by gravity-driven flow in streams and uptake by plant roots and transpiration in wetlands. During recharge events (such as rainfall and snowmelt), some of the water runs off and swells streams while another portion recharges the aquifer. The runoff ends within a few days after the precipitation ends and the levels in the stream become lower. However, the stream flow is still greater after the runoff has ended than it was prior to the recharge. This is because the water level in the aquifer (after the period of runoff) is higher relative to the stream than it was before the event. Consequently, the rate of ground water flow is faster and the rate of discharge at the stream is greater than before. This portion of flow in the stream that is due to the discharge from the aquifer, as opposed to the contribution from runoff, is called baseflow.

Baseflow reaches its peak rate during times of recharge and gradually decreases during the intervals between events. During extended droughts, normally perennial streams can go dry simply because the water level in the aquifer falls below the lowest point in the streambed. This is why the upper reaches of streams tend to be more intermittent than lower reaches. When water levels are highest, the water table rises above the streambeds of the uppermost, often dry stream reaches and they begin to flow. Thus, the aquifer can be seen as a water storage system that maintains flow in the streams during dry weather. The streams can be seen as overflow protection for the aquifers. In a sense, the aquifers are full as long there is flow in the streams. Even during the worst droughts, only the shallow aquifers and shallow wells in deep aquifers are ever in danger of going dry.

Baseflow to streams is reduced by ground water diversions. Discharges at wells are true discharge areas and cause ground water to flow toward the wells by lowering the hydraulic potential in and near the wells. Some of the water that would otherwise discharge at streams and wetlands is currently discharged at wells. Unlike the flow in streams, the demand from wells does not decrease by orders of magnitude during droughts. If the aquifer is locally being pumped for a diversion, there is a danger of changing a normally upward gradient and inducing the downward migration of contamination from a surface water body or water-table aquifer or, in coastal areas, of inducing the intrusion of saline water. There is also the danger that the streams will go dry. In addition to the population dependent upon surface water, the loss of baseflow can damage or destroy wetlands and impair stream ecosystems and water quality.

When water is diverted for various uses, a portion of it is lost through evaporation. What remains is either discharged to the ground surface, to subsurface disposal systems, or is directed to a storm or sanitary sewer. Ultimately, the water reaches the stream, although it may some distance downstream from the point it would have otherwise discharge if it were not diverted. In some cases, the treated wastewater is discharged into a different basin.

The principal impact of ground-water diversion on baseflow can be expected during times of low stream flow. Extremely low stream flow conditions recur with a certain frequency. Some tributaries will intermittently go dry. Because ground-water diversions remove water that would otherwise discharge to sustain flow rates during drought conditions, the low flows, normally associated with severe droughts, may recur more frequently. The USGS has calculated low-flow recurrence statistics for streams that it monitors. One means of estimating the impact of ground-water diversions on the baseflow of a stream is to calculate a low-flow statistic, such as the MA7CD10, using historical data and then to calculate it a second time using recent data. The MA7CD10 of a measuring point on a stream is the minimum flow averaged over seven continuous days that recurs with an average frequency of 10-years. It is also called the 7Q10 or $7Q_{10}$. Comparing the two values will give an indication of the amount of impact induced by the increase of diversions over time. Unfortunately, such a comparison is not available, despite the existence of an excellent benchmark study (Gillespie and Schopp 1982) for all the major river basins in New Jersey based upon pre-1976 data.

A rough idea of the impacts of increased demands for ground water in WMA 6 on baseflow can be obtained by plotting the average monthly diversions obtained from USGS gaging stations with long periods of record. These stations include one on the Rockaway River above the Boonton Reservoir, which has been maintained since 1938, another station below the reservoir (maintained since 1961), one on the Passaic River at Millington (since 1922), another on the Passaic River at Chatham (since 1904), and a fifth station on the Whippany River at Morristown (since 1922).

Because the Boonton Reservoir has a heavy supply demand, the flows immediately downstream do not always reflect the actual flow in the Rockaway River upstream of the station. Regulation reportedly affects the flow at the station upstream of the reservoir as well. In addition, diversions have been known to affect the flow measured at the Rockaway and Passaic River stations during times of low flow. Gillespie and Schopp (1982) deemed the occasional regulation of the flow in the Whippany River at Morristown to be “not usually significant” with respect to low flows. The average monthly flows for these locations were downloaded from the websites of the individual gaging stations and are presented here. These were located using a helpful website with an index linking all the gaging station home sites in New Jersey:

http://waterdata.usgs.gov/nj/nwis/current/?type=flow

The lowest flow time of the year at the five gaging stations tends to be the summer. Plots of the average monthly flows for the summer months show great differences between dry years and wet years. The wet year monthly average flows can be two orders of magnitude greater than those of dry year flows. Only summer monthly flows at the Rockaway River station downstream of the Boonton Reservoir clearly exhibit the effects of regulation. The remaining four stations appear to resemble the flows at the Whippany River station, which were practically unregulated. In each case, the lowest average flows, which typical occur during the summer months of the driest years, do not seem to be significantly lower or to recur more often in recent years than they did in previous years. However, in the drought of 2001-2002, extremely low monthly stream flows occurred not only in the summer, but also extended for 8 months from July 2001 to March 2002, through the usual winter recovery period.

APPENDIX 1.8

AVERAGE SUMMER MONTH FLOW RATES
AT USGS GAGING STATIONS IN WMA 6

This appendix contains plots of the average summer month flow rates for USGS gaging stations with continuous or daily records in WMA 6. The data were obtained from the USGS New Jersey Surface Water Gaging Station website:

http://waterdata.usgs.gov/nj/nwis/current/?type=flow

The average monthly stream flows are presented in units of cubic feet per second (cfs) and plotted on a logarithmic scale against the date that they represent.