
GROUND WATER IN THE RARITAN RIVER BASIN

A Technical Report for the Raritan Basin
Watershed Management Project

New Jersey Water Supply Authority

Final Report: June 2002



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This report was developed using geographic information system digital data developed under the auspices of the New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP or the original author(s) of the study.

The NJ Water Supply Authority would like to thank the Characterization Committee, Project Team and Technical Advisory Committee of the Raritan Basin Watershed Management Project for all of their comments, hard work and suggestions. Project Team members include:

- New Jersey Department of Environmental Protection
- New Jersey Water Supply Authority
- North Jersey Resource Conservation and Development Council
- Rutgers Center for Environmental Communication
- South Branch Watershed Association
- Stony Brook-Millstone Watershed Association
- United States Department of Agriculture – Natural Resources Conservation Service
- United States Geological Survey
- Upper Raritan Watershed Association

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GROUND WATER OF THE RARITAN RIVER BASIN

A Technical Report for the Raritan Basin Watershed Management Project

Summary

The Raritan River Basin includes 16 major watersheds, and comprises approximately 1,100 square miles. The New Jersey Department of Environmental Protection (NJDEP) has aggregated these watersheds into three Watershed Management Areas (WMAs), as shown in Figure 4-Municipalities and Road Network within the Raritan Basin, of the technical report "Setting of the Raritan River Basin." These areas are the Upper Raritan WMA (WMA 8), the Lower Raritan WMA (WMA 9) and the Millstone WMA (WMA 10).

This technical report focuses on the ground water resources of the Raritan River Basin and includes detailed descriptions of ground water recharge capabilities and carrying capacity for septic systems for the subwatersheds of the Basin. It includes information on public community water supply wells and known contaminated sites and provides a general summary of the existing regulations and plans that aid in the protection of ground water resources. This report should serve as a tool to manage and protect against future ground water recharge losses and as well as aid in better management of septic systems densities. Municipal master plans, zoning, development ordinances, land management practices and restoration projects all can make use of information from this and other Raritan Project technical reports.

Descriptions in this report of geologic features and water availability rely heavily on other technical reports prepared for the Raritan Basin Watershed Management Project including the "Water Budget" and "Water Availability of the Raritan River Basin" Technical Reports. Detailed geographic information system (GIS) analyses conducted by the Upper Raritan Watershed Association provide the basis for the sections on ground water recharge and estimated carrying capacity for septic systems. The ground water recharge analysis was performed using the New Jersey Geological Survey's (NJGS) Geological Survey Report (GSR-32) method, which estimates ground water recharge below the plant root zone using municipality-based climatic, soil and land use/land cover factors. The septic system carrying capacity analysis was conducted using a New Jersey Department of Environmental Protection (NJDEP) method that estimates the total number of septic systems that may be accommodated within a geographic area using average loadings of nitrates per septic system, estimates of ground water recharge from precipitation based on the GSR-32 method, and a target concentration for nitrates from the Ground Water Quality Standards (NJAC 7:9-6) using the Class II-A antidegradation policy. Limitations of the model and results are discussed further in the section on estimating carrying capacity for septic systems, below. Other GIS data included in this report were obtained from the NJDEP's Bureau of Geographic Information and Analysis, Division of Watershed Management and Site Remediation Program.

Ground Water Recharge

The ground water recharge analysis reveals that of the 136 subwatersheds in the Raritan Basin, 130 have experienced losses in recharge between 1986 and 1995 due to land uses changes from more to less permeable surfaces. Of these, the majority of losses have ranged primarily between 0–10%; however, several watersheds have lost between 10-25% of their recharge, primarily in the Route 1 corridor in the southern part of the Basin and the Route 46 corridor of the extreme northern part of the basin. Of the Basin subwatersheds, all 51 in the Upper Raritan WMA, 42 of the 46 in the Lower Raritan WMA, and 37 of the 39 in the Millstone WMA

experienced some recharge losses. Increases in recharge occurred in 4 of the 46 subwatersheds in the Lower Raritan WMA and 2 of the 39 subwatersheds in the Millstone WMA. It is important to note that the estimates are for recharge to ground water units; recharge of underlying aquifers (which support large-scale water supply wells) may well be lower, depending on local geology. As ground water recharge supports stream flow during dryer periods, significant reductions in recharge are expected to have harmful effects on this stream baseflow, causing stresses to stream ecosystems and human uses of surface waters. Close attention to controlling the creation of more impervious surface, and the implementation of possible mitigation measures, will be necessary if ground water recharge is not to decline further in the Basin.

Ground Water Contamination

The known contaminated sites of the Basin are generally concentrated in the more urbanized sections of Union, Middlesex and Mercer counties and fall within major transportation corridors of the Basin. Additional sites are scattered in more suburban areas of the Basin. Other potential ground water contamination sources include the 60 landfills, 500 permitted ground water discharges, 4,600 underground storage tanks and 28 Superfund sites of the Basin. Of the approximately 350 public community water supply wells located in the Basin, 48% are located within a half-mile of a known contaminated site (with confirmed ground water contamination). Forty-three percent (43%) of the wells in the Upper Raritan WMA, 51% in the Lower Raritan WMA, and 52% in the Millstone WMA are located within a half-mile of one of these sites. Of the approximately 980 contaminated sites known to exist in the Raritan Basin, approximately 180 are located within the well head protection areas delineated by NJDEP and 59 are located within Tier 1 areas, closest to the wells. Information from the NJDEP Source Water Assessment Program, due in 2003, will provide a more detailed understanding of the potential risk to public water supply wells from contaminated sites and other pollutant sources.

Septic System Capacity

Using a nitrate target of 5.5 mg/L and the NJDEP method, the estimates of septic system capacity indicate that no subwatershed can support septic systems with lot sizes of less than 1.64 acres on average, and most subwatersheds would require average lot sizes of more than 2 acres, with many in excess of 3 and 4 acres. As these estimates use a standard, basin-wide method and a nitrate level that is considerably above the current average quality, the estimates should be considered the highest density (septic systems per square mile) appropriate for septic systems. Local geology, development patterns, existing septic systems and other existing pollutant sources may justify larger average lot sizes. Perhaps even more importantly, the use of a lower nitrate target (e.g., closer to current concentrations of 1 to 2 mg/L) would have a proportional effect on the resulting calculation of septic system capacities. For instance, a soil that yields a result of 2.4 acres per septic system with a nitrate target of 5.5 mg/L would yield a result of 6.5 acres per septic system with a nitrate target of 2.0 mg/L.

In general, the model indicates that the Upper Raritan WMA could support the most septic systems per area and the Lower Raritan WMA could support the least, primarily due to precipitation, soil percolation and land use differences. These results are consistent with the ground water recharge results and also reflect the impact of impervious surfaces. The Lower Raritan WMA is by far the most developed. The Upper Raritan WMA has the least development, higher precipitation levels and many soils that have higher infiltration rates (although some of the underlying aquifers may have limited storage capacity).

Given that the NJDEP methods are based on statewide analytical methods and water quality policies, Basin municipalities can consider the results of this report as the minimum level of stringency necessary to protect ground water resources, and should consider more localized analyses that reflect local geology and incorporate antidegradation policies reflecting local needs. Further, the Raritan Project did not assess the number of existing septic systems per subwatershed, due to the large size of the Basin. One sample analysis, for the subwatersheds of the Spruce Run Reservoir, indicated that there is significant remaining capacity for septic systems (using the basin-wide methods described above, rather than local analyses), but that the majority of

existing septic systems were placed at a much higher density than the carrying capacity would allow. For specific subwatersheds, the next step would be a comparison of the estimated septic system capacity from this report or more local analyses, to the number of existing septic systems. The result is the remaining capacity for new septic systems, which would then be compared to the available land for development to determine an appropriate development density for septic systems. Other development constraints should be considered as well in any zoning analysis.

Hydrology

Definition of Ground Water

Ground water is defined as “that part of the subsurface water that is in the saturated zone,” or the “subsurface zone in which all voids are filled with water.”¹ Ground water is “that fraction of the precipitation on the land surface that has worked its way downward by gravity through the soil and into the underlying bedrock” in areas underlain by bedrock.² Ground water includes all water in the saturated zone; however, not all ground water is contained in aquifers. Aquifers are geologic formations that store, transmit and yield significant amounts of water for human use, generally through wells. In other words, all aquifers contain ground water, but only a fraction of all ground water is in aquifers.

Concepts of Ground Water Flow and Recharge

As precipitation reaches the Earth’s surface, some flows over the land’s surface as surface water runoff, some evaporates and some seeps into the ground. The process by which water seeps into the ground is referred to as infiltration. Some of the water that infiltrates is taken up by plant roots and returned to the atmosphere, while some penetrates deeper into the ground to become ground water. Factors such as climate, soil and vegetation types and existing land uses affect the process of ground water recharge. For instance, wind conditions, humidity, air temperatures, soil texture, water-holding capacity of the soil, the water content of the soil prior to a precipitation event, and the depth of plant roots may enhance or reduce infiltration.³

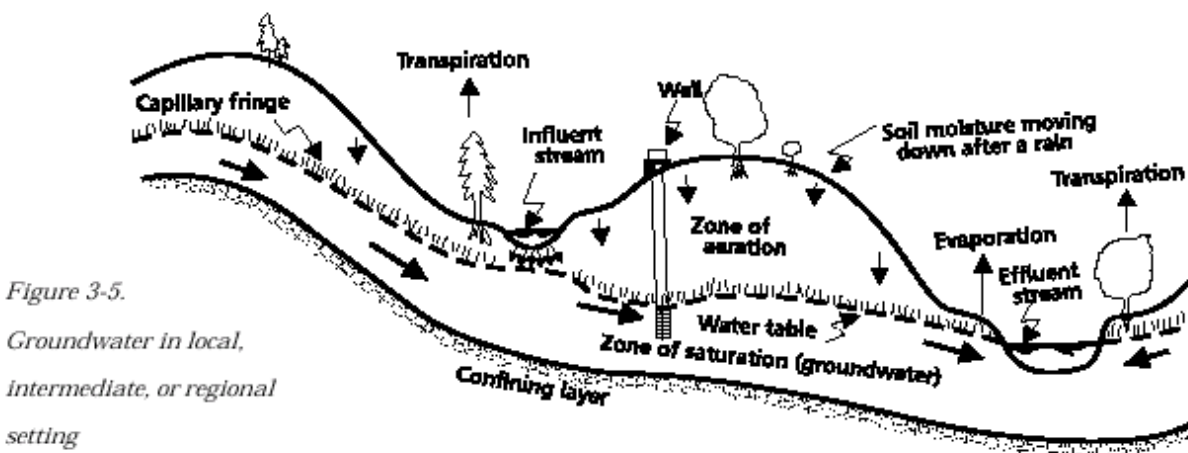


Figure 3-5.
Groundwater in local,
intermediate, or regional
setting

From Prince George’s County, MD, 1999, Low-Impact Development Design Strategies, p. 3-8

Long after rainfall events, when surface runoff ceases, ground water that is close to the surface sustains the water flow in streams. This ground water discharges slowly to streams. This process occurs where the water table (the upper surface of the saturated zone) is higher in elevation than the stream surface. During periods of

low precipitation, when there is little or no surface water runoff, the only natural contribution to streamflow is that discharged from ground water systems. However, if excessive well pumping or loss of ground water recharge has reduced the ground water levels, this critical baseflow to streams can be lost.⁴

Hydrology, Topography and Geography

Variations in rock type and geologic history of different regions of the State have created three different physiographic provinces in the Raritan Basin, each with unique surface topographies: the Coastal Plain, Piedmont and Highlands provinces. Each province consists of different types of consolidated (e.g., rocks) and unconsolidated (e.g., sand, gravel, silt and clay) deposits with characteristic physical properties (see Figure 6 of the technical report "Setting of the Raritan River Basin"). In the northwest portion of the Basin, glacial deposits cover parts of the Piedmont and Highlands. Each physiographic province and glacial deposit is associated with characteristic aquifer systems and ground water flows. The major aquifer units within these physiographic provinces in the Raritan Basin are discussed in the technical report "Setting of the Raritan River Basin." Ground water supplies in the Raritan Basin range from limited to prolific, depending on the geology of the area (see Figure 7 of the technical report "Setting of the Raritan River Basin").

The Basin is higher in elevation to the north, northwest and (in places) to the southwest (see Figure 5 of the technical report "Setting of the Raritan River Basin"). Surface water movement is generally from west to east in the central part of the Basin, from north to south in the northern portion, and from south to north in the southern portion of the Basin (see Figure 10 of the technical report "Setting of the Raritan River Basin"). Stream flow is monitored at a number of stations within the Basin through a cooperative network operated by the U.S. Geological Survey (USGS) and the NJDEP (see Figure 10, "Setting" report). There are 100 municipalities and 7 counties partially or wholly within the Basin (see Figure 4 of the technical report "Setting of the Raritan River Basin").

The Coastal Plain Province covers the southeastern Raritan Basin, in eastern Middlesex County, western Monmouth County, and northeastern Mercer County. In cross section, it is a wedge shaped sequence of unconsolidated sediments composed of sand, gravel, silt and clay that thickens to the southeast (with the exception of the Tinton formation). The sequence is composed of four major aquifer systems separated by clay or silt layers that act as confining or semi-confining barriers. The major coastal plain aquifers are, from oldest to youngest: the Potomac-Raritan-Magothy (also referred to as the Lower, Middle and Upper aquifers), Englishtown, Wenonah/Mount Laurel, and Kirkwood-Cohansey. All are present in the Raritan Basin. As these are unconsolidated sediments, water migrates through areas of higher hydraulic conductivity (natural channels) and pore spaces between the aquifer sediments. These characteristics make them prolific water sources for public wells.

The Piedmont Province covers a large portion of the Raritan Basin, in Middlesex, Union, Somerset, Mercer and Hunterdon Counties. Sedimentary rock units such as the Stockton and Lockatong Formations and the Brunswick Group are the primary aquifers. Other geologic formations in the Piedmont that have limited water bearing potential include the diabases and basalts of the Sourland Mountains in the southwest portion of the Basin and the Watchung Mountains in the northeast. Water movement in these consolidated rocks is primarily through joints, bedding planes and fractures that were created by the original deposition and weathering of the rock formations. This type of flow allows relatively limited movement of water through the aquifer system, though some wells in the Brunswick Group can produce large volumes of water. Formations of the Piedmont are hydraulically connected with local streams, where semi-confining glacial deposits do not cover them.

The Highlands Province covers most of the northwest Raritan Basin. Some of the Highlands rock formations are among the oldest in New Jersey. All but the dolomitic limestone formations in the Green Pond Outlier are poor aquifers. The limestone aquifers can be very prolific, with water movement through solution channels in the rock. However, these aquifers are very vulnerable to pollution from the land surface. The Spruce Run and Peapack-Gladstone valleys are part of the Highlands Province and are underlain by these limestones. Similar

to the Piedmont, water movement outside of the limestone areas is primarily through joints, fractures and in particular through bedding planes in the formations. The older, Precambrian aquifers do not generally produce large yields, except near streams or where wells intercept major fault zones.

Glacial deposits consist of unconsolidated stratified (layered) and unstratified (mixed) deposits of gravel, sand, silt and clay. The thickest glacial deposits generally occur in New Jersey north of the Wisconsinan terminal moraine line that extends from Perth Amboy through Morristown to Belvidere. Only a small portion of the northern Raritan Basin has glacial deposits. North of this line, upland areas are generally covered by a thin layer of discontinuous glacial till (unstratified, mixed sediments), usually less than 50 feet thick. The valleys are filled with stratified drift and lake bed sediments that comprise aquifers and confining units, sometimes up to 300 feet thick. Glacial aquifers supply important quantities of water in Northern New Jersey. These buried valley (or valley-fill) aquifers are frequently the main local water supply sources. Streams flowing on top of the glacial deposits extensively recharge many wells that draw from the underlying aquifer. The Lamington aquifer system is an example of glacial sediments lying over bedrock aquifers, both of which are used for public water supply purposes.

Two major artificial aquifer recharge systems exist in the South River watershed. Middlesex Water Company operates one on behalf of the City of Perth Amboy. This system can take water from Deep Run and recharge it to the upper aquifer through a recharge basin. The Duhernal Water System (originally formed by Dupont, Hercules and National Lead; hence the name Duhernal) uses surface water from Duhernal Lake, on the South River in Old Bridge and Spotswood, to also recharge the upper aquifer. In addition, the Matchaponix Water System reportedly also utilizes ground water recharge as part of its supply.

Water Table vs. Confined Aquifer

The water table (or unconfined) aquifer is defined as a usable ground water unit that is in contact with the atmosphere through pores in the unsaturated soil above. Conversely, a confined aquifer is a usable ground water unit that is separated from an unconfined aquifer by an impermeable layer that “traps” the water under pressure in the aquifer below (refer to Figures 1 and 2 of the “Water Budget of the Raritan Basin” Technical Report).

According to the USGS, confined and unconfined aquifers are distinguished using the following criteria:

“An unconfined aquifer has a water table, which is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. This means that when a water table well is drilled, water will remain approximately at the same level where it is first encountered.”

“In wells tapping a confined aquifer, the water will rise in the well when it is first encountered during drilling, and will stand at a level above the top of the aquifer.”⁶

Aquifers are porous and permeable geologic formations that store, transmit and yield economically significant amounts of water. Aquifers store and pass water along to other aquifers or to surface waters. Bedrock geology plays a major role in determining what purpose an aquifer will serve – for example, limestone formations serve as passageways for water, while sandstone formations serve as effective storage areas.

In the Basin, confined aquifers exist within the Coastal Plain Province, particularly in lower Middlesex and Monmouth Counties. These aquifers are separated by confining or semi-confining barriers of clay or silt as discussed above.

Karst

Carbonate rocks such as limestone and dolomite are water-soluble and are particularly common in the southern portion of the Highlands province in the northwestern part of the Basin. Water that seeps downward into the cracks of limestone rock can dissolve the limestone to some extent. As this happens, caverns or openings form that allow water to flow downward through the rock. Eventually, even the densest limestone formations acquire enough porosity and permeability to become prolific aquifers.⁶

Karst refers to land areas that are underlain by soluble rock such as limestone or dolomite. Karst features include sinkholes, disappearing streams, springs and underground caverns. The most familiar karst feature is the sinkhole, which is a depression in the land's surface created by cavities formed in the underlying soil and rock. A number of factors contribute to the formation of sinkholes including the thickness of the material overlying the bedrock, natural factors such as heavy rain or drought or artificial changes to the land surface caused by human activities.⁷

According to the NJ Geological Survey, carbonate rock formations are located in the Highlands province of the Upper Raritan WMA. A number of municipalities including Clinton Township, the Town of Clinton, Union Township, Lebanon Township, the Borough of Califon in Hunterdon County, Chester Township, Mendham Borough, Mendham Township, Washington Township, Mount Olive and Roxbury Townships in Morris County and Peapack/Gladstone in Somerset County contain formations consisting of carbonate rock.⁸ These areas often have karst topography, which presents special constraints on land uses, as the land surface is not stable.

Basalt/Diabase

The hard, dense and fine-grained composite of the trap rock comprising the diabase and basalt ridges of the Basin make them more resistant to erosion than other lower lying areas. These areas are well drained with highly jointed bedrock that have limited water bearing potential and water movement.⁹ Diabase ridges of the Basin include Cushetunk Mountain (surrounding Round Valley Reservoir), Rocky Hill, Bunker Hill and the Sourland Mountains in the Millstone WMA. The Watchung Mountains in the northeastern part of the Basin are comprised of basalt.

"Age" of Ground Water

The "age" of ground water refers to the amount of time that has passed since a particular drop of water entered into the ground. Some water remains underground only a year or two, while other samples may be from thousands of years ago. Confined aquifers tend to have much older water than water table aquifers.

Recharge time to wells can "range from a few days to a few hundred years, depending on the length of the flow path and the average velocity along the flow path."¹⁰ The amount of time it takes for ground water to travel from contributing recharge areas to deep wells typically takes many decades or hundreds of years, but distance from contributing recharge areas to shallow wells typically takes a much shorter time. Water that enters the ground close to a stream may reach the stream within days to a few years, as part of that streams base flow. The movement of ground water is contingent upon the permeability of the soil or rock, which is higher for sandy materials than for silt and clay.

Recharge and Uses

Definition of Recharge

Recharge occurs when enough water infiltrates into the soil to penetrate the unsaturated zone (soils and geologic strata), and makes its way down to the water table. Generally, a precipitation event yielding one inch of rain over a longer period of time is adequate to recharge ground water, unless the ground is frozen. A one-inch rainstorm event occurring in 30 minutes would probably recharge very little as compared with a one-inch rainfall occurring over 24 hours. In general, the more intense a rainstorm is, the less recharge occurs.¹¹

A ground water recharge area is the land surface area that allows precipitation to seep into (recharge) the saturated zone. The term ground water infiltration refers to all of the water that soaks into the ground past the root zone, whereas ground water recharge means that the water reaches the saturated zone. Aquifer recharge refers specifically to the water that recharges a geologic formation that is capable of supplying economic quantities of water, the aquifer.¹²

Ground Water Recharge in the Raritan Basin

Ground water recharge is a function of geology, soil depth and characteristics (well-drained, permeable soils), depth of plant roots and existing land uses. Areas with high ground water recharge capabilities are generally found on shallower slopes with permeable soils that are connected to underlying ground water units, allowing easy downward movement of the water.

The Raritan Project evaluated ground water recharge areas by subwatershed (or hydrologic unit, HUC-14) for the Raritan Basin, using the New Jersey Geological Survey's method (GSR-32) for evaluating ground water recharge areas in New Jersey. The GSR-32 method estimates ground water recharge (the volume of water transmitted to the saturated zone through soils) rather than aquifer recharge (recharge to geologic formations that can yield economically significant quantities of water to wells or springs) and is useful for evaluating the effect of present and future land uses on recharge areas.¹³ Estimates are for long-term average ground water recharge; these estimates are not appropriate for analyzing the impact of dry or wet years.

The NJGS model is based on site factors that are a function of a site's municipality (related to climatic factors such as rainfall and temperature), soil and land use/land cover. The model is used to estimate ground water recharge on a parcel of land and can also estimate changes in recharge resulting from changes in land use.¹⁴ The results can be aggregated to larger geographic areas such as subwatersheds, watersheds or political jurisdictions. This report provides results at the subwatershed level, aggregated from estimates for each land use polygon in the Basin using a Geographic Information System.

Figure 1a (Hydrologic Unit Codes in the Raritan Basin) was prepared for use in identifying the Hydrologic Units with 14-digit Hydrologic Unit Codes (HUCs) as shown on the ground water recharge figures. (Figure 1b shows the same HUC-14 areas with municipal boundaries, while Figure 1c shows municipal boundaries and surface waters.) Figures 2 through 4 show ground water recharge in inches per year and millions of gallons/day/square mile of recharge area for each Watershed Management Areas (WMA) of the Basin. Figure 5 shows the percent loss and gain in recharge for the subwatersheds of the Basin between 1986 and 1995. Figure 6 illustrates which land uses have changed to urban land uses between 1986 and 1995, while Figure 7 illustrates the urban land uses to which those lands have been changed; both figures are used to further assess recharge losses in the subwatersheds of the Basin.

Recharge to aquifers is dependent upon the surficial geology of an area. Determining aquifer recharge is beyond the capacity of the Raritan Basin project. In the Raritan Basin, it is likely that infiltration into the sandy soils of the Coastal Plain will make its way downward to the aquifers; however infiltration in areas underlain by

clays will not. Due to the consolidated rock units (e.g., diabase and basalt) in the Sourlands, Watchung Mountains, Locketong Formation and crystalline Precambrian rocks of the Highlands, there is very little aquifer recharge in these areas. As the Highlands receive more rainfall but contain consolidated rock units, it is possible for the Precambrian areas to have higher average levels of ground water recharge while having lower average levels of aquifer recharge.

In other areas of the Basin, including the Brunswick shale and limestone aquifers of the Highlands, it is difficult to predict how well aquifers are recharged. Infiltration is potentially available for aquifer recharge; however, true aquifer recharge rates are determined by underlying soils and geology and are not included in this report.

Ground Water Recharge in the Upper Raritan Watershed Management Area

Figure 2 illustrates ground water recharge in average inches per year for the subwatersheds of the Upper Raritan WMA based on 1995 land use/land cover data. Recharge ranged between 8.3 and 16.8 inches per year for the subwatersheds of the WMA, with the highest infiltration rates having occurred in the South Branch Raritan River watersheds (above Spruce Run and Three Bridges to Spruce Run) and in the Lamington River watershed. The WMA's average rate of recharge for 1995 was 12.15 inches per year as compared with 12.91 inches per year in 1986, for an overall loss of nearly 6 per cent.

Figure 2 also depicts annual average recharge in million gallons per day/square mile (mgd/mi²) for the WMA subwatersheds. The portions of the subwatersheds that NJGS assumes do not recharge to ground water such as wetlands and waterbodies are not reflected in these averages; only those land areas that contribute recharge are. The average 1995 recharge for recharge areas within the Upper Raritan WMA was 0.58 mgd/mi². The estimated recharge for the entire WMA (including areas that both do and do not recharge) for 1995 was 0.51 mgd/mi². This number compares well with the estimated recharge of 0.43 mgd/mi² (for the entire WMA) as calculated for the "Water Budget of the Raritan Basin" Technical Report using a less sophisticated method.

According to Figure 5, all 51 subwatersheds (HUC-14s) in the Upper Raritan Watershed Management Area experienced losses in recharge between 1986 and 1995, with the majority of the losses ranging between 0 and 10%. As reported in Table A-1, the losses ranged between 1.26% (0.15 inch loss) and 25.81% (2.9 inch loss).

Conversion of agricultural and forested land to residential, commercial and industrial land uses near the headwaters of the South Branch Raritan River in Roxbury Township, Mount Olive Township, Washington Township (Morris County) has contributed to significant recharge losses in the subwatersheds of the South Branch Raritan River above Spruce Run watershed. The headwaters of the Lamington River watershed in Mount Arlington Township and Mine Hill lost approximately 26% of its annual recharge between 1986 and 1995 (the highest loss of the WMA) and also saw conversion of several large tracts of forested land to commercial land uses.

Further downstream, Clinton Township and Lebanon Township also experienced conversion of forested and agricultural land to residential and urban land uses (Figures 6 and 7). In the South Branch Raritan River from Three Bridges to Spruce Run watershed, conversion of agricultural land uses to urban land uses in Union and Clinton Townships between 1986 and 1995 contributed to losses in recharge areas. As forested lands tend to have higher recharge rates and commercial lands tend to have high percentages of impervious surfaces, this land use change will tend to result in the largest reductions in ground water recharge. Randolph Township, Bedminster Township and Readington Township in the Lamington River watershed also experienced conversion of forested land to other land uses. Along the South Branch of the Rockaway Creek in the Lamington River watershed, Clinton Township, Lebanon Borough and Readington Township also experienced conversion of agricultural and forested land to residential and commercial land uses.

In Randolph, Chester and Mendham Townships in the North Branch of the Raritan River watershed (above its confluence with the Lamington), subwatersheds that lost greater than 5% of their annual recharge also experienced conversion of forested land as well as some agricultural land primarily to residential land uses. In

Bridgewater and Branchburg Townships in the North Branch Raritan River watershed (below Lamington), subwatersheds that lost greater than 5% of their annual recharge also experienced significant conversions of agricultural and barren land to residential and commercial land uses.

Ground Water Recharge in the Lower Raritan Watershed Management Area

According to Figure 3, average annual recharge in the Lower Raritan WMA ranged between 2.5 and 10.6 inches per year for the subwatersheds of the WMA, with the highest infiltration rates in the northern (Lower Raritan River - Lawrence to Millstone watershed) and southern (Manalapan Brook watershed) portions of the WMA. The average rate of recharge for 1995 was 6.68 inches per year as compared with 7.03 inches per year in 1986, a loss of nearly 5 per cent.

Figure 3 also depicts annual average recharge in million gallons per day/square mile (mgd/mi²) for the land areas that contribute recharge. The average 1995 recharge (for the recharge areas) within the Lower Raritan WMA was 0.33 mgd/mi². The estimated recharge for the entire WMA (including areas that both do and do not recharge) for 1995 was 0.25 mgd/mi². This number is less than the estimated recharge of 0.33 mgd/mi² (for the entire WMA) as calculated for the "Water Budget of the Raritan Basin" Technical Report, but does agree with the concept that recharge to the Lower Raritan WMA is much less than recharge to the Upper Raritan WMA.

According to Figure 5, of the 46 subwatersheds (HUC-14s) in the Lower Raritan WMA, 42 experienced losses in ground water recharge between 1986 and 1995. Losses reported in Table A-2 range between 0.51% (0.04 inch - a minimal change) and 17.73% (1.06 inches). Conversely, 4 of the subwatersheds in the Lower Raritan River watershed (Lawrence to Millstone) showed very small increases in recharge ranging from 0.97% (0.06 inches) and 3.45% (0.16 inches).

In the Lower Raritan River watershed from the Millstone River to the North & South Branch Confluence, Bridgewater Township was the only municipality including a subwatershed that lost greater than 5% of its estimated 1986 recharge. This area also experienced conversion of forested land, barren land, wetlands and agricultural land to industrial and residential land uses between 1986 and 1995 (Figures 6 and 7).

In the Lower Raritan River watershed from the Lawrence Brook to the Millstone River, three subwatersheds lost greater than 5% of their recharge potential. These subwatersheds (especially those within Franklin Township and along the Route 27 corridor) experienced significant conversion of agricultural land, forest land, wetlands, and barren land to commercial and industrial uses between 1986 and 1995. This area also experienced limited gains in recharge, particularly in the more urbanized areas of the Basin. Three of the subwatersheds in this watershed experienced minimal gains in recharge of 0.97% - 1.7% (0.06-0.07 inches per year); however one subwatershed increased by 3.45% (0.16 inches). Gains in recharge in this watershed may be attributed to the conversion of impervious lands (e.g., barren land) to more pervious land cover. In addition, areas of the watershed that were developed prior to 1986 may be experiencing re-growth of vegetation in residential areas or near commercial establishments, which could provide an increase in recharge in these areas.

More than half of the subwatersheds in the Lawrence Brook watershed experienced losses greater than 5% and 10%, particularly in the headwater areas of the Lawrence Brook in South Brunswick, East Brunswick and North Brunswick Townships. This watershed contains a subwatershed (located in South Brunswick Township) with a loss of 17.73%, the greatest loss experienced in the Lower Raritan WMA. All three municipalities in this watershed converted agricultural and forested land, wetlands and barren land to industrial and other mixed urban land uses between 1986 and 1995.

In the Manalapan Brook watershed, two of three subwatersheds lost greater than 5% of their recharge and also converted a significant percentage of forested and agricultural land to residential land uses. Similarly, the Matchaponix Brook watershed in Freehold and Manalapan Townships experienced conversion of forested and agricultural land to commercial and industrial land uses.

The Lower Raritan watershed (below the Lawrence Brook), which contains Deep Run and the South River, experienced losses in the lower reaches of the watershed near the tidal portion of the mainstem of the Raritan River. The greatest losses have occurred in the Edison/Woodbridge Township area and the Old Bridge Township/Sayreville Borough area.

Ground Water Recharge in the Millstone Watershed Management Area

Figure 4 illustrates annual average ground water recharge in inches per year for the subwatersheds of the Millstone WMA. Recharge ranged between 5.4 and 11.7 inches per year for the subwatersheds of the WMA, with the highest infiltration rate in the Stony Brook watershed along the Sourland Mountains, an area with very limited aquifers. The average rate of recharge for 1995 was 8.19 inches per year as compared with 8.62 inches per year in 1986, for a loss of nearly 5 per cent.

Figure 4 also depicts annual average recharge in million gallons per day/square mile (mgd/mi²) for the land areas that contribute recharge. The average 1995 recharge (for the recharge areas) within the Millstone WMA was 0.40 mgd/mi². The estimated recharge for the entire WMA (including areas that both do and do not recharge) for 1995 was 0.31 mgd/mi². This value is the same as the estimated recharge of 0.31 mgd/mi² (for the entire WMA) as calculated for the "Water Budget of the Raritan Basin" Technical Report.

According to Figure 5, of the 39 subwatersheds (HUC-14s) in the Millstone WMA, 37 experienced losses in ground water recharge between 1986 and 1995. Losses reported in Table A-3 ranged between 0.79% (0.07 inch - a minimal change) and 21.63% (1.58 inches). Conversely, two of the subwatersheds in the Millstone WMA showed very minor increases in recharge ranging from 0.01% (0.001 inches) to 0.38% (0.04 inches).

In the Stony Brook watershed of the Millstone WMA, the lower reaches of the watershed experienced recharge losses greater than 5% in Princeton Township and West Windsor Township -- two municipalities that converted a large portions of their agricultural and barren land to residential, commercial and industrial land uses (Figures 6 and 7). In addition, the easternmost subwatershed of this watershed bisected by the Route 1 corridor near West Windsor Township lost 21.63% (1.58 inches) of its recharge between 1986 and 1995.

In the Millstone River watershed upstream of Carnegie Lake, losses in recharge greater than 10% are evident in the portion of the watershed at the confluence with Devil's Brook near Plainsboro, South Brunswick, Montgomery, West Windsor and Princeton Townships. This area of the watershed (also adjacent to the Route 1 corridor), experienced conversions of large tracts of agricultural land, forested land and wetlands to urban land uses. Losses in recharge greater than 5% occurred in the downstream (northern) reaches of the watershed, to the west of the Route 1 Corridor in Plainsboro, South Brunswick, Montgomery and Princeton Townships. Additional recharge losses greater than 5% also occurred in North Brunswick Township and Franklin Township (Somerset County). These municipalities all experienced conversion of agricultural, forested and barren land as well as wetlands to residential, commercial and industrial uses. Minimal increases in recharge (0.01% and 0.38%) also occurred in two subwatersheds including the Beden Brook subwatershed in Montgomery Township near the Sourland Mountains, perhaps due to reforestation.

Simulation of Ground Water Flows

Computer simulation models of ground water flows play an important role in evaluating alternatives to ground water development and management. These models use a mathematical counterpart to represent an actual ground water system. Although the computer-based simulations are not always completely accurate in forecasting the future, they provide the best available decision making information at a given point in time.¹⁵

Carbonate Rock Aquifer System, Southwestern Morris County

In an effort to determine potential sources of ground water contamination to a valley-fill and carbonate rock aquifer system that extends along valleys of the Drakes Brook and Lamington River in the Highlands in Morris County, the USGS conducted a study in 1998 to better understand ground water recharge areas and flow patterns. The study used a numerical simulation model to describe ground water flow patterns and estimate areas contributing recharge to wells in the aquifer system. USGS determined that recharge to the aquifer system occurs as 1) direct infiltration of precipitation through the valley floor, 2) seepage from streams and lakes, and 3) infiltration of unchanneled runoff from adjacent bedrock upland areas, and that the recharge provides the source of water for supply wells that serve communities in southwestern and central Morris County.

The study indicated that the land areas contributing recharge to shallow wells were typically located near the well, however, areas contributing recharge to deeper wells typically consisted of "highly irregular or fragmented areas, parts of which were located thousands of feet from the well."¹⁶ Flow patterns varied throughout the aquifer system; however, it was determined that "areas that contribute recharge to wells increased and areas that contribute recharge to surface water decreased, resulting in streamflow reduction."¹⁷ Under simulated conditions, it was found that under full-allocation pumping rates from wells, ground water recharging the aquifer system would reach the active wells within 5 years as compared with the 12 years it would take under recent pumping conditions. This indicates that water would reach wells more quickly when pumping rates are greater, creating a greater potential for ground water contamination as pumping rates increase.

Ground Water Flow and Distribution of VOCs – Piscataway Township, Middlesex County

During a site excavation in 1988, volatile organic compounds (VOCs) (primarily carbon tetrachloride and tetrachloroethylene) were detected in an area surrounding a former laboratory of the Rutgers University Busch Campus in Piscataway Township, Middlesex County. In an effort to determine the source of VOC contaminated soil and ground water on the Campus, a digital model was used to characterize the hydrogeologic framework and to simulate ground water flow on the site. Ground water on the site discharges to the Raritan River and its tributaries, with a small amount discharging to wells in the study area.

To analyze ground water flow on the site, conceptual and digital models were used to determine the effects of flow on the distribution of contaminants. Water samples taken at the site revealed eleven VOCs that were present at concentrations above the reporting limits. "The digital model was used to approximate the configuration of ground water flow paths to determine whether a broken sump pipe was the source of the VOCs detected in the wells in the study area and to estimate the effects of pumping on flow paths."¹⁸ It was determined that the carbon tetrachloride plume was localized near the laboratory building, while the tetrachloroethylene was detected as far as 2,370 feet away from the building. The flow path analysis proved that the carbon tetrachloride originated at the broken pipe near the building. "Methods used in this investigation may be applicable to other areas of the Newark Basin where site-specific ground water flow patterns are of concern."¹⁹

Simulation of Ground Water Flow in the Kirkwood-Cohansey Aquifer System

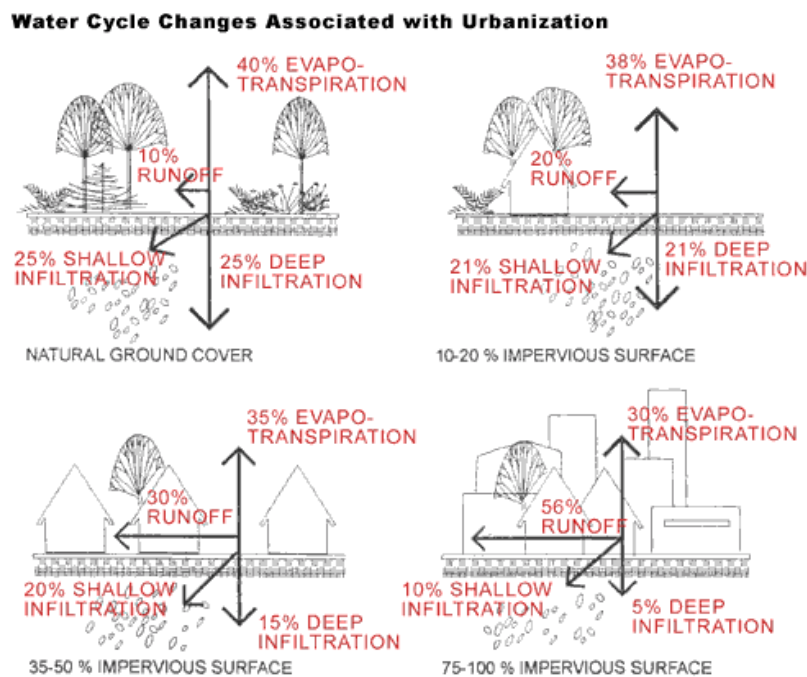
The Kirkwood-Cohansey aquifer system, a major source of water supply for coastal communities in Ocean and Monmouth Counties, is located partially in the Raritan Basin at the southernmost tips of the Lower Raritan and Millstone WMAs. This aquifer system is an unconfined system comprised of unconsolidated sediments including gravel, sand, silt and clay. Streams and other surface water features are hydraulically connected to the aquifer system. A 1997 study by the USGS in cooperation with the NJDEP simulated ground water flow in a portion of the aquifer system of the Toms River, Metedeconk River and Kettle Creek watersheds (located outside of the Raritan Basin).

The study was conducted to address concerns about possible hydrologic effects of additional ground water withdrawals on the system. Simulation results showed that withdrawals have lowered water levels from

predevelopment positions by as much as about 20 feet near pumping centers. Projected increases would further reduce ground water levels up to 20 feet in some areas. Historic withdrawals have resulted in average base flow reductions of 12% in some streams and projected withdrawals would further reduce average base flows.²⁰ The results of this study are generally applicable to the unconfined Coastal Plains aquifers of the Raritan Basin, but a local study would be necessary to determine precise effects of additional pumping.

Adverse Effects of Impervious Cover and Soil Compaction
Relative to Ground Water Recharge

Extensive impervious cover including roadways, driveways, buildings and sidewalks usually accompanies moderate to high density urban and suburban developments and can have dramatic effects on the natural landscape. Impervious surfaces increase surface water runoff, reduce recharge rates and leave less water to enter the ground to sustain baseflow of local streams. Impervious cover also results in increases in nonpoint sources of pollution as road salts and other contaminants wash off the surface and move directly to streams or other waterways.



Source: Environmental Protection Agency, *Guidance Specifying Management Measures for Sources of Nonpoint Source Pollution in Coastal Waters*, #840-B-92-002, 1993.

Compacted soils, or soils that have been compressed or are without air spaces, act in a manner similar to impervious surfaces. Soils that do not contain air spaces do not allow water to infiltrate but instead contribute to surface water runoff. The Landscape of the Raritan River Basin Technical Report provides detailed information on the location of impervious surfaces throughout the Basin.

Occurrences of Drought in the Basin

Ground water levels do not significantly fluctuate during short-term droughts. However, when precipitation drops off for longer periods, waterways and wells can dry up. As a result of record low stream flows in July of 1999 and a long-term rain deficit that began in the summer of 1998, a drought emergency was issued for the

entire State of New Jersey on August 5, 1999.²¹ Although reservoirs and stream flows were restored following Hurricane Floyd, the storm did not fully replenish ground water levels. The drought emergency was lifted for counties of the Basin on September 27, 1999 following Floyd; however, a statewide drought warning remained in effect until July 17, 2000. Water emergencies prior to the drought of 1999 occurred in late 1998, September 1995 and April 1985. The drought emergency of early 2002 also resulted in record low stream flows for many areas of New Jersey, providing more evidence that ground water levels did not recover from prior droughts.

Ground Water Withdrawals

The dependable yields of aquifers in the Basin are difficult to determine. Major aquifers tend not to be drought-sensitive, so the primary issue becomes an aquifer's long-term ability to provide sufficient water for stream flow, human use and aquifer storage levels. The NJ Statewide Water Supply Plan estimated that 20 percent of the total ground water recharge in non-coastal aquifers could be used and not returned to the aquifer without significant harm to stream flows. Coastal aquifers can be sensitive to saltwater intrusion, so the assumption was made that only 10 percent of total recharge is available from those areas. The NJDEP-NJ Geological Survey estimated ground water recharge in the early 1990's using baseflow analysis of streams within each watershed. The assumption made is that ground water recharge will equal stream baseflow over long periods, if ground water is not diverted through water supply withdrawals. Based on the NJGS analysis, the following quantities were used for annual average yields from Basin aquifers.

RARITAN AQUIFER AREA	ESTIMATED DEPENDABLE YIELD
Raritan River Basin (except below)	110.5 MGD
South River/Lawrence Brook Watersheds	24.7 MGD
TOTAL	135.2 MGD

Because the South River area is included within Water Supply Critical Area #1 and is subject to extensive restrictions on ground water withdrawals, NJDEP assumed that little if any additional ground water is available from that region. It should be recognized that the figures for dependable yields of ground water are general estimates for large areas, and are not appropriate for use in small watersheds, site-specific or municipal planning, etc. For such localized applications, estimates should be tailored to the actual area. In addition, assessments must consider yield losses from ground water pollution in certain areas. Rural, urban and industrial areas have all been affected. A number of public water supply wells have been taken "off line" due to contamination; industrial solvents and petroleum hydrocarbons are the most frequent causes. However, the impacts are difficult to generalize. Some contaminated wells have been replaced by new wells in nearby parts of the same aquifer. Others could be restored to use by adding water treatment systems, but are currently not used. In the latter case, surface water supplies have been used to replace the "off line" or abandoned wells.

Ground Water Discharges

Natural recharge to ground water by soils with natural recharge capabilities is obviously the preferred method for recharging ground water supplies; however, due to the rapid drawdown of ground water aquifers for human uses, artificial recharges to ground water help maintain ground water supplies in some areas.

Direct discharge of treated wastewater effluent to ground water is beneficial in sustaining ground water supply systems, provided the water being discharged is not contaminated. Once an aquifer becomes contaminated, it takes a long time to return the water quality to an unimpaired quality due to the slow movement and natural processes of ground water. In addition, ground water remediation projects are very expensive and generally only partly successful.

The discussion below on NJPDES Discharges to Ground Water (in the Water Quality section) provides a list of the facilities discharging wastewater effluent to ground water systems within the Basin. In addition, tens of thousands of domestic septic systems discharge less well-treated effluent to ground water in rural and some suburban areas.

Public Uses

Wells of the Basin

The New Jersey Safe Drinking Water Act (NJSA 58:12A-3) defines a public community water system as a system for the provision to the public of piped water for human consumption, which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. A public non-community water supply well is a public water system that services less than 15 connections or at least 25 non-permanent residents (e.g., a business or hospital). In both cases, the well owner may be a public entity, investor-owned, or private. Non-public wells (including domestic wells for individual homes) are not regulated by the Safe Drinking Water Act and are not addressed in this technical report. However, testing of domestic wells will be required at the time of real estate transfers beginning late in 2002.

As part of the Source Water Areas delineation process, the NJDEP has cataloged and field-located public community water supply wells for New Jersey. Figure 8 provides an illustration of the 349 wells in the Raritan Basin as of 2002 by pump rate (the number of gallons a well can pump per minute). This coverage includes wells added and wells abandoned after June 3, 1998. Table B-1 lists the 349 wells for the Basin by municipality, watershed management area, physiographic province, status of the well, depth of the well, geologic formation, confinement status, and pumping capacity. Of these wells, 301 are classified as operational, 33 are inactive, 8 are standby (operational but used for emergency or other short-term purposes; not used on a regular basis) and 7 are new wells.

Wellhead Protection Areas

A wellhead protection area (WHPA) is a delineation at the ground surface of the portion of an aquifer that contributes water to a well within a defined time period. The NJDEP intends to delineate WHPAs for all public wells using the 3-tier approach by 2003 through the Source Water Assessment Program, as required by the federal Safe Drinking Water Act.

“Aquifers are recharged with water from precipitation that percolates through pervious land surfaces and becomes part of the flow of ground water. It is within the wellhead protection areas that land uses that introduce pollutants are most likely to contaminate drinking water sources. Historically, the land uses and commercial and industrial facilities/activities that have been identified as major sources of ground water contamination in New Jersey include, but are not limited to: underground storage tanks, septic systems, surface spills, unsecured landfills, leaking drums, above-ground storage tanks, road salt piles, and lagoons/surface impoundments.”²²

A WHPA consists of three tiers that are based on a time of travel (TOT) within the zone of contribution, or the time it takes a particle of water to travel in the saturated zone from a given point to a pumping well. Tier 1 has a TOT of two years, Tier 2 has a TOT of 5 years and Tier 3 has a TOT of 12 years. TOT's are important in determining the risk of contamination to a well or the amount of time it would take for a new plume of contamination to reach a certain well.

Due to the effects of long periods of drought conditions, well overuse and water quality impairment of ground water resources, and as a result of the 1986 Federal Safe Drinking Water Act Amendments, the NJDEP has developed a well head protection plan for both public community and public non-community water supply wells.

The plan was approved by the USEPA in 1991 and its primary goal is to prevent the contamination of the State's ground water resources, which provide drinking water to approximately 42% of New Jersey's population.²³

Figure 8a provides the draft WHPAs for public community water supply wells within the Raritan Basin, as delineated by the New Jersey Geological Survey in 2001. The shape and size of the WHPAs vary greatly based on their geological location, well depth and pumping capacity. Some Coastal Plain wells, in the southeastern Raritan Basin, have no apparent WHPA. These wells are in confined aquifers and only have a circular 50-foot WHPA that does not show on the map. Other wells in the Coastal Plain province and many in glacial deposits of the northwestern Raritan Basin tend to have round shaped (indicating that the wells draw evenly from all around them) or a shape like a baseball diamond (indicating that ground water flow to the well is normally from one general direction). Wells in the Piedmont tend to have lozenge-shaped WHPAs, which may indicate that the wells draw primarily from two sides due to a relatively flat ground water table that is affected by ridges or the direction of aquifer fractures on the other two sides. Table 1 provides information on the land area contained within the WHPAs shown in Figure 8a. The total area of all WHPAs for public community water supply wells is approximately 138 square miles, or 12 percent of the Raritan Basin. The Upper Raritan, which is primarily dependent on aquifers for its potable water supplies, has the greatest percentage of land in WHPAs, with the Millstone having the least.

Table 1 – Wellhead Protection Areas (WHPA) by Watershed Management Area (WMA)							
WMA	Tier 1 (square miles)	Tier 2 (square miles)	Tier 3 (square miles)	WHPA Total Area (square miles)	WMA Total Area (square miles)	Pct WMA in WHPA	Pct WMA out of WHPA
Upper Raritan	16.7	19.2	29.8	65.7	468.4	14%	86%
Lower Raritan	13.1	12.5	19.3	44.9	351.5	13%	87%
Millstone	5.8	7.8	13.8	27.5	284.6	10%	90%
Totals	35.6	39.6	62.9	138.1	1104.5	12%	88%

Figures 9 and 10 illustrate two other examples of methods that have been used to map wellhead protection areas in the Basin. Figure 9, a re-creation of a map prepared by the Upper Raritan Watershed Association for the Alamatong Wellhead Protection Study, based on modeling by the US Geological Survey, illustrates highly detailed wellhead protection areas for public community water supply wells and large capacity industrial wells in and near the Alamatong well field in the uppermost portion of the Basin in Morris County. This figure shows the well locations and the surrounding land uses that contribute recharge within the 12-year TOT to the well. For some deeper wells, the 12-year recharge area is not contiguous with the wells. It also provides locations of known contaminated sites and solid waste landfills that may be located within the contributing land use areas. This sophisticated method provides a useful tool for determining the level and type of protection needed for a major well field area. The Alamatong Wellhead Protection project focused on information about land cover and land use within contributing recharge areas as a basis for developing strategies for protecting the well field and other supply wells in the highly productive aquifer in western Morris County. The study analyzed the 5 year and 12 year TOT criteria and it was determined that within the 5 year TOT area, there was a potential for pollution to affect one or more of the wellhead areas.

Figure 10 illustrates the results of a public non-community well mapping project conducted by the South Branch Watershed Association as part of the New Jersey Highlands Wellhead Protection Program in 1998. The project used a relatively simple method to map approximately 430 public non-community wells in 29 municipalities of Hunterdon and Morris Counties located along the South Branch of the Raritan River. As part of

the project, the three wellhead protection tiers were plotted for each well, which have served as interim wellhead review areas and can be further refined once specific calculations are performed on each individual well. Figure 10 shows the location of 13 public non-community wells located in Roxbury Township, Morris County extracted from the SBWA wellhead protection program database. Figure 10 was created in an effort to demonstrate how the well data can be used to assess surrounding land uses and potential threats to wellhead protection areas as delineated by the SBWA. The wells depicted in Figure 10 are primarily located within commercial and industrial land use zones. SBWA created the document to be easy to use, to aid local government in protecting wells within their jurisdiction.

Water Quality

Causes of Ground Water Contamination and Effects of Land Use on Ground Water Quality

Although it was once believed that ground water was naturally protected from contamination, research in the 1970s showed that contaminants did indeed pass through the many layers of soil and particles of sand, gravel, crushed rocks and larger rocks to reach ground water and aquifers. Ground water contamination may originate on the surface of the land (e.g., dumps, accidental spills, fertilizers, pesticides), underground above the water table (e.g., septic systems, underground storage tanks, underground pipelines) or underground below the water table (e.g., mines, waste disposal in wells). The location at which a contaminant is introduced and the rate at which the contaminant moves through the ground determine the amount of time it takes the substance to reach the ground water.²⁴

Ground water contamination occurs from a variety of sources including substances that occur naturally (e.g., iron, calcium and selenium) or from man-made substances including synthetic organic chemicals and hydrocarbons, liquid waste from landfills, and other substances such as heavy metals, road salt, bacteria and viruses. Other sources include improper disposal of used motor oil and other household hazardous materials including batteries, paints and cleaning products. In addition, waste products from septic tanks, pet and other animal wastes can make their way into ground water supplies. Land use activities involving the application of fertilizers and pesticides have the potential to harm ground water quality. When too much fertilizer is applied, the plants cannot absorb it so it makes its way to local streams and ground water. Past industrial practices and storage areas also contribute to ground water contamination.

Saltwater intrusion

When coastal aquifers are drawn down too far, salt water from oceans, bays or estuaries can advance underground towards the freshwater aquifer. Encroachment of saltwater often renders aquifers unfit for human consumption and reduces the intensity and distribution of pumping from the aquifer. Saltwater intrusion can occur in both confined and unconfined aquifer systems if they are located near saltwater sources.

The Water Supply Critical Area (WSCA) #1 was identified as a major aquifer area with declining water levels and evidence of saltwater intrusion. To help alleviate this problem in WSCA #1, located in Middlesex, Monmouth and Ocean Counties (partially in the southeastern Raritan Basin), the NJDEP reduced the use of ground water from the depleted system and required water allocation permittees to develop a replacement supply, which is Raritan Basin surface water. Reductions in withdrawals of 50 percent went into effect into 1990, and surface water from the Raritan Basin was piped to the South River area. Since that time, significant aquifer level recoveries have been evident, and a reanalysis of the WSCA #1 is currently in progress.

*Vulnerability of Public Drinking Water Supplies to Pesticides and Arsenic**Pesticides*

In an effort to determine the vulnerability of ground water supplies to pesticide contamination, the NJDEP Bureau of Safe Drinking Water commissioned a study that looked at land uses surrounding wells and the types of pesticides used on the land parcels to determine the sensitivity of the wells to contamination. In the study, wells in New Jersey were assigned a ranking of low, medium or high sensitivity to contamination. Of the 554 wells in the Potomac-Raritan-Magothy aquifer of the Coastal Plain, 110 had a high sensitivity, 129 had a medium sensitivity and 315 had a low sensitivity ranking. Of the 186 wells in the sedimentary bedrock aquifers of the Piedmont province, 182 had a high sensitivity, 4 had a medium sensitivity and none had a low sensitivity ranking.²⁵

The USGS, in cooperation with the NJDEP determined the vulnerability of wells and surface water intakes to pesticide contamination on the basis of hydrogeology and pesticide use. Of the 1,955 public supply wells monitored for pesticides in New Jersey, the vulnerability was low for 26%, medium for 70% and high for 4%. Of 90 wells tested, 6 contained pesticide concentrations with concentrations ranging from 0.01 to 2.2 micrograms per liter (all below the USEPA maximum contaminant level). Pesticides were not detected in any wells in the low vulnerability group but were detected in 19% of the wells in the high vulnerability group. Pesticides were detected most frequently in agricultural areas and less so in residential and undeveloped areas. In the Raritan Basin, wells of the Highlands Province in Morris and northern Somerset Counties are characterized primarily as medium vulnerability with several wells characterized as low. The majority of the wells in the western section of the Piedmont in Hunterdon, Mercer and Somerset Counties are characterized as high vulnerability, with those in the eastern part of the Basin near the Watchung Mountains characterized as medium vulnerability. Wells of the Coastal Plain portion of the Basin in Middlesex and Monmouth Counties, most of which are in confined aquifers, are characterized as low vulnerability.²⁶

Arsenic

In June 2000, the NJDEP issued an "arsenic in drinking water advisory" for people living in the Piedmont physiographic province that use well water as their drinking water supply. Arsenic is an element that occurs naturally in soil and rock and has also been used as an ingredient in certain industrial processes and in some pesticides. Based on recent research, the USEPA adopted a rule to lower the standard from 50 parts per billion (ppb) to 10 ppb. Arsenic in drinking water has been associated with long-term health risks such as cancer and other diseases including cardiovascular disease, diabetes and neurological effects. The NJ Drinking Water Quality Institute will be re-evaluating the New Jersey human health criterion for arsenic during future rule making, but the federal standard now applies to New Jersey. Further information on New Jersey's drinking water standards is available on the NJDEP web page at <http://www.state.nj.us/dep/watersupply/standard.htm>.

According to data from the NJDEP Ambient Ground Water Quality Network and the Bureau of Safe Drinking Water, ground water in the Piedmont generally has higher arsenic concentrations than in other physiographic provinces in New Jersey. Data provided by the NJDEP Bureau of Safe Drinking Water showed that over 15% of the community wells sampled in the Piedmont Province had arsenic concentrations greater than 5 ppb while only 1.5% in the Coastal Plain Province and 0% in the Ridge and Valley and Highlands Provinces exceeded 5 ppb. A study by the NJ Geological Survey is expected to determine the sources, mobilization, transport and fate of the arsenic in the western Piedmont, where the highest concentrations (up to 57 ppb) have been found.²⁷

Results from reconnaissance sampling in the western Piedmont indicate that approximately 32 percent of the 92 wells sampled have concentrations exceeding 5 ppb. In the Raritan Basin, the highest concentrations are found in western Hunterdon County "in parts of the Jurassic-Triassic Brunswick formation, and in the Triassic Lockatong Formations. The lowest levels are in the Triassic Stockton Formation and Jurassic Diabase. Based on the chemistry of several rock samples and the location of the highest arsenic concentrations, it is believed that the arsenic is mainly natural in origin and associated with dark fine-grained lacustrine sedimentary rocks of

the Passaic and Lockatong Formations. Further work is being conducted which may lead to drilling and corrective practices that could reduce exposure to arsenic.”²⁸

Known Contaminated Sites

A “known contaminated site” is a place where contamination of soil or ground water is confirmed and where remediation is either underway or pending. Known contaminated sites include those which have or had contamination present at levels greater than the applicable soil cleanup criteria, ground water quality standards and/or maximum contaminant levels at the Safe Drinking Water Standards. Contamination is normally identified at a site through sampling of the soil, sediment, surface water and/or ground water. There have also been instances where visual inspection has been used to confirm the existence of contamination (e.g., identification of floating hazardous substance or free product on water).

NJSA 58:10-23.16-17, the New Jersey statute on the discharge of petroleum products, debris and hazardous substances into waters, requires that the NJDEP prepare, adopt and update a master list for the cleanup of all hazardous discharge sites throughout the State. The master list, called the Contaminated Sites List (of which the Known Contaminated Sites list is a sub-list), must include an inventory of the sites that have been cleaned up, that have been identified as in need of cleanup, and that will be cleaned up. The list of sites used in this report is based on the most recent GIS coverage (2001 Known Contaminated Sites list) obtained from the NJDEP Site Remediation Program in 2002.

Remedial levels are based on the NJDEP Site Remediation Program’s 1989 Case Assignment Manual, which determines levels based on the overall degree of contamination at a site. It should be noted that sites often proceed through several remedial levels over time. Site remedial levels are classified as follows:

“A” – An emergency action taken to stabilize an environmental and/or health threatening situation from sudden or accidental release of hazardous substances. Appropriate remedial actions involving a single phase of limited or short-term duration.

“B” – A single phase remedial action in response to a single contaminant category effecting only soils. May be a sub-site of a more complex case. Does not include ground water investigation or remediation. Examples of level B cases include, but are not limited to “cut-n-scrape”; surface drum removals; fences; temporary capping or tarping.

“C-1” – A remedial action that does not involve formal design where the source is known/identified. May include the potential for (unconfirmed) ground water contamination. Examples of C-1 cases are regulated or unregulated storage tanks containing gas or heating oil; septic tanks, etc.

“C-2” – A remedial action that consists of a formal engineering design phase, and is in response to a known source or release. Since the response is focused in scope and address a known, presumably quantifiable source, this remedial level is of relatively shorter duration than responses at sites with higher remedial levels. Usually involves cases where ground water contamination has been confirmed or is known to be present.

“C-3” – A multi-phase remedial action in response to an unknown and/or uncontrolled source or discharge to the soils and/or ground water. In this remedial level, the contamination is unquantifiable (or presumed unquantifiable) and, therefore, no determinable timeframe for the conclusion of the remedial action is known.

“C-4” or “D” – A multi-phase remedial action in response to multiple, unknown and/or uncontrolled sources or releases affecting multiple media which includes known contamination of ground water. In this remedial level, the contamination is unquantifiable (or presumed unquantifiable) and, therefore, no determinable timeframe for the conclusion of the remedial action is known.

Table B-2 provides a listing of approximately 1,270 known contaminated sites in the Basin that are classified as levels B through D as defined above as of September 1997. This list has not been updated to the 2001 listing due to time constraints, but most sites will be the same and some will have gone off the list due to cleanup activities. Many of the known contaminated sites fall within major transportation corridors of the Basin as shown on Figure 11, with many multi-phase remedial sites concentrated in the more urbanized sections of Union, Middlesex and Mercer counties. Other known contaminated sites of the Basin occur within town centers or are scattered in the more suburban areas of the Basin. Figure 11 also shows Classification Exception Areas and Currently Known Extent areas where the ground water or drinking water quality standards are currently exceeded. Additional information and identification of sites within a specified area are available from the NJDEP Site Remediation Program at www.state.nj.us/dep/srp.

Contaminated Wells

Comprehensive information on contaminated public water supply wells is not readily available and could not be collected for this report. Elizabethtown Water Company provided information on their system as an example of the issue within the Raritan Basin. Of the approximately 350 public community water supply wells in the Basin, 67 are owned by the Elizabethtown Water Company. For this assessment of well contamination, Elizabethtown Water provided information on the number of wells that have been closed due to contamination or are currently being treated for contamination. Of the 67 wells, 23 are fully operable, 23 are in service, but treated with a stripping tower for VOC contamination, 15 are out of service due to VOC contamination, and 6 are out of service due to naturally high radon levels.²⁹

The Raritan Project identified wells that could be at risk for contamination in the Basin due to their proximity to known contaminated sites. Table 2 lists the number of known contaminated site classified as C-2, C-3 or C-4 (confirmed ground water contamination) mapped as being within a WHPA shown on Figure 8a, by WMA (980 sites). NJDEP’s Source Water Assessment Program reports, due out in 2003, will provide a much more detailed assessment of well vulnerability and susceptibility to pollution, using well head protection areas and information on potential pollutant sources, including but more inclusive than known contaminated sites.

Table 2 – Known Contaminated Sites (KCSL) within Wellhead Protection Areas (WHPA)							
WMA	Tier 1	Tier 2	Tier 3	All Tiers	Outside Tier	Total KCSL	Pct KCSL in WHPA
Upper Raritan	22	16	25	63	142	205	31%
Lower Raritan	28	21	36	85	539	624	14%
Millstone	9	12	11	32	119	151	21%
Totals	59	49	72	180	800	980	18%

Source: NJ Water Supply Authority, June 2002

The Upper Raritan WMA, which is primarily dependent on aquifers for potable water supplies, in turn has the greatest percentage of known contaminated sites within its WHPAs – 31 percent. The Lower Raritan WMA, which is primarily served by surface water supplies, only has 14 percent of known contaminated sites within WHPAs. This low value may be due in part to a choice to close many contaminated public community water supply wells, rather than use costly advanced treatment, because alternative supplies were available. Many known contaminated sites in the Upper Raritan and Lower Raritan are within Tier 1, and therefore pose the most significant threats.

Ground water is also used by individual homes and businesses. A study conducted in December 2000 in Hillsborough Township to assess well contamination associated with the Somerville Depot of the U.S. General

Services Administration revealed that four domestic wells on Roycefield Road were contaminated with trichloroethylene (TCE), a dense liquid carcinogen. The heavy metals stored at the Hillsborough Depot were not found in any of the wells that were tested. The source of the TCE contamination is not known, though TCE was "widely used as a degreasing solvent in automobile repairs, removing oil from metals and a degreaser in septic systems."³⁰ The Township has made arrangements for the residences with wells affected by the TCE to be supplied by the public water supply system. Numerous other incidents of residential well contamination have occurred in the Raritan Basin; however, the information is in dispersed locations and was not collected for this project.

Facilities Handling Solid Waste and Hazardous Materials

Landfills

Figure 12 illustrates the solid waste landfills located throughout the Raritan Basin by acreage and by status of operation as of June 1992. Of the 60 landfills in the Basin, there are 10 in the Upper Raritan WMA, 41 in the Lower Raritan WMA and 9 in the Millstone WMA, with the largest in acreage located in the Lower Raritan and Millstone WMAs. According to Table B-3, which shows the location, operational status and underlying geology of each landfill, only 6 of the 60 landfills were open as of 1992. Of those that have been closed, most were closed in the 1970s and 1980s. Of the 60 landfills, the Bound Brook Landfill was the only one in 1992 that contained a comprehensive leachate collection system (a system that collects contaminated liquids that accumulate in a landfill and prevents them from potentially escaping into the underlying ground water). Others, such as the Monroe Township landfill, have since installed leachate collection systems. Landfill types in the Basin include municipal, dry sewage sludge, bulky waste, vegetative waste, animal and food processing waste, dry industrial, bulk liquid and semi-liquids, septic tank clean-out and liquid sewage waste.

Permitted Ground Water Discharges

The NJDEP regulates the discharge of pollutants to ground water under the New Jersey Water Pollution Control Act (NJSA 58:10A) and the Ground Water Quality Standards (NJAC 7:9-6) in order to restore, enhance and maintain the ground water quality of the State. The Act requires that a permit be obtained for all sanitary and industrial waste discharges from the New Jersey Pollutant Discharge Elimination System (NJPDES) program (NJAC 7:14A) prior to the discharge of pollutants to ground water, other than for domestic septic systems that are regulated under a separate law.

Discharge activities regulated by the NJDEP include: surface effluent impoundments; infiltration/percolation lagoons/ overland flow systems; spray irrigation systems; and various types of subsurface disposal systems that are classified as underground injection systems. The type of facilities regulated include: mines, pits and quarries; schools and hospitals; potable water treatment plants; large corporate office buildings; industrial manufacturing facilities; campgrounds and mobile home parks; food processing plants; and sewage treatment plants and other dischargers of wastewater that can affect ground water quality, including dredge spoils disposed on land. The NJDEP Site Remediation Program regulates sources such as spills from past activities, underground storage tanks, and non-operating or closed landfills. Some aspects of these operations may also require a NJPDES permit.

Table B-4 provides a list of the NJPDES-permitted discharges to ground water for the municipalities of the Basin. The list is not limited entirely to the Basin; permits for parts of the municipalities located outside of the Basin are included. According to Table B-4, there are approximately 500 permitted discharges to ground water within the 100 Basin municipalities. Table B-4 lists the NJPDES permit number, facility name, municipality, county and category of discharge as well as a designation of those facilities that have been closed or terminated.

Underground Storage Tanks

Underground storage tanks (UST) are any one or combination of tanks as set forth in NJAC 7:14B-1.4, including appurtenant pipes, lines, fixtures and other related equipment, used to contain an accumulation of hazardous substances (whether wastes, product or raw materials), the volume of which, including the volume of the appurtenant pipes, lines, fixtures and other related equipment, is 10 percent or more beneath the surface of the ground (http://www.state.nj.us/dep/srp/regs/ust/ust_01.pdf). The NJDEP Site Remediation Program lists registered USTs by county for the State of New Jersey. This information was last updated on April 10, 2000 and can be accessed at the following website: <http://www.state.nj.us/dep/srp/bust/>.

As seen in Table 3 below, there are approximately 4,600 USTs located within municipalities of the Basin. If not properly maintained and monitored, these tanks have the potential to leach their contents into the ground and contaminate ground water resources. The state requires that all USTs be monitored in an effort to protect ground water sources.

County	# of Active USTs	# of Inactive USTs	Total USTs
Hunterdon	108	266	374
Mercer	127	303	430
Middlesex	713	1,599	2,312
Monmouth	94	196	290
Morris	19*	41*	60*
Somerset	94	196	290
Union	277	584	861
Total for Basin Municipalities	1,432	3,185	4,617

Source: NJDEP Site Remediation Program, 2000. Internet site: <http://www.state.nj.us/dep/srp/bust/>

Note: Although some of the 100 municipalities are located only partially in the Basin, the number of USTs cited above is for the entire municipality, not only the part that is located in the Basin.

* Indicates complete set of data for municipalities not available for this county.

Superfund Sites

Prior to 1980, thousands of uncontrolled or abandoned contaminated sites were created as a result of the many wastes that were dumped on the ground or in rivers. Common contaminated sites included abandoned warehouses, manufacturing facilities, processing plants and landfills that posed threats to the environment and human health. In 1980, Congress established the National Superfund program in an effort to clean up the contaminated sites. Superfund sites are usually the more complex sites where multiple media (soil, ground water, etc.) are affected and a threat to public health may exist. In New Jersey, the Superfund program is administered by the United States Environmental Protection Agency (USEPA) in cooperation with the NJDEP Site Remediation Program.

The list of Superfund sites is maintained on the National Priorities List (NPL), which is a published list of contaminated sites eligible for extensive, long-term cleanup action under the federal Superfund program. The NPL is maintained and revised on an annual basis. As of July 27, 2000, the list of Superfund sites in New Jersey included 111 sites (Table 4), 28 of which are located within municipalities of the Raritan Basin.³¹

Table 4 - Superfund Sites on the National Priorities List For Municipalities in the Raritan Basin as of December 17, 2000		
Site Name	Municipality	County
Myers Property	Franklin Township	Hunterdon
Fried Industries, Inc.	East Brunswick Township	Middlesex
Chemical Insecticide Corporation	Edison Township	Middlesex
Kin-Buc Landfill	Edison Township	Middlesex
Renora, Inc.	Edison Township	Middlesex
Middlesex Sampling Plant	Middlesex Borough	Middlesex
Monroe Township Landfill (de-listed 1994)	Monroe Township	Middlesex
CPS/Madison Industries	Old Bridge Township	Middlesex
Evor-Phillips Leasing Company	Old Bridge Township	Middlesex
Chemsol, Inc.	Piscataway Township	Middlesex
Horseshoe Road	Sayreville Borough	Middlesex
Sayreville Landfill	Sayreville Borough	Middlesex
Jones Industrial Services Landfill (JIS)	South Brunswick Township	Middlesex
South Brunswick Township Landfill (BFI)	South Brunswick Township	Middlesex
Cornell Dubilier Electronics, Inc.	South Plainfield Borough	Middlesex
Lone Pine Landfill	Freehold Township	Monmouth
Burnt Fly Bog	Marlboro Township	Monmouth
Imperial Oil Company, Inc./Champion Chemicals	Marlboro Township	Monmouth
Combe Fill North Landfill	Mount Olive Township	Morris
Combe Fill South Landfill	Chester and Washington Twps	Morris
Brook Industrial Park	Bound Brook Borough	Somerset
American Cyanamid*	Bridgewater Township	Somerset
Higgins Disposal Services, Inc.	Franklin Township	Somerset
Higgins Farm	Franklin Township	Somerset
Kryswaty Farm	Hillsborough Township	Somerset
Federal Creosote Company	Manville Borough	Somerset
Montgomery Township Housing Development	Montgomery Township	Somerset
Rocky Hill Municipal Wells	Rocky Hill Borough	Somerset

Source: NJDEP Site Remediation Program, 2000. Web page: <http://www.state.nj.us/dep/srp/superfund/index.html>

Notes: * indicates a partial deletion on the Hill Property portion of the American Cyanamid site.

Estimating Carrying Capacity for Septic Systems

The New Jersey Department of Environmental Protection's New Jersey Geological Survey (NJGS) has developed a methodology for estimating the maximum number of septic systems (formally known as individual subsurface sewage disposal systems) that can be located within specific watersheds, municipalities or properties.³² Briefly stated, this model estimates the total number of septic systems that may be accommodated within a geographic area using average loadings of nitrates per septic system, estimates of ground water recharge from precipitation within that area (including the impacts of development on recharge), and a target concentration from the Ground Water Quality Standards, NJAC 7:9-6. The complete method is available on the Web site of the NJDEP's Division of Watershed Management, at <http://www.state.nj.us/dep/watershedmgt>.³³

The Raritan Basin Watershed Management Project applied the May 2000 model to the entire Raritan River Basin, using a number of assumptions and estimates as provided for in the model. The purpose of this section is to make clear the assumptions and estimates used. Limitations to the results are also described to help ensure that the modeling results are not misused.

Geographic Area and Sub-areas

The model was applied to all 1,100 square miles of the Raritan River Basin. However, aggregate results at that large a scale are not useful for planning purposes. Therefore, the analysis focuses on smaller hydrologic units within the Raritan Basin. The United States Geological Survey defines these units, essentially equivalent to subwatersheds, as HUC-14 areas (see Figures 1a and 1b). The analyses were performed using a Geographic Information System (GIS) for each combination of soil, municipally based rainfall, development density and population density (people/home). The results for each such area (known as a polygon) were then aggregated up to the HUC-14 level (see Figures 13-15). While the analyses were performed on a polygon basis, the results cannot be mapped on a polygon basis at the scale used in this report due to the many thousands of individual polygons involved; therefore, the HUC-14 aggregations are used here.

An important implication of the Raritan Basin analysis is that it aggregates results from land and water areas that range from no recharge to some positive level of recharge. The NJGS model recognizes soil series for which the method is inapplicable (i.e., hydric soils and wetlands). A carrying capacity value of zero was assigned to such soils, as there is no recharge. As a result, Figures 13-15 and Tables C1-C3 provide an estimate of the total number of septic systems that can be accommodated per HUC-14 watershed, and an estimate of the number of acres of recharge area (excluding any hydric soils and wetlands, which have no recharge) that are required to support each septic system on average. Within each HUC-14 watershed, the actual densities will vary by polygon. The polygon-based results are available from the Raritan Project.

Purpose of Carrying Capacity Analysis

The Project Team and Characterization Committee of the Raritan Project both recognized that much development in the Raritan Basin is taking place in areas that lack public sanitary sewer systems. Septic systems are the primary means of wastewater disposal. Because ground water is a renewable, though limited, resource, the use of too many septic systems will contaminate ground water and can also contaminate surface water. The identification of a carrying capacity for septic systems provides an initial basis for planning to ensure that the overall pollutant assimilation capacity of watersheds is not exceeded. Nitrates are used for this analysis, as a good indicator of septic system impacts.

This carrying capacity analysis does not address other possible limitations on watershed carrying capacity. It does not address the potential for contamination of individual wells, as the target nitrate concentrations from this model are averages, not site-specific levels. This analysis does not address the effects of impervious surfaces on stream health, or the impact of development on forest or aquatic ecosystems. As such, septic system carrying capacity is an important indicator of the watershed effects of development, but not the only one. Finally, this analysis is based on one set of assumptions; other assumptions (such as lower nitrate targets related to protection of special waters) can be used to generate alternative results that may be more appropriate to a specific subwatershed than this regional analysis.

The Raritan Project developed this analysis to help spotlight watersheds and subwatersheds that are inherently limited for septic systems, and those that already may have septic systems near or above their capacity. The project has not estimated the current number of septic systems in watersheds, but expects that this step will be taken for some watersheds or subwatersheds during the planning process (see Critical Needs, below).

Assumption – Initial Nitrate Concentration in Ground Water

The New Jersey Geological Survey has compiled information on ground water quality in all aquifers of New Jersey. Their findings indicate that natural ground water quality for nitrates is usually below 1 mg/L (milligram per liter) of nitrate-nitrogen (discussed in this report as “nitrates”). Rainwater is also approximately 1.5 mg/L in nitrates, some of which is used by plants before passing into ground water. Human activity at or near the land

surface (e.g., lawn fertilizers, agricultural fertilizers, septic systems) can increase those concentrations greatly. The Raritan Project analysis is using a 1 mg/L concentration as a reasonable estimate of the “initial concentration” for the following reasons:

- The analysis seeks to estimate the total number of septic systems that each watershed can accommodate. The resulting numbers includes both current and potential septic systems. Therefore, the initial value should not include impacts from existing septic systems.
- Fertilizer use varies widely, and high nitrate levels from fertilizers have been found in ground water. However, fertilizer use is not a constant source like septic systems, and can be modified by education and management practices. The fertilizer loading value of nitrate was set to the model default, 90 lbs/acre/year, 5% of which goes to ground water. This factor provides some additional protection for ground water, along with the antidegradation policy explained below. In addition, there are some conservative assumptions in the antidegradation policy and the modeling process that can offset somewhat higher levels of fertilizer use.
- The project is basin-wide. Using different initial concentrations for nitrate would require a technical justification for each value in each watershed, but could be appropriate. Current concentrations vary between and within watersheds. Therefore, using different initial concentrations is beyond the capability of this project.

Target Nitrate Concentration In Ground Water

NJDEP’s Ground Water Quality Standards include two factors that affect the target concentration of nitrates in ground water. First is the “criterion” – a health-based concentration that should never be exceeded in drinking water. That value is 10 milligrams per liter (mg/L), a health-based criterion used in the Ground Water Quality Standards, Surface Water Quality Standards and Drinking Water Quality Standards. Second, the Ground Water Quality Standards include an “antidegradation” provision to constrain discharges so that the ground water does not actually reach the 10 mg/L value. The antidegradation policy for nearly all of the Raritan Basin is that the target concentration should be no greater than half of the difference between background concentrations and the 10 mg/L criterion. Therefore, if there were no nitrates in ground water originally, the antidegradation policy would limit the target concentration to 5 mg/L.

The target concentration used in this modeling effort is 5.5 mg/L, providing for a net increase of no more than 4.5 mg/L from the initial nitrate concentration. It should be noted that this target level is based on NJDEP’s standards, but there is nothing in State law or regulations that prohibits municipalities from using more stringent targets for septic system capacity analysis, based on local needs. Also, the antidegradation policy was developed to address point source discharges to ground water (e.g., industrial sites, small community wastewater systems), not septic systems, and therefore may not be stringent enough to address situations where groups of septic systems could affect domestic well quality, trout production waters and other sensitive resources. However, in the absence of other defined policies, the existing antidegradation policy was used to develop this example.

NJDEP is apparently considering modifications to the Ground Water Quality Standards, which could include changes to the antidegradation policy. If such modifications were adopted into law, the septic system carrying capacity analysis would have to be run with a new target concentration. Further, there may be areas where impacts other than human health are of concern and would justify a reduction in the target nitrate concentration. To the extent that lower nitrate targets are used, the model will provide lower estimates of septic system carrying capacity and therefore larger average lot sizes.

Assumption – Flow and Nitrate Loadings from Septic System

The model assumes a flow of 350 gallons per day per septic system,³⁴ based on NJDEP regulations for septic systems at NJAC 7:9A. The model uses an average nitrate loading of 43 mg/L (milligrams per liter) for each septic system, based on research into residential septic system effluent quality.

Assumption – Nitrates from Other Sources

As mentioned above, the Raritan Basin analysis does not address the input of nitrates from every source, but does address natural background levels and an assumed level of nitrogen fertilizer use. Anthropogenic sources of nitrates such as fertilizers and livestock manure beyond the assumed level can be reduced through active management. Standard septic systems discharge nitrates at levels determined by human physiology, which cannot be managed. Therefore, this modeling process uses an average loading of nitrates for each septic system, and a nitrate loading from fertilizer set at the model default of 90 lbs/acre/year, five percent of which goes to ground water. In general, nitrates from non-residential septic systems will be minimal, because such land uses rarely occupy a large percentage of any subwatershed. However, where concentrations of non-residential septic systems or other significant discharges of nitrates exist, the analysis should include their impacts. Such analyses are beyond the scope of the Raritan Project.

Approach to Estimating Ground Water Recharge

The model starts with estimates of ground water recharge in pre-development conditions, using soils and precipitation levels as the primary factors, as determined using the GSR-32 method described above. Wetlands and open waters are assigned a level of zero recharge. Other soils are assigned some potential for recharge. The recharge level for each land area is then reduced based on the percentage of impervious surface resulting from development. Higher impervious surface densities will have a greater impact on recharge than lower development densities, resulting in a reduction in ground water recharge and therefore in the sustainable density of septic systems. It is critical to note that this model uses long-term annual average recharge rates to ground water, not rates based on lower or higher precipitation periods. As ground water systems react slowly to short-term variations in precipitation, only longer-term patterns might affect the results of this model. Use of other modeling periods, such as multi-year droughts, is a policy decision of the affected regulatory entity, and would reflect a lower tolerance for risk than the model results as depicted here. If periods of lower precipitation (and therefore recharge) are used, the septic system carrying capacity would be proportionally lower, resulting in larger average lot sizes per septic system.

General Limitations to Use of the Model

There are a number of limitations that must be understood.

- **First, this model is a model – it provides estimates, not certainty. This is true of all models, which are simplifications of reality.**
- Second, the model provides geographic averages, not point-specific results. It is a “mass balance” model rather than a “particle tracking” model. If a watershed has only half the density of septic systems that the model estimates can be accommodated, that watershed will still have some areas where nitrate levels exceed the Ground Water Quality Standards. Discharges from septic systems move in discrete plumes through ground water. They do not miraculously dissolve into an average concentration. Therefore, a shallow well located downgradient (downslope) of a septic system has a much higher chance of contamination than a well located elsewhere. This model cannot predict such site-specific risks.

- Third, the model relies on long-term precipitation averages, generalized septic system flows, and a “standard” septic system construction. These assumptions and averages are perfectly valid for use in long-term regional planning, but they must be understood for proper use. The model also bases ground water recharge on long-term baseflow rates in streams, with the assumption that recharge equals baseflow over the long term. However, some aquifers have better storage capacity than others. Multi-year periods of low precipitation can have a significant effect on stream baseflow during such periods. Different baseflow rates can be derived from different periods of time, thus affecting modeling results. For these reasons, municipalities may wish to assess septic system capacity using more detailed information about the geology and other physical factors within that area. A well-designed local study should be considered superior to the regional application of a model, such as performed for this study. However, local studies are still rare in the Raritan Basin, and so this regional analysis should have considerable value where no prior analyses have been prepared.
- Fourth, the model provides only a general indication of the impacts of nitrates in ground water on nitrate levels in surface water. Recent research indicates that nitrate concentrations in ground water are very conservative until the ground water approaches a surface water body where the nitrate levels tend to drop by as much as 30 to 40 percent.³⁵ However, the dynamics are not well understood. It is expected that increases in ground water concentrations will result in surface water concentration increases.³⁶
- Fifth, the model has an inherent level of resolution that makes it less accurate as the parcel size decreases. For this reason, watershed, subwatershed and large area results are very useful for planning purposes, but the results for a 3-acre parcel are not really useful for site design. Site-specific understanding of soils is more important at that level.
- Sixth, historic fertilizer use in certain agricultural areas and current fertilizer use in suburban lawns can both contribute to localized concentrations of nitrates that approach or exceed the 10 mg/L criterion, regardless of septic system contributions. Where such levels exist, decontamination must rely primarily on controlling new loadings and the long process of ground water movement to surface water.³⁷ Such areas should be managed as remedial projects and special attention given to new loadings from any sources. The model addresses future fertilizer use partially through a default value, but not excessive historic or future use.
- Seventh, nitrates are used as a general indicator for pollutants for septic systems, but they are not the only concern. Septic systems can be significant sources of bacteria and viruses. If used improperly, septic systems can also be sources of toxic chemicals from household cleaning and industrial processes. For this reason, attention should be paid to other aspects of septic system and suburban land uses.
- Eighth, this model uses the antidegradation policy for Class II-A Ground Water, that the addition of pollutants should not increase ground water concentrations to more than 50 per cent of the difference between background levels and the criterion. This antidegradation policy was adopted in 1993 primarily for application to point source discharges regulated under the NJPDES program, with the expectation that the standard would be met at the property boundary at least, if not before. This policy may not be as appropriate for septic systems, where effluent plumes will clearly violate the nitrate criterion of 10 mg/L well beyond property boundaries, even if the average nitrate levels meet the antidegradation policy. If lower nitrate targets were used, the average septic system carrying capacity would reduce proportionally (e.g., carrying capacity estimates of 2.4 acres per septic system at a nitrate target of 5.5 mg/L would change to 6.5 acres per septic system with a 2.0 mg/L nitrate target).

Limitations to Use of the Raritan Project Results

In addition to the limitations noted above, there are some limitations specific to the Raritan Project. Perhaps most important is that the maps provided in this report show carrying capacity for HUC-14 watersheds rather than for individual properties. A parcel-based map would be too complex for general use and publication. However, the Raritan Project has parcel-based results available for use by municipalities.

As noted above, no effort has been made for this report to compare the number of existing septic systems basin-wide to the estimated carrying capacity for septic systems. This step is very time-consuming and should be taken only in priority subwatersheds or watersheds where there is concern that existing zoning, existing development or both threaten to exceed the carrying capacity (see Critical Needs, below). One example has been run for a few subwatersheds.

Finally, the specific attributes of a watershed or subwatershed should be assessed when using this model. The results presented here are a first step, rather than a last step. Known contamination problems (such as from past fertilizer use), special needs for surface water protection (such as in Category 1 watersheds) and other concerns for carrying capacity (such as endangered and threatened species, riparian areas and other special ecosystems) all will prompt modifications in plans for development and redevelopment.

For the reasons outlined above, these results should be used for planning purposes, and should be seen as an estimate of the maximum number or density of septic systems allowed within subwatershed and watersheds, with local factors of historic land uses, geology, etc., being used as factors to modify the results.

Results of the Septic System Carrying Capacity Analysis

As discussed above, the NJGS model from 30 May 2000 was applied to the entire Raritan River Basin with a target nitrate concentration of 5.5 mg/L. Detailed findings are noted in Figures 13 through 15, and in Appendix C. The highest carrying capacity (i.e., smallest average lot sizes, minimum number of acres per septic system, or greatest number of septic systems per square mile) Basin-wide is found in the Upper Raritan WMA, at 1.64 acres per septic system. The maximum carrying capacity in the Lower Raritan WMA is 2.4 acres per septic system, and for the Millstone WMA is 2.59 acres per septic system.

The lowest carrying capacities (i.e., largest average lot sizes, maximum number of acres per septic system, or lowest number of septic systems per square mile) are 3.36, 10.97 and 3.9 acres per septic system in the Upper Raritan, Lower Raritan and Millstone WMAs, respectively.

In general, the Upper Raritan WMA has the most HUC-14 subwatersheds with high carrying capacities (lowest average lot sizes). The Highlands area often shows values of less than 2 acres per septic system, except in the highly developed subwatersheds of the upper Lamington River in the Roxbury Township area (a sewered area). The most limited carrying capacities (highest average lot sizes) in the Upper Raritan WMA are generally shown in the Piedmont sections, such as the Neshanic River watershed and the South Branch River watershed below Stanton. Although not shown at this scale, subwatersheds with both Precambrian and limestone aquifers will have side variations in septic system capacity; Figures 13 through 15 are average values.

The Lower Raritan WMA has the highest variability in carrying capacity. One HUC-14 subwatershed (located within a sewered area) shows a value of nearly 11 acres per septic system, but no other subwatershed has values above 5 acres per septic system. On the other hand, many subwatersheds show values between 3 and 5 acres per septic system, and none were below 2.4 acres per septic system. The lowest values (highest sustainable densities) are generally shown in the Bound Brook/Green Brook watershed, the Lawrence Brook watershed and along the Lower Raritan River in the area of Piscataway and Franklin Townships. However, most if not all of these areas are already sewered and the remainder is approved for sewers.

The Millstone WMA has a relatively narrow range of septic system carrying capacities, from approximately 2.6 to 3.9 acres per septic system. The upper Millstone River and Stony Brook watersheds, along with the Route 1 corridor, generally show lower carrying capacities (higher average lot sizes). While the Route 1 corridor is mostly sewerred, the upper Millstone River area and much of the Stony Brook watershed rely on septic systems.

Of the results summarized above, the greatest discrepancies known between these regional results and local studies are found in the Highlands region. One possible explanation could be the existence of soils that allow high rates of ground water infiltration, but overlie either bedrock or dense sub-soils that do not allow the infiltration to penetrate to aquifers. A second possible explanation could be the use of different methods for estimating stream baseflow – a critical parameter for calibrating infiltration models and estimates. Further work is needed in this area.

Comparison to Existing Septic Systems

The results for four subwatersheds draining to the Spruce Run Reservoir were compared to the number of existing septic systems within each subwatershed, with the results shown in Table 5. The existing septic systems were estimated by identifying the number of residentially zoned lots located outside of approved sewer service areas, using Figure 8 from the Landscape of the Raritan River Basin technical report, "Approved Wastewater Management Area Boundaries within the Raritan Basin." NJDEP's 1995-97 Land Use/Land Cover maps were then intersected with those non-sewerred lots to identify each lot that included developed land. One septic system was assumed to exist on each developed lot. The analysis shows a significant amount of septic system capacity remaining, with a 5.5 mg/L nitrate target. Reducing the target to 2.0 mg/L (somewhat about the current average nitrate concentration in ground water of the area) would reduce the remaining capacity significantly. However, it is also interesting to note that the median size of lots with existing septic systems is lower than the estimated carrying capacity in all subwatersheds. This raises the possibility that clusters of septic systems may already be causing ground water contamination at unacceptable levels.

HUC14	HUC14 Area (Acres)	Maximum Septic Systems Per HUC14	Average Acres Per Septic System	Septic Systems Per HUC14 (1995)	Average Lot Size (Existing Systems)	Median Lot Size (Existing Systems)	Remaining Capacity in 1995 (lots)
010	7,867.826	4,662.9	1.69	1,593.0	4.4	1.0	3,069.9
020	2,056.527	1,240.0	1.66	199.0	6.1	1.6	1,041.0
030	9,413.410	3,570.2	2.64	1,219.0	7.0	2.0	2,351.2
040	7,808.142	2,807.5	2.78	570.0	11.7	2.1	2,237.5

Source: URWA 2001, NJWSA 2002

Management Conclusions of Existing Plans

Several programs have been designed to protect the quality of New Jersey's ground water supply sources. In an effort to manage point and nonpoint source pollution and maintain aquifer recharge areas, the following water resource protection programs have been implemented and protect ground water resources of the Basin and the State.

Existing and Proposed Regulations

The NJDEP Ground Water Quality Standards (NJAC 7:9-6) designate protected uses of ground water, ground water quality criteria to protect those uses, and antidegradation policies (NJAC 7:9-6.7) to ensure that existing ground water quality (that is higher quality than the water quality criteria) is not degraded to the criteria, with the most stringent antidegradation policy (nondegradation) applying to certain watersheds that are extremely sensitive to change. These three components (designated uses, criteria and policies) result in constituent standards pursuant to the Water Pollution Control Act (NJSA 58:10A-1 et seq.) and the Water Quality Planning Act (NJSA 58:11A-1 et seq.). The Standards are the source for numerical criteria for limits on discharges to ground water and standards for ground water cleanups. The Ground Water Quality Standards regulate discharges to ground water and ensures compliance with Surface Water Quality Standards (NJAC 7:9-4) to protect surface waters.

The NJDEP Bureau of Safe Drinking Water ensures that public drinking water supply systems meet federal and state drinking water standards as required by the federal Safe Drinking Water Act (42 USC 300F et seq.) and the NJ Safe Drinking Water Act. Major categories of contaminants monitored under the Act include inorganic chemicals, trihalomethanes, radionuclides, turbidity, coliform bacteria, synthetic organic compounds and volatile organic compounds. Specific contaminants are listed at the Bureau of Safe Drinking Water home page at <http://www.state.nj.us/dep/watersupply/standard.htm>.

In January 2001, the NJDEP adopted an amendment to the Statewide Water Quality Management Planning Rules (NJAC 7:15-8) requiring new development using septic systems to undergo the same environmental assessments as proposed new sewer service areas. The rule (known generally as the Subchapter 8 rule) requires that residential developments of six or more units and commercial development discharging 2,000 gallons of wastewater or more per day into the ground undergo analysis. The rule became operative on March 20, 2001. The required environmental assessments, which are part of an applicant's new or amended wastewater plan, examine the potential impacts and alternatives, and include evaluations of water use, riparian buffer impacts and nonpoint source pollution. However, in March 2002 the Appellate Court of New Jersey invalidated this rule for procedural and substantive reasons.

In an effort to protect ground water quality and assure public health protection, the USEPA is proposing a rule that specifies the appropriate use of disinfection in ground water and addresses other components of ground water systems to assure public health protection. The Ground Water Rule (GWR) establishes multiple barriers to protect against bacteria and viruses in drinking water from ground water sources and will establish a targeted strategy to identify ground water systems at high risk for fecal contamination. The GWR was scheduled to be issued as a final regulation in summer 2001 but is still pending.³⁸

NJ State Development and Redevelopment Plan

The State Planning Act (NJSA 52:18A 196 et seq.) adopted by the State of New Jersey in 1985, declared that New Jersey needed to implement a statewide planning initiative to:

"...conserve its natural resources, revitalize its urban centers, protect the quality of its environment, and provide needed housing and adequate public services at a reasonable cost while promoting beneficial economic growth, development and renewal..."

Under the Act, the State Development and Redevelopment Plan should establish statewide planning objectives that would encourage State and local governments to guide future growth into compact forms of development and redevelopment. This would support and maintain the capacities of infrastructure, environmental, natural resource, fiscal, economic and other systems. Although the State Plan is not a regulation, "it is a policy guide for State, regional and local agencies to use when they exercise their delegated authority."³⁹ County and municipal master plans should be modified to incorporate the provisions of the Plan.

The Statewide Policy on Water Resources of the 2001 State Plan calls for the State to:

“Protect and enhance water resources through coordinated planning efforts aimed at reducing sources of pollution and other adverse effects of development, encouraging designs in hazard-free areas that will protect the natural function of stream and wetland systems, and optimizing sustainable resource use.”⁴⁰

Ground Water Policies of the State Plan call for the protection of ground water sources, aquifer recharge areas, limestone areas and well fields, and for management programs for on-site waste disposal and septage removal. The technical report “Landscape of the Raritan River Basin” includes an extensive discussion of the State Development and Redevelopment Plan provisions regarding watershed management.

1989 Ground Water Strategy

In 1989, the NJDEP published “A Ground Water Strategy for New Jersey,” in an effort to protect ground water quality and quantity of the State of New Jersey. As required by the USEPA in 1984, the NJDEP developed the “Strategy” which includes new policies, practices, priorities and programs to guide the use of federal funds for ground water quality planning purposes. Policies of the “Strategy” recommended the establishment of the same drinking water quality standards for domestic wells as for public water supply wells, require parties responsible for pollution to remedy the problems, protect new wells from contamination, establish a ground water antidegradation policy and protect aquifer recharge areas. The document was created in an effort to guide the NJDEP to implement ground water initiatives that would “provide the greatest gains in health protection, provide the greatest benefits relative to cost, or have dedicated funds from Federal or State sources.”⁴¹ Since that time, the Legislature has approved a new law requiring that domestic wells be tested prior to home sales to ensure that they meet drinking water standards; the site remediation program of NJDEP has adopted detailed rules for remedial projects; the source water assessment program has incorporated the basic framework of the Well Head Protection Program Plan (see below); and the Ground Water Quality Standards were adopted with a detailed antidegradation policy.

NJDEP Wellhead Protection Program Plan

The 1986 Federal Safe Drinking Water Act Amendments required all states to develop a Wellhead Protection Program Plan for both public community and public non-community water-supply wells. New Jersey’s WHPP Plan, approved by the USEPA in 1991 was established to prevent contamination of ground-water resources, which supply drinking water to over 40% of the State. The delineation of Well Head Protection Areas (WHPAs) is one component of the WHPP. “The WHPA is the area from which a well draws its water within a specified time frame. Once delineated, these areas become a priority for efforts to prevent and clean up ground water contamination. Other components of the WHPP Plan include pollution-source inventories, development and implementation of best management practices to protect ground water, land-use planning, and education to promote public awareness of each person’s role in protecting our ground water resources. In addition, the Safe Drinking Water Act Amendments of 1996 (P.L. 104-182) established the need for state Source Water Assessment Programs. In New Jersey, source-water areas for all public supply wells will be established by use of WHPA delineation methods.”⁴²

South Branch Watershed Association Wellhead Protection Plan

In 1995, the South Branch Watershed Association initiated a wellhead protection program and inventoried all public, non-community wells, in Hunterdon County, and three townships in Morris County: Washington, Mount Olive and Roxbury. Latitude and longitude coordinates for each well were collected using a Global Positioning System (GPS) during the inventory, which will be used in coordination with GIS to identify adverse impacts on drinking water sources. Well owners and municipal officials were also surveyed to determine their understanding of water quality and ground water protection issues. Findings from the survey will indicate areas

of focus for SBWA's educational outreach efforts. A report on the status of the wellhead protection project is currently being written, and will be available through SBWA.⁴³

New Jersey Statewide Water Supply Plan

In 1982 the NJDEP adopted the first New Jersey Statewide Water Supply Master Plan as required by the Water Supply Management Act to plan for future water supply needs. The New Jersey Statewide Water Supply Plan (SWSP) developed by the NJDEP in 1996 with the assistance of three consulting firms revised and replaced the 1982 Water Supply Master Plan. The purpose of the 1982 Master Plan was to improve surface water supply capacity, ensure proper maintenance of aging water supply infrastructure, investigate the status of major aquifers, and plan for future water supply needs. The 1996 SWSP was created to address the changing needs for water supplies, address development trends, and develop management concepts.⁴⁴ It emphasized the need to protect existing supplies, including ground water supplies, to reduce the stress of new uses on available resources.

NJDEP Site Remediation Plan

Beginning with the passage of the New Jersey Spill Compensation and Control Act in 1976, the NJDEP initiated a program to clean up contaminated sites that posed a danger to human health and the environment. The federal Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, more commonly known as Superfund was strengthened in 1986 by the Superfund Amendments and Reauthorization Act (SARA). The passage of several key State laws, including the Environmental Cleanup Responsibility Act (later replaced by the Industrial Site Recovery Act) and Underground Storage Tank Act, facilitated cleanup efforts for a variety of pollution problems. The inventory of contaminated sites maintained by the NJDEP Site Remediation Program and known collectively as the Comprehensive Site List (CSL) includes 39,473 sites statewide.

Critical Needs

In order to perform a more complete assessment of the ground water resources of the Raritan Basin, the following information would be required:

- Updated NJDEP Landfills coverage
- Estimation of the current number of and zoning for septic systems in selected watersheds or subwatersheds to determine whether they combine to exceed the estimated carrying capacity for septic systems. There are more and less time-intensive methods for this analysis. A simple method would be to compare residential land uses (1995/97 NJDEP data) to the sewer service area map in the Raritan Project's Landscape Report. For any particular subwatershed, the houses outside the sewer service area boundaries would be counted as having septic systems. The total number of current septic systems for that subwatershed would be compared to the carrying capacity to determine whether or not further capacity exists.
- Septic system capacity analyses using alternative nitrate targets, such as 1.5 mg/L reflecting average nitrate concentrations in ground water. Estimates using alternative approaches for extrapolating long-term precipitation patterns from the available weather station data would also be useful, to provide a finer distribution of rainfall patterns. The current system tends to cause sharp changes in carrying capacity estimates across municipal or subwatershed boundaries.

Conclusions

Topography and geology are the primary factors affecting ground water availability and recharge within the Raritan Basin. While the unconsolidated sediments of the Coastal Plain and some Highlands glacial deposits contain prolific water supplies for public wells, the Sourlands, Watchungs and consolidated rocks of the northern portion of the Basin are limited water-bearing formations. Of the consolidated rocks, all but the dolomitic limestone formations in the Highlands Province are relatively poor aquifers. Water movement outside of the limestone areas is primarily through joints and fractures and in bedding planes and occurs at a very local scale.

Carbonate rocks including limestone and dolomite are water-soluble and are common in the northwestern part of the Basin in the Highlands Province of the Upper Raritan WMA. These areas have development limitations due to their susceptibility to sinkholes and vulnerability to pollution, but are prime aquifers for public use.

Areas with high ground water recharge capabilities are generally found on shallow slopes with permeable soils. Some high recharge areas overly poor aquifers, and so the recharged ground water tends to move quickly to streams. Some, however, are connected to good underlying aquifers, allowing easy movement of the water. Increases in impervious surfaces can reduce ground water recharge. According to the results of a basin-wide application of the Geological Survey Report (GSR-32) methodology (*A Method for Evaluating Ground-Water-Recharge Areas in New Jersey*), all 51 subwatersheds in the Upper Raritan WMA, 44 of the 46 subwatersheds in the Lower Raritan WMA, and 37 of the 39 subwatersheds of the Millstone WMA experienced losses in recharge between 1986 and 1995. Losses in recharge are attributed to the conversion of areas of higher recharge (including forested and agricultural land) to residential, commercial and industrial land uses.

Very minor increases in recharge occurred in 4 of the 46 subwatersheds in the Lower Raritan WMA, and in 2 of the 39 subwatersheds in the Millstone WMA between 1986 and 1995. Gains in recharge may be attributed to the conversion of impervious land covers such as barren land to more pervious land cover or to a reforestation of some previously agricultural or barren areas. However, to verify gains, an assessment of the detailed land cover of the subwatersheds would need to be conducted. In any event, the gains are very small.

Overall recharge in million gallons per year declined for all three WMAs between 1986 and 1995. Average recharge in million gallons per day/square mile was calculated as 0.58 for recharge areas of the Upper Raritan WMA, 0.33 for recharge areas of the Lower Raritan WMA, and 0.40 for recharge areas of the Millstone WMA based on 1995 land use classifications.

Ground water contamination is evident in areas throughout the Basin, with a legacy of contaminated sites from past and current activities. Saltwater intrusion has occurred in Water Supply Critical Area #1 (a major aquifer of Middlesex, Monmouth and Ocean counties in the 1980s), and occurrences of pesticide and arsenic contamination are evident in wells in the western portion of the Raritan Basin in the Piedmont Province.

There are 351 public community water supply wells in the Basin, and the Wellhead Protection Areas (WHPA) for these wells cover approximately 12 percent of the Basin. These WHPA are the areas that supply water to the wells within a time of 12 years, with inner tiers of 2 years and 4 years Time of Travel (TOT). Many known contaminated site with confirmed ground water contamination are located within the WHPAs of public community water supply wells. Of 980 such sites that have been mapped, 18 percent (or 180) are located within WHPAs, and 59 of those are within a 2-year TOT and could be significant contamination risk. The NJDEP intends to assess public well vulnerability to pollution in much more detail by 2003 through the Source Water Assessment Program. However, measures to protect public water supply wells should be implemented by municipalities and counties prior to then wherever possible. Other potential sources of ground water contamination could stem from the 60 landfills, 500 permitted ground water discharges, 4,600 underground storage tanks and 28 Superfund sites of the Basin.

Results of the methodology used to estimate the total number of septic systems that may be accommodated within subwatersheds of the Basin reveal that the highest carrying capacity (i.e., smallest average lot sizes, minimum number of acres per septic system, or greatest number of septic systems per square mile) Basin-wide is found in the Upper Raritan WMA, at 1.64 acres per septic system. The maximum carrying capacity in the Lower Raritan WMA is 2.4 acres per septic system, and for the Millstone WMA is 2.59 acres per septic system. The lowest carrying capacities (i.e., largest average lot sizes, maximum number of acres per septic system, or lowest number of septic systems per square mile) are 3.36, 10.97 and 3.9 acres per septic system in the Upper Raritan, Lower Raritan and Millstone WMAs, respectively. These estimates are based on a NJDEP method, using a 5.5 mg/L nitrate target and average annual recharge. Lower nitrate targets would yield a lower carrying capacity, as would lower recharge estimates. The values of this report should be regarded as the highest carrying capacity possible.

Much development in the Basin is taking place in areas that lack public sanitary sewer systems, and the development of too many septic systems would have the potential to contaminate ground water and surface water resources. It should also be noted that maps in this report show carrying capacity for subwatersheds (HUC-14 watersheds) rather than for individual properties. A parcel-based map would be too complex for general use and publication; however the Raritan Project does have polygon-based results for municipal use.

Despite federal, state and local regulations that have been established to protect ground water supply sources and recharge areas, conversion of natural recharge areas to urban land cover types is evident throughout the Raritan Basin. Open space preservation projects and other initiatives to preserve critical recharge areas will help prevent a loss of recharge areas, but additional efforts to prevent further losses are needed. More stringent regulations such as the proposed water quality and watershed management rule, and proper planning may guide future growth patterns, but more needs to be done to protect these valuable resources.

Glossary of Terms

“Aquifer” means a formation, group of formations, part of a formation or interconnected fractured bedrock, capable of supplying useful quantities of water to wells and springs.

“Carrying capacity” means a measure of how much activity a particular resource can withstand before it is affected beyond a set amount.

“Impervious cover” means that part of the land surface that does not allow recharge. For example, roof tops and paved areas.

“Leachate collection system” means a system that collects liquid that results from water collecting contaminants as it trickles through wastes, agricultural pesticides or fertilizers. Leaching may occur in farming areas, feedlots, and landfills, and may result in hazardous substances entering surface water, ground water, or soil.

“Nitrate” means the most highly oxidized form of nitrogen in the nitrogen cycle. It is generally nonreactive (conservative) and moves readily in water.

“Public community water system” means a public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

“Public non-community water system” means a public water system that is not a community water system.

“Recharge” means the process of addition of water to the saturated zone; also the water added.

“Saturated zone” means the zone in which all the subsurface voids in the rock or soil are filled with water.

“Septic tank” means an underground tank designed to hold household sewage waste and its decomposition products. It commonly is connected to a series of pipes (leachate field) to allow liquid to exit the tank to the ground. These components in total are called a “septic system” or, more formally, an “individual subsurface sewage disposal system.”

“Stripping tower” means the system used to remove volatile compounds from contaminated ground water.

“Time of travel” (TOT) means the average time that particles of water will take to travel in the saturated zone from a given point to a pumping well.

“Water table” means the upper surface of a zone of saturation except where that surface is formed by a confining unit. The upper surface of the zone of saturation at which the water pressure in the porous medium equals atmospheric pressure.

“Wellhead” means the well borehole and related equipment.

“Wellhead Protection Area” (WHPA) means an aquifer area described in plan view around a well, from within which ground water is reasonably likely to flow to the well and through which ground water pollution, if it occurs, is reasonably likely to pose a significant threat to the water quality of the well. The Wellhead Protection Area is delimited by the use of time-of-travel and hydrologic boundaries, and is further subdivided by multiple times of travel.

“WHPP” means the Wellhead Protection Program established pursuant to Section 1428 of the Federal Safe Drinking Water Act, P.L. 93-523, 42 USC 300 et. seq. and described within the New Jersey Wellhead Protection Program Plan (NJDEP, 1991) and subsequent documents.

“Zone of contribution” means the portion of an aquifer surrounding a pumping well that encompasses all areas or features that supply ground water or ground water recharge to the well over time.

Common Acronyms

D&R Canal – Delaware and Raritan Canal
HUC – Hydrologic Unit Code
HUC-14 – 14-digit Hydrologic Unit
MSL – Mean Sea Level
NJDEP – New Jersey Department of Environmental Protection
NRCS – Natural Resources Conservation Service
TOT – Time of Travel
WHPA – Wellhead Protection Area
WMA – Watershed Management Area
USDA – United States Department of Agriculture
USFWS – United States Fish and Wildlife Service
USGS – United States Geological Survey

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APPENDIX A

APPENDIX B

APPENDIX C

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- ¹ NJDEP, 1993
 - ² Middlesex-Somerset-Mercer Regional Study Council, Inc., 1984
 - ³ NJDEP, 1993
 - ⁴ USEPA, 1997, p. 81
 - ⁵ NJDEP, 1993 (p. 149)
 - ⁶ Manning, John C., 1992
 - ⁷ Mitchell, Alison E., 1992
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 - ⁹ Tedrow, J.C.F., 1986
 - ¹⁰ USGS, 1998
 - ¹¹ Jeff Hoffman, May 2001, personal communication
 - ¹² NJDEP, 1993
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 - ¹⁶ USGS, 1998 (p. 35)
 - ¹⁷ USGS, 1998 (p. 35)
 - ¹⁸ Lewis-Brown, Jean C. and Vincent T. dePaul, 2000 (p. 35)
 - ¹⁹ Lewis-Brown, Jean C. and Vincent T. dePaul, 2000 (p. 2)
 - ²⁰ Nicholson, Robert S., and Martha K. Watt, 1997
 - ²¹ However, conditions in the Raritan Basin probably did not warrant the declaration regarding surface water supplies
 - ²² <http://www.state.nj.us/dep/dsr/whpaintro.html>
 - ²³ <http://www.state.nj.us/dep/dsr/whpaintro.html>
 - ²⁴ USEPA, 1990
 - ²⁵ Louis, Judith B., et al.
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 - ²⁷ NJDEP, 2000b
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 - ²⁹ Elizabethtown Water Company, 2001
 - ³⁰ Toto, Laura, 2001
 - ³¹ http://www.state.nj.us/dep/srp/superfund/sf_faq.htm#sf_faq2
 - ³² Hoffman, Jeffrey L., and Canace, Robert J., 2000
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 - ³⁵ Reiser, Robert G., 2000
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 - ³⁷ Kauffman, et al. 2001
 - ³⁸ <http://www.epa.gov/safewater/gwr.html>
 - ³⁹ <http://www.state.nj.us/osp/plan/sdrpsumm.htm>
 - ⁴⁰ <http://www.state.nj.us/osp/sdrp2.htm>
 - ⁴¹ NJDEP, 1989
 - ⁴² <http://www.state.nj.us/dep/dsr/whpaintro.html>
 - ⁴³ <http://www.eclipse.net/~sbwa/Wellhead.htm.htm>
 - ⁴⁴ NJDEP, 1996a