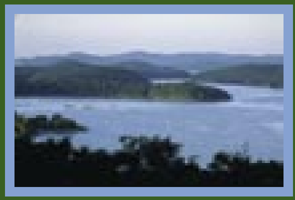


WATER QUALITY

GROUND WATER

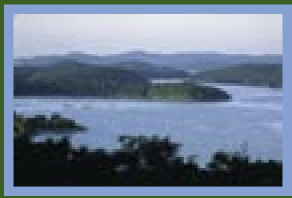
Although the ground water within the Highlands is generally of good quality for most uses, in local areas individual constituents may exceed accepted standards as established by the U.S. Environmental Protection Agency Secondary Drinking Water Regulations that primarily regulate aesthetic quality. Based on analytical results from more than 300 wells within the study area, 16 percent of all wells sampled exceeded the limit of 50 parts per billion (ppb) for manganese. Samples from 12 wells exceeded the limit of 300 ppb for dissolved iron. Manganese and iron usually occur together especially where dissolved oxygen is low. Median values of dissolved oxygen were lowest in the clastic and glacial aquifers; consequently, values of dissolved iron and manganese were usually highest. Dissolved arsenic was detected in several samples; only 1 of 205 samples exceeded the proposed U.S. Environmental Protection Agency maximum contaminant level of 10 ppb for arsenic. Occasional detectable levels of dissolved lead were also observed. Other constituents that occasionally did not meet the standards include dissolved sodium, dissolved chloride, and total dissolved solids. Dissolved solids are generally highest in samples from the glacial and carbonate aquifers, while dissolved chloride values were typically highest in samples from the glacial aquifers.

Most ground water samples had pH values within the acceptable range of 6.5 to 8.5 units, with values typically highest in the carbonate and glacial aquifers.

Elevated concentrations of naturally occurring radon-222 are common in Highlands ground water, particularly from crystalline aquifers, where uranium deposits are common in the rocks. A comprehensive examination of New Jersey radon data by dePaul and others (2000) found that more than 90 percent of 565 samples from within the Highlands exceeded the proposed maximum contaminant level of 300 picocuries per liter.

Dissolved nitrate analyses were available for 307 sites. Dissolved nitrate was present in detectable amounts in 80 percent of all samples; however, only one sample exceeded the maximum contaminant level of 10 parts per million (ppm). Nitrate was detected most frequently and in highest concentrations from water in wells open to the carbonate and glacial aquifers, with median values of 1.3 milligrams per liter (mg/L) in carbonate aquifers and 0.9 mg/L in glacial aquifers. This is consistent with the rapid transport of water from the land surface down to well intakes in these aquifers.

Volatile organic compounds as well as some pesticides were also detected in ground water samples. Data from known regulated sites were excluded. The most commonly detected volatile organic compounds in ground water samples were chloroform, methyl tert-butyl ether (MTBE), trichloroethene (TCE),



tetrachloroethene (PCE), and 1,1,1-trichloroethane (TCA). MTBE is a fuel additive, and TCE, PCE and TCA are chlorinated solvents used extensively in commercial and industrial applications. Most detections were at or below 1 ppb; however, three samples did not meet drinking water criteria. Pesticides were detected in ground water samples, although less frequently and in lower concentrations than in surface water. Most occurrences were in trace amounts, and drinking water criteria were not exceeded. Deethylatrazine, a degradation product of atrazine, was most frequently detected. Identified contaminants are of particular concern to domestic well owners because current regulations do not address the routine sampling of these types of wells.

Although these data were not evaluated with respect to land use within the recharge area at each well, the premise that human activities can affect the quality of ground water has been tested and validated in numerous studies. Elevated ground water nitrate concentrations have been attributed to application of nitrogen-bearing fertilizers and septic-system effluent. In a detailed study of the effects of land use on water quality in the Croton Watershed, elevated nitrate levels were related to density of unsewered housing (Heisig 2000). Elevated chloride concentrations have been attributed to road deicing but may also occur from septic-system effluent. Pesticide occurrence in ground water is more frequent in agricultural or urban areas than in areas that are undeveloped. Volatile organic compounds have been associated with urban and industrial development.

SURFACE WATER

In order to assess changing conditions in Highlands surface water quality over time, trends analyses were conducted at 23 sites within the region for selected constituents from 1986 to 1995 (Hickman and Barringer 1999). Most Highlands streams showed decreases (improving conditions) in total ammonia, phosphorus, and nitrogen, attributable to sewage treatment plant upgrades; however, nitrates are increasing at several sites. Highlands waters are generally well oxygenated and have appropriate temperatures to sustain aquatic life. Results of trends' tests indicate relatively stable conditions with respect to temperature and stable to improving conditions for dissolved oxygen. Bacterial (fecal coliform) levels were also found to be stable. Total dissolved solids, sodium, and chloride, however, were found to increase at most sites.

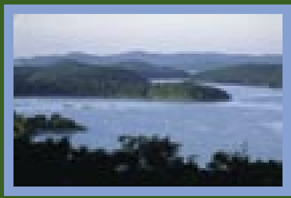
To assess current conditions, water quality data were examined from a network of stations within the Highlands that were routinely sampled from 1995 to 2001. As a basis of comparison, median values of selected constituents were examined with respect to New Jersey surface water criteria (New Jersey Department of Environmental Protection 1998) and median values of all established surface water status sites for the same period. These status sites are a randomly selected population of New Jersey streams from each of the 20 Watershed Management Areas. These streams represent a current condition of waterways Statewide and

can serve as a point of comparison for the water quality of Highlands streams. Most streams within the Highlands are typically higher in dissolved oxygen and pH than those at status sites (higher quality) but also contain higher median concentrations of total nitrogen, dissolved nitrate, total phosphorus, as well as total dissolved solids, sodium, and chloride (lower quality).

Nitrogen and phosphorus are essential elements for plant and animal growth; however, elevated concentrations in streams can promote excessive growth of algae and other nuisance plants. Although concentrations of dissolved nitrate do not exceed surface water quality standards, concentrations are elevated with respect to status sites and are increasing in several Highlands waterways. Although total phosphorus concentrations are decreasing in many of the Highlands streams, elevated levels of this nutrient are still a concern. Fifteen percent of all samples exceed the phosphorus criterion of 0.1 ppm, and more than half of the samples were observed at two stations.

The fecal coliform count is an indicator of the sanitary quality of water. Fecal coliform contamination can originate from point and nonpoint sources. The primary point source is sewage treatment plant outfalls; nonpoint sources include runoff from manure-treated fields, septic system failure, sewer overflow, and wildlife waste. Fecal coliforms do not necessarily cause illness, but high levels may indicate the presence of other pathogens that can cause waterborne diseases. Although they have stabilized, levels of fecal coliform bacteria remain somewhat elevated in streams within the Highlands. In fact, fecal coliform count was the measure that most frequently did not meet instream standards. Forty-one percent of all samples at the evaluated sites exceeded the reference level of 400 coliforms per 100 milliliters of water. This criterion is based on a 10 percent exceedance rate for samples taken during a 30-day period; exceedances here are attributed to all samples taken from 1995 to 2001. Most individual sites examined had more than 10 percent of samples above this reference level, with several sites at more than 70 percent. Fecal coliform counts were generally higher than those at status sites.

Pesticides (herbicides and insecticides) were detected more frequently and in higher concentrations in Highlands surface water than in ground water, but rarely did levels approach drinking water standards or health advisories. All detections were less than 1 ppb. The most commonly detected pesticides in study area surface waters were herbicides such as atrazine and prometon and an insecticide, diazinon. The most frequently detected volatile organic compounds in streams and ground water are compounds used in gasoline or for commercial and industrial purposes. Volatile organic compounds were detected in surface waters, but less frequently and in lower concentrations than in ground water. Methyl tert-butyl ether (MTBE), a gasoline additive, was the most frequently detected in nearly 50 percent of 42 samples at 28 sites. Occasional detections of chlorinated solvents in surface water were also observed, but in low concentrations.



Many of the routinely sampled sites in the Highlands are located within large watersheds of mixed land uses and therefore reflect the cumulative effects of those various land uses as well as point discharges into the streams. Studies that are designed to examine the effects of land use on stream water quality, such as the U.S. Geological Survey's National Water Quality assessment (NAWQA) Program, have found that nutrient concentrations in surface water are related to urban and agricultural activities. Concentrations in streams that drain urban and agricultural watersheds tend to be significantly higher than those that drain predominantly forested watersheds. Pesticide occurrence was related to both agricultural and urban settings. In general, volatile organic compound occurrence in streams is directly correlated to the percent of urban land use within a watershed, increasing as an area becomes more urban.

BIOLOGICAL INDICATORS

Aquatic communities such as benthic macroinvertebrates and algae are used as biological indicators of stream health because their condition enables the discrimination of human influences on the environment in a predictable way. These communities respond to changes in stream quality from a variety of factors that modify habitat or other environmental features such as land-use, water chemistry, and streamflow.

The primary factors related to degradation of benthic communities are the percentage of urban land use within the associated drainage basin as well as the amount of upstream wastewater discharges (Kennen 1999). Hydrologic factors such as reduced baseflow and increased peak discharges commonly associated with urbanization can substantially alter stream habitat by scouring the streambed, increasing siltation, and transporting contaminants. Conversely, the total amount of forested land within a drainage basin is the best predictor of an unimpaired community.

The New Jersey Department of Environmental Protection's Ambient Biomonitoring Network (AMNET) is a Statewide network of sampling sites designed to monitor the condition of benthic macroinvertebrate communities in New Jersey streams. The network incorporates more than 800 sites, of which 138 are within the Highlands study area. The initial round of sampling was conducted from 1992 through 1996 with a second round to be completed in 2002. The New York Department of Environmental Conservation (Bode and others 1993) operated a similar network from 1986 to 1992, although data within the Highlands area are limited.

Macroinvertebrate community sampling sites shown in Figure 2-7 are classified as nonimpaired, moderately impaired, and severely impaired. (New Jersey data depicted are from the second round of sampling.) Impairment may be indicated by the absence of sensitive species, such as mayflies, stoneflies, and caddis flies;

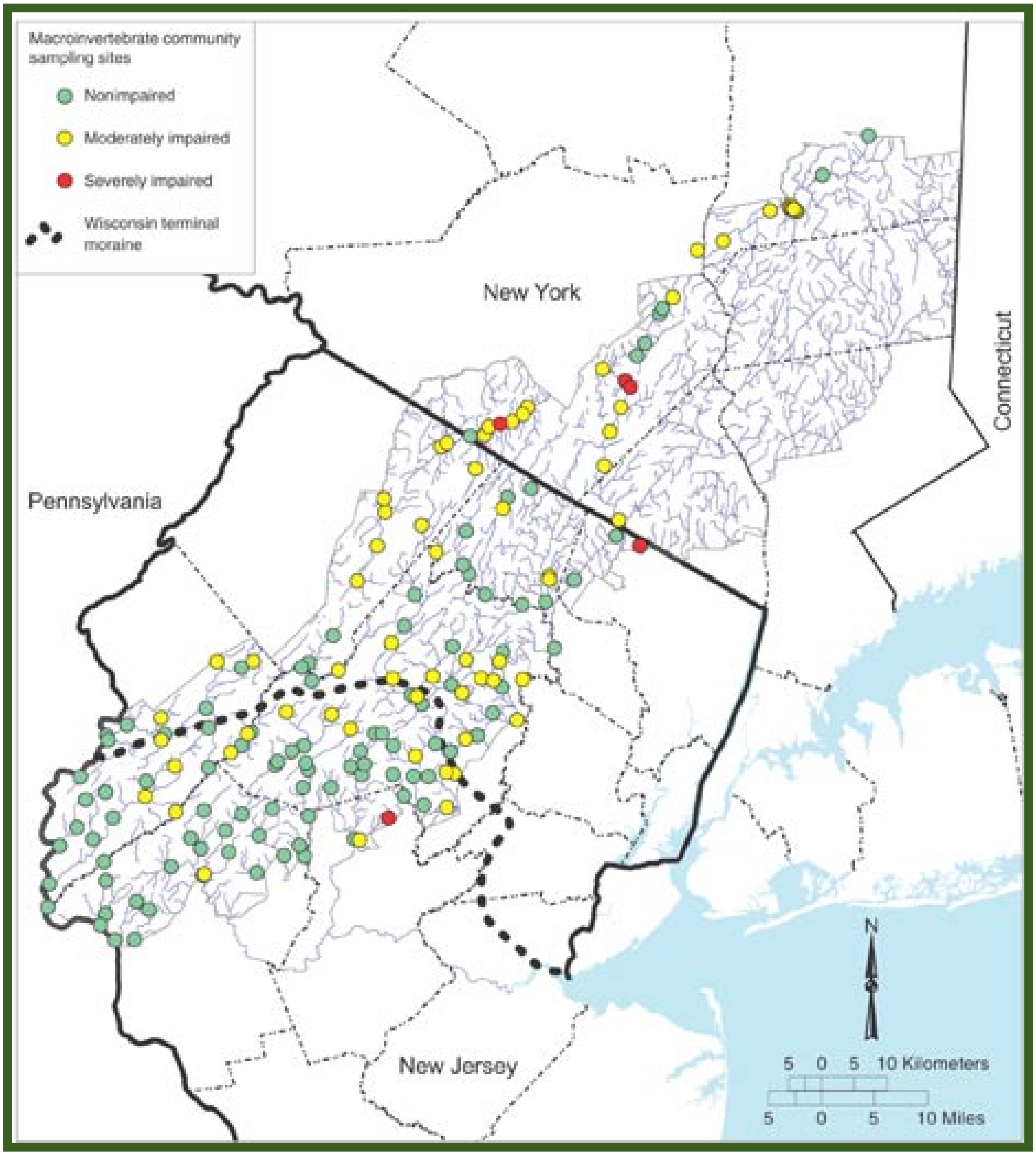


Figure 2-7. Condition of macroinvertebrate communities in streams. Sampling of macroinvertebrate communities—predominantly aquatic insects—in surface water shows comparatively healthy populations and good water quality. Nonimpaired sites (highest quality) have diverse, well-balanced communities; moderately impaired sites have less diverse communities, and severely impaired sites are dominated by a few tolerant species. (New Jersey data was collected from 1997 to 1999; New York data from 1986 to 1992. Adapted from New Jersey Department of Environmental Protection, Bureau of Freshwater Biological Monitoring 2001, and Bode and others 1993).

by the dominance of more tolerant species such as aquatic worms and midges; or by an overall reduction in community diversity. Nonimpaired sites have diverse, well-balanced macroinvertebrate communities comparable to those of other undisturbed streams with similar characteristics. Moderately impaired sites show alterations of the community from a pristine state, with a reduction in species diversity and in the number of sensitive species present. Severely impaired sites are dominated by a few tolerant invertebrate species.

Data from the first round of sampling indicated comparatively healthy aquatic invertebrate populations within Highlands waters (Kennen 1999). Streams within the Upper Delaware drainage basin as well as those south of the Wisconsin terminal moraine were least likely to exhibit an impaired macroinvertebrate community. Of the sites within the study area, 38 percent exhibited some degree of impairment (5 percent severely impaired) and 62 percent showed no impairment. Of non-Highlands sites, 70 percent indicated some degree of impairment (14 percent severely impaired) while only 30 percent were considered nonimpaired.

The second round of sampling showed that 3 percent of the sites within the study area exhibited impairment (1 percent severe impairment) while 67 percent were nonimpaired, indicating stable to slightly improving conditions. Of the non-Highlands sites that have been sampled, 67 percent retain some degree of impairment. Some of the major waterways having impaired communities at more than one sampling site include the Whippany River, the Rockaway River, the Wallkill River, the Musconetcong River, the upper reaches of the Pequannock River, and the Pohatcong Creek. Within New York, waters identified as having impaired communities include the Ramapo River and Wawayanda Creek.

The U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program compared the aquatic community status of 36 northern New Jersey stream sites to 140 selected NAWQA sites nationwide. Invertebrate and algal status are related to an urban land use gradient (Figure 2-8). Generally, highest scores (most degraded sites) occur where percentage of urban land use is greatest within a basin. The Rockaway River at Boonton, Lamington River near Pottersville, South Branch Raritan River at Arch Street, Spruce Run at Glen Gardner, and Pequannock River at Riverdale had some of the lowest scores (least degraded sites) nationally for algae and invertebrates (Ayers and others 2000). Land use in the basins of these sites is less than 34 percent urban and greater than 41 percent forested.

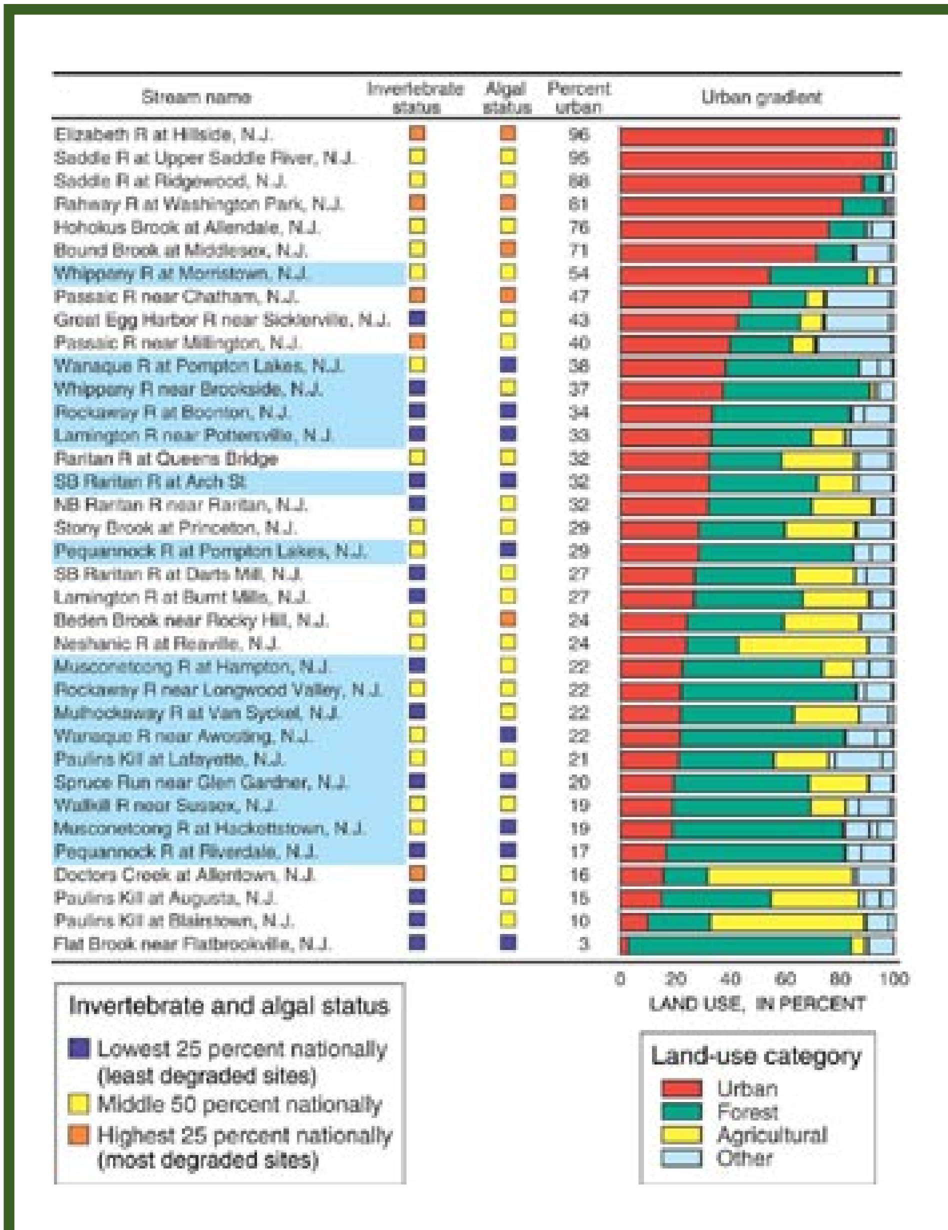
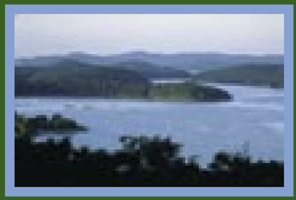


Figure 2-8. Land use and biological status of streams. The invertebrate and algal status of New Jersey Highlands stream sites (shaded in blue) and other northern New Jersey stream sites show that stream health is greatest where urban land-use is lowest (modified from Ayers and others 2000, p. 10).

WATER: WATER QUALITY

KEY FINDINGS:

- **The natural ground water within the Highlands is of good quality for most uses.** Exceedances of U.S. Environmental Protection Agency's Secondary Drinking Water Regulations, which primarily regulate aesthetic quality, may be encountered locally and include manganese, iron, sodium, chloride, and dissolved solids.
- **Elevated concentrations of naturally occurring radon-222 are common in Highlands ground water, particularly from crystalline aquifers.** More than 90 percent of 565 ground water samples from within the Highlands exceed the proposed maximum contaminant level of 300 picocuries per liter.
- **Elevated ground water nitrate concentrations have been attributed to application of nitrogen bearing fertilizers, septic-system effluent, and unsewered housing density. Elevated chloride concentrations** in ground water have been **attributed to road de-icing** but may also occur from septic-system effluent. **Pesticide occurrence** in ground water is **more frequent in agricultural and urban areas** than in areas that are undeveloped. **Volatile organic compounds** have been **associated with urban and industrial development.**
- **Over the past decade, many Highlands streams show improving conditions.** Decreases in total ammonia, phosphorus, and nitrogen are attributable to sewage treatment plant upgrades. Fecal coliform levels are generally stable, however elevated levels remain a concern. Dissolved solids, sodium, and chloride were found to increase at most sites, possibly due to road deicing or upstream point discharges.
- **Pesticides (herbicides and insecticides) were detected more frequently and in higher concentrations in Highlands surface water than in ground water; but levels rarely approached limits for drinking water standards or health advisories.**
- **The most frequently detected volatile organic compound in Highlands streams was** methyl *tert*-butyl ether **(MTBE), a gasoline additive.**
- **Sampling of macroinvertebrate communities in Highlands streams indicate comparatively healthy aquatic invertebrate populations.** In the most current sampling, 67 percent of Highlands macroinvertebrate sites was nonimpaired, 33 percent exhibited some degree of impairment, and 1 percent was severely impaired.



WATER BUDGET

A water budget is a valuable tool in understanding how human activities can alter the natural cycle and availability of water in the Highlands. The water budget considers all water, both surface and ground, entering, leaving, or stored within a watershed. Each component of the hydrologic cycle (Illustration 2-3)—precipitation, infiltration, overland runoff, evapotranspiration, and ground and surface water withdrawals—can be assigned a value in order to create a water budget.

ANALYSIS AT A REGIONAL SCALE

A water budget for the entire New York – New Jersey Highlands region provides a basis for understanding the function and magnitude of the various components (Figure 2-9). The primary source of water is precipitation, which totals about 50 inches annually when averaged over the entire study area. This is the equivalent of receiving 5,300 Mgal/d of water over the 2,218 square miles of the study area. Of the total precipitation, an estimated 2,153 Mgal/d evaporates from land or water surfaces and transpires from vegetation; these processes together are referred to as evapotranspiration. The remainder of the precipitation either infiltrates into the ground (1,958 Mgal/d) and recharges ground water or runs off the land surface (707 Mgal/d) to streams and rivers during storms and snowmelt. The ground water in turn discharges to streams, which is known as stream baseflow, and generally equals the amount of water infiltration or recharge into the ground (1,958 Mgal/day). Stream baseflow is responsible for maintaining flow in streams even during prolonged dry periods. Therefore, natural streamflow out of the Highlands region is a combination of baseflow (1,958 Mgal/d) and runoff (707 Mgal/d) and totals 2,665 Mgal/d.

Human activities can add to or subtract from evapotranspiration, infiltration, baseflow, and runoff. Consumptive use of surface and ground water amounts to an estimated 482 Mgal/d removed from the overall Highlands water budget. This amount is based on the 427 Mgal/d transferred out of the region from Highlands reservoirs to supply major urban areas to the south and east in New York City and New Jersey, plus 20 percent of the region's ground water use (29 Mgal/d), and 20 percent of surface-water withdrawals (26 Mgal/d) for use within the Highlands.

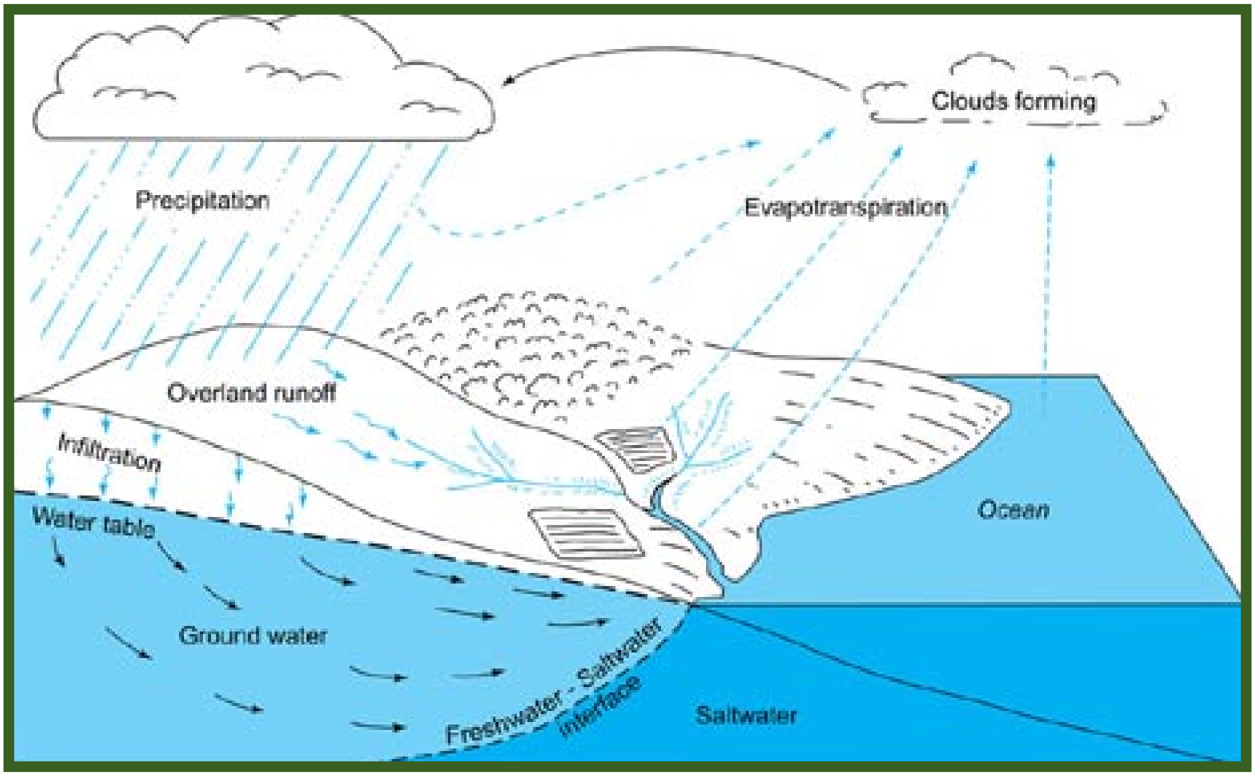
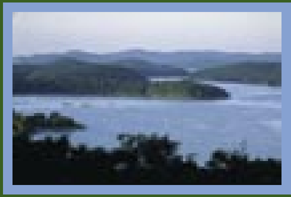


Illustration 2-3. Hydrologic cycle. The constant movement of water above, on, and below the Earth's surface constitutes the hydrologic cycle. Precipitation runs over the land surface and into streams, which discharge into the ocean. Some precipitation infiltrates into the ground-water system and discharges to streams or the ocean. Transpiration and evaporation return water to the atmosphere, completing the cycle (modified from Heath 1983, p. 5).



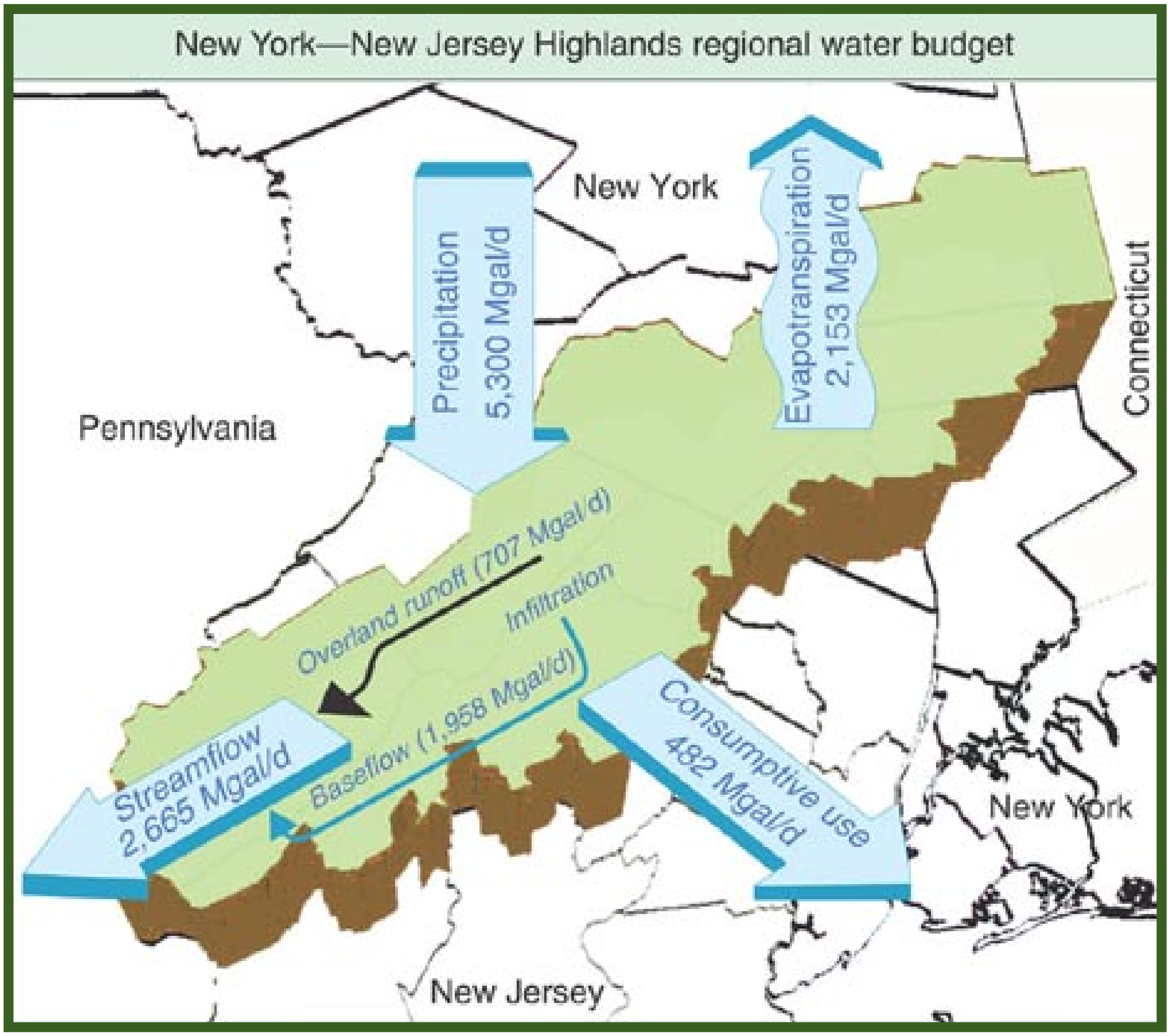


Figure 2-9. Highlands regional water budget. The water budget considers all water, both surface and ground, that enters and leaves the Highlands. On an average annual basis, the Highlands receives about 50 inches of precipitation which is the equivalent of 5,300 million gallons per day (Mgal/d) over the study area. About 50 percent (2,665 Mgal/d) of this water leaves via streamflow. An estimated 41 percent (2,153 Mgal/d) is lost to evapotranspiration, and about 9 percent (482 Mgal/d) is consumptive water use that is not returned to Highlands watersheds.

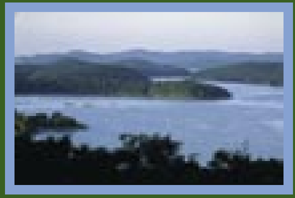
ANALYSIS AT A WATERSHED SCALE

The amount of precipitation that falls on Highlands watersheds varies geographically based mainly on topography, and generally averages 44 to 52 inches per year. The areas of highest elevation generally receive the most precipitation. On a year-to-year basis over the past century, annual precipitation has varied from these averages locally as much as 10 to 20 inches. An example of how the major water budget components are influenced by annual fluctuations of precipitation in the Highlands region is shown graphically in Figure 2-10. Annual mean streamflow for a period of 80 years, recorded at a gauging station on the Pequest River at Pequest in Warren County, New Jersey, is compared with local annual precipitation for the period. Approximately half of the precipitation that falls on the watershed leaves the watershed as stream discharge. Most of the remainder that does not discharge as streamflow leaves the basin as evapotranspiration. A similar relationship exists over most of the Highlands region.

The annual variability in precipitation a watershed receives can significantly affect annual totals of stream discharge, particularly during very dry and very wet periods. These variations in turn affect the quantity and quality of water available to downstream users. Total annual stream discharge averages about 20 inches per year at the Pequest gauge. During the drought of record (1961-1966) total annual stream discharge averaged 40 to 70 percent less than long-term averages. During unusually wet years, such as 1952, 1975, and 1996, total annual stream discharge was 70 to 90 percent greater than long-term averages. Other stream gauging stations in the Highlands indicate similar ranges of departure from average streamflow conditions during extremely dry and wet periods including the Whippany River at Morristown, Ramapo River at Mahwah, and the South Branch Raritan River near High Bridge (Bauersfeld and Schopp 1991).

Floods and droughts can affect the quality of surface water. During floods, large quantities of pollutants are washed into streams, but because of the large volume and velocity of the water, the pollutants are diluted and move quickly downstream. During droughts, however, streamflows may not be sufficient to dilute effluents from industries and sewage treatment plants, and contaminants that may be in the ground water that is discharging to streams.

Changing streamflow characteristics are strong indicators of changing watershed conditions. Of particular importance in water budget analyses are the two components of streamflow, which are baseflow and runoff. At the Pequest stream gauge, baseflow makes up about 83 percent of total stream discharge and runoff makes up the remaining 17 percent (Figure 2-10). There is only a slight variation in the percentage of these two components over the period of record. However, baseflow and runoff characteristics of streams vary from watershed to watershed and are important indicators of dependable ground water and surface-water yields and of changing hydrologic conditions. Land use that reduces



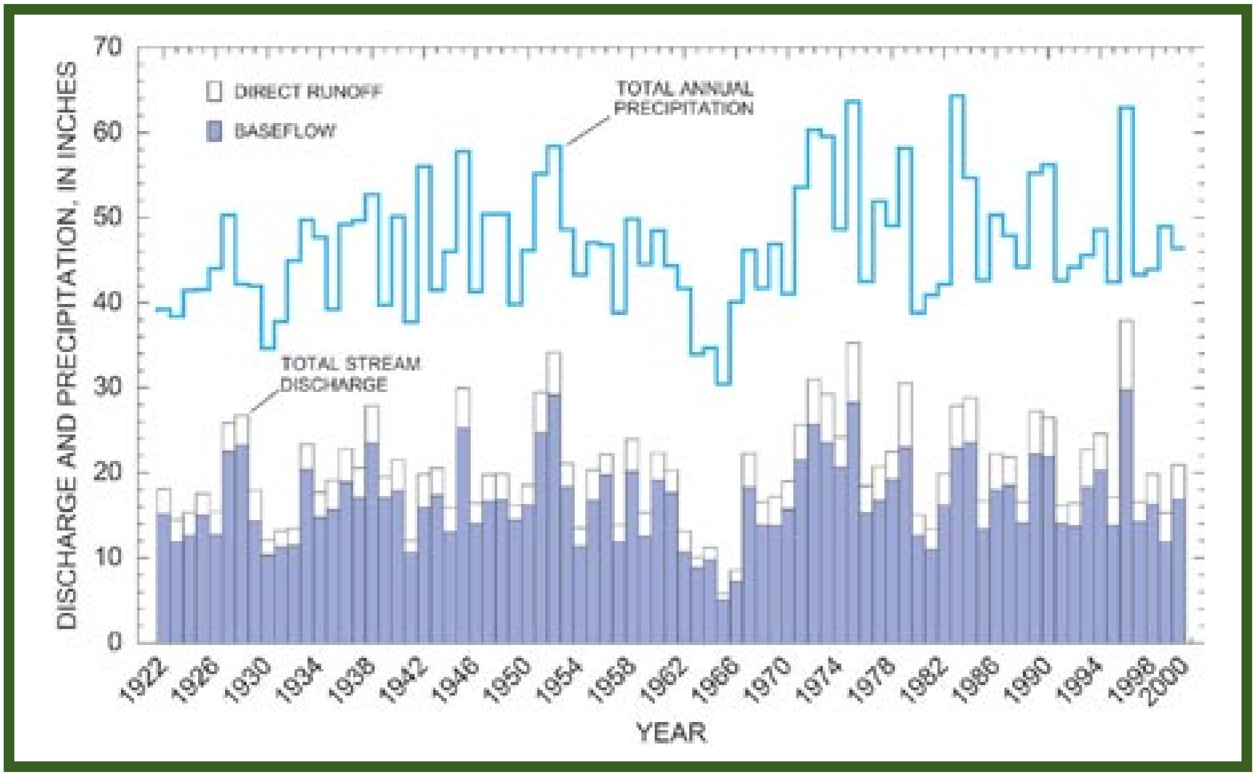
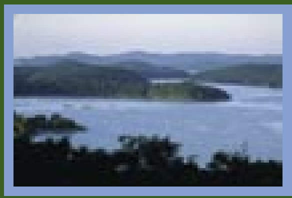


Figure 2-10. Relationship of streamflow and precipitation. The direct relationship of annual precipitation to stream discharge for the Pequest River at Pequest, New Jersey, is representative for most of the Highlands. Approximately half of the precipitation that falls on the watershed leaves as stream discharge. As precipitation increases total discharge also increases; however, the percentages of the components of total streamflow (baseflow and runoff) vary only slightly.



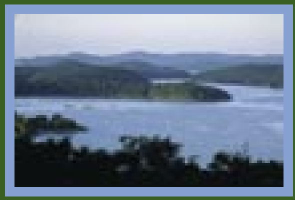
evapotranspiration (by deforestation, for example) and reduces infiltration (by creation of impervious surfaces) consequently increases the amount of runoff, thereby contributing to increased flood levels. The percentage of streamflow that is composed of baseflow and runoff can be modified by land-use changes that reduce recharge to ground water by increasing surface runoff. These changes can include new buildings, paving, soil compaction, and results of other human activities.

Watershed Conditions

To evaluate existing conditions on a watershed scale and potential changes to watershed hydrology based on future change scenarios (Section 3, Changes in Water Resources), a computer simulation model was used. The model used was developed by the U.S. Geological Survey in cooperation with the New Jersey Office of State Planning, for the purpose of defining streamflow characteristics associated with 820 biologic monitoring sites in New Jersey. The watershed model incorporates long-term climate, topography, soils, impervious surface, and water withdrawal data and is calibrated to existing long-term stream gauge data (Kauffman 2001).

The model is suitable for use in the Highlands regional study because it provides water budgets for a large part of the study area including all of the New Jersey Highlands and the New York part of the Passaic River Basin. Because sufficient data were unavailable for the rest of the New York portion of the Highlands, the modeled area was limited to 1,456 square miles or 932,141 acres of the 1.4 million-acre Highlands study area. Water budgets were analyzed at watershed and subwatershed scales related to previously defined Hydrologic Unit Codes (Ellis and Price 1995). Hydrologic Unit Codes (HUC) are used to identify the boundaries and the geographic area of watersheds for the purpose of water-data management. The largest drainage area is HUC 8, which corresponds to the entire surface water drainage area for major river basins as shown in Figure 2-5. These large drainage basins have been further subdivided into smaller watersheds (HUC 11) and subwatersheds (HUC 14) that drain specific reaches of streams and tributaries within the larger basin. The model was used to predict water budgets for HUC 11 and HUC 14 basins within the modeled area. HUC 11 watersheds within the Highlands region have an average area of about 50 square miles and a maximum area of 150 square miles. There are 30 HUC 11 watersheds that are wholly or partially within the modeled area of the Highlands. In contrast, HUC 14 subwatersheds have an average area of 8 square miles and a maximum area of 20 square miles. There are 182 HUC 14 subwatersheds in the modeled area.

Figure 2-11 shows the regional difference in baseflow characteristics of HUC 14 subwatersheds and provides a basis for the evaluation of existing hydrologic conditions. Baseflow is a good indicator of the water-yielding capacity of the underlying aquifer and the stream's ability to sustain flow. The percentage of streamflow composed of baseflow for streams within each subwatershed was



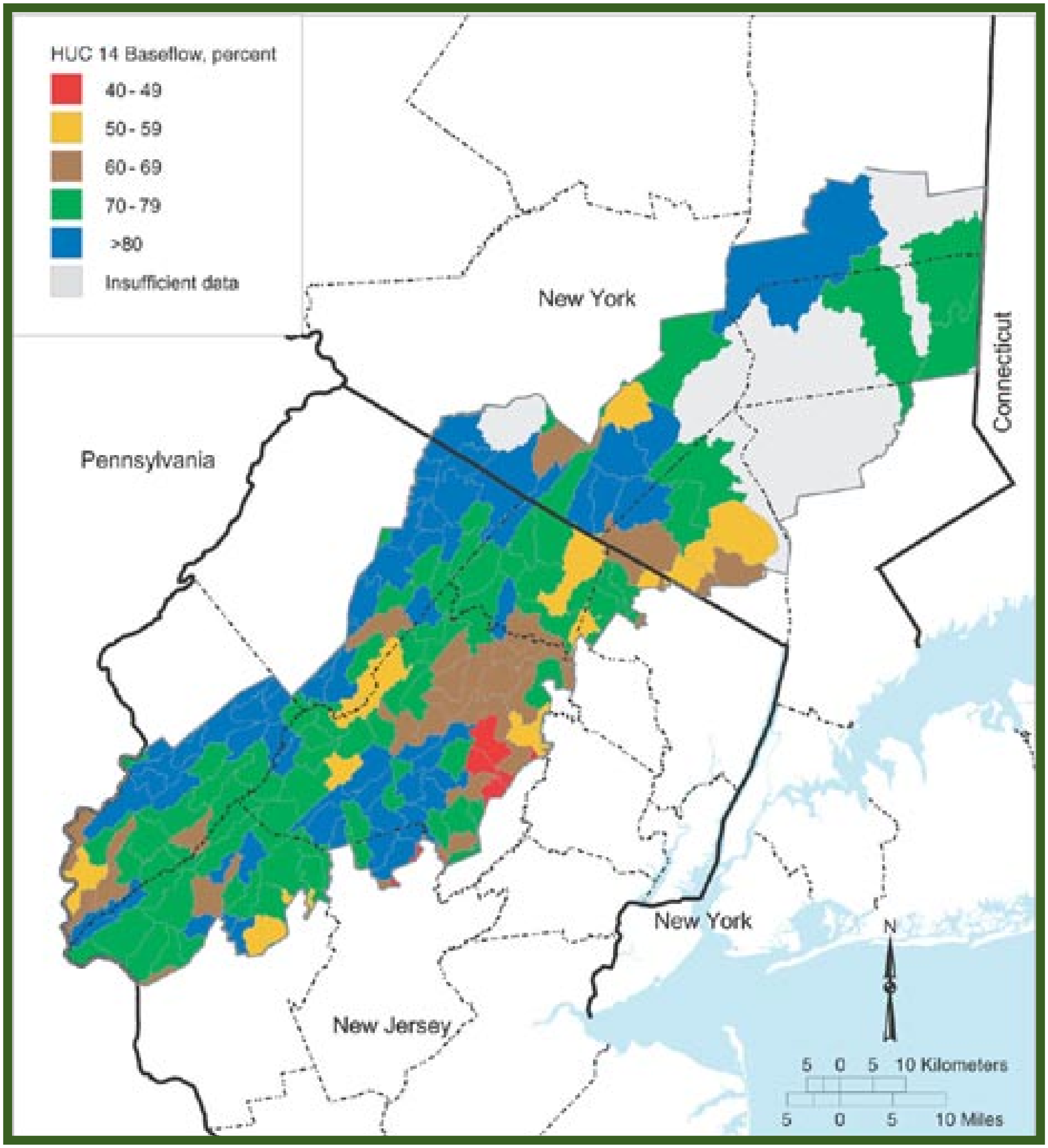


Figure 2-11. Variations in baseflow by subwatersheds. Regional differences in the amount of baseflow in Highlands streams during 1995 are related to the geology and degree of development within HUC 14 subwatersheds. The percentage of baseflow in relation to total streamflow indicates the water yielding capacity of an aquifer and a stream's ability to sustain flow. Baseflow is greatest in areas with carbonate and glacial aquifers and with the least urbanization. Hydrologic Unit Code 14 subwatersheds cover an average area of 8 square miles.

calculated from model-generated water budgets using 1995 water withdrawals and impervious surface data. The percentage of baseflow to total streamflow calculated from long-term streamflow data is also provided for larger watershed areas in New York where gauging data were available.

Model results and calculations indicate that, on average, baseflow comprises 73 percent of streamflow over the Highlands study area. The amount of baseflow in a stream depends mainly on the geology and type of development in the watershed. In rocky areas with little or no soil cover, the ground water contribution to streamflow is small because ground water storage capacity is minimal. In areas with thick glacial deposits or carbonate rocks with solution channels that can store large amounts of water, or both, the ground water contribution to streamflow is large. Figure 2-11 shows that baseflow accounts for more than 80 percent of total streamflow in many of the watersheds along the western boundary of the study area. These watersheds are underlain by a high percentage of carbonate and glacial aquifers (Figure 2-1) and include areas of highest aquifer recharge as noted in the 1992 Highlands Regional Study report (Michaels and others 1992). Areas where baseflow accounts for less than 50 percent of streamflow occur in some of the most urbanized areas of the study area with documented large ground water withdrawals, including parts of Rockland County, New York, and eastern Morris County, New Jersey.

In addition to providing an evaluation of existing conditions, water budget analyses are an important tool in evaluating the effect of future land use change, development, and water withdrawals on Highlands water resources. This evaluation is provided in Section 3, under Changes in Water Resources.

KEY FINDINGS:

- **Regionally, the Highlands study area receives about 5,300 Mgal/d of water from precipitation. The Highlands loses about 50 percent or 2,665 Mgal/d from river and stream outflows and about 9 percent or 428 Mgal/d from consumptive water use. An estimated 41 percent or 2,153 Mgal/d is lost by evapotranspiration.**
- **On a watershed scale, the amount of precipitation varies** geographically across the region and ranges **from about 44 to 52 inches per year.** Annual precipitation has varied from these averages by as much as 10 to 20 inches during unusually wet or dry periods.
- Total streamflow recorded by long-term gauging stations within the Highlands show that **during periods of prolonged drought, total annual streamflow can be as much as 40 to 70 percent less than long-term average annual totals. During unusually wet years, streamflow can be as much as 70 to 90 percent greater than long-term averages.** These climatic variations have an effect on the quantity and quality of water to downstream users.
- **Baseflow and runoff characteristics of streams are two of the most important components of the water budget analyses of Highlands watersheds.** Changing streamflow characteristics are strong indicators of changing watershed conditions.
- A watershed model used to simulate streamflow characteristics and provide water budgets for 182 HUC 14 subwatersheds indicates, that on average, **baseflow comprises 73 percent of streamflow over the Highlands study area. The percentage of baseflow to total streamflow depends mainly on the geology and degree of development in the watershed. Baseflow accounts for more than 80 percent of streamflow in many watersheds underlain by a high percentage of carbonate and glacial aquifers** that have relatively high recharge rates and water storage capacity. Areas where **baseflow accounts for less than 50 percent of streamflow** occur **in some of the most urbanized areas within the Highlands with documented large ground water withdrawals,** including Rockland County, New York and eastern Morris County in New Jersey.